CT SCAN MEASURES AND LATERALITY INDICES:
RELATIONS BETWEEN ANATOMICAL AND FUNCTIONAL MEASURES

by

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ABSTRACT

The investigation of the neuroanatomic substrates underlying function has been an important area of study in human neuropsychology and clinical neurology. This study examined the possible relations between measurements of hemispheric widths and lengths from computed tomographic (CT) scans and functional laterality indices of a)results from carotid amytal testing (speech dominance), b)handedness, c)performance on a verbal dichotic listening test, and d) performance on a verbal divided visual field task. Existing procedures (Chui & Damasio,1980; Piendiaz,et al. 1983)) for measuring asymmetries on CT scans were used.

The results, based on a sample of 48 patients with epilepsy, suggest that the non-invasive approach of measuring widths and lengths are not reliable predictors of performance on measures of laterality. Also, the possible neuroanatomic substrates that might underlie language dominance may not be reliably reflected in simple measurements of hemispheric widths and lengths.

Due to the low subject-to-variable ratio, the study needs to be replicated and suggestions are made regarding future designs. Since similar measurement techniques have been used with other clinical populations (e.g. aphasics) with different results,the findings from this current study lead to some speculation regarding the possible effects of epilepsy on brain morphology.

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To my parents, Sam and Mary - you may not have always understood what I do or why, but thank-you for the silent understanding.

INTRODUCTION

It has been well established that the two cerebral hemispheres differ in terms of their functional specialization (see Bradshaw & Nettleton,1983, for a review). For most people, damage to specific regions in the left hemisphere results in distinct language disorders (Goodglass & Kaplan,1972). By contrast, damage to the right hemisphere results in disturbances in non-verbal,spatial analysis, but leaves language functions relatively intact (Hecaen & Albert,1978). Currently, an important area of study in human neuropsychology involves the investigation of the possible neuroanatomic substrates that might underlie the left hemisphere's dominance for language.

Anatomical Asymmetries

Anatomical asymmetries in language-related zones have been recorded by simple observations with the naked eye, by measurements of post-mortem specimens, endocasts, by radiological methods such as, cerebral angiograms,CT scans and by highly sophisticated cytoarchitectonic studies (see Strauss,Kosaka, & Wada,1983 for a review).

With regard to the posterior language region, researchers have documented a larger left than right planum temporale, an area which forms part of the posterior language zone known as Wernicke's area (von Economo & Horn,1930; Geschwind & Levitsky,1968). This anatomical asymmetry has also been noted in neonates, suggesting that this morphological asymmetry precedes functional asymmetry (Wada,1969; Witelson & Pallie,1973; Wada, Clark, & Hamm,1975; Chi,Dooling, & Gilles,1977). There are other indirect measures of the posterior language zone. These include a longer and lower left Sylvian fissure and a smaller left arch of the middle cerebral artery as it leaves the posterior end of the Sylvian fissure (LeMay & Culebras,1972; LeMay,1976; Yeni-Komishian & Benson,1976; Rubens et al.,1976; Galaburda, et al.,1978; Ratcliffe, et al., 1980). Horizontal, sagittal, and coronal CT images of post-mortem specimens have also revealed gyral and sulcal markings indicating surface asymmetries (left wider than right) in the planum temporale (Habib, et al., 1984).

Asymmetries in the anterior language zone, Broca's area, had been reported as early as 1911 by Mellus. He found that the frontal opercular cortex was thicker in the left than in the right hemisphere. Asymmetries in favor of the left side have also been reported more recently by Falzi, et al., (1982) who measured the cortex buried in the sulci of this area, and by Galaburda (1980) who performed a cytoarchitectonic analysis.

Functional Asymmetries

Attempts to find reliable behavioral indicators of cerebral language dominance have included a)invasive techniques such as carotid amytal testing,and non-invasive methods that measure of (b)hand preference, (c) performances on an auditory perceptual task called dichotic listening and (d) performances on divided visual-field tasks (see Beaumont, 1982; Strauss, Kosaka, & Wada, 1983 for a review.) The following is a brief discussion of each technique.

a)Carotid Amytal Testing

The carotid amytal test requires the patient to undergo unilateral injections of sodium amytal into the left and right internal carotid arteries on separate days (Wada,1949; Wada & Rasmussen,1960). Although this technique unequivocally determines speech lateralization, it is a procedure that is used with caution as further vascular complications can occur in patients with possible cerebrovascular disease or severe hypertension (Lishman,1978). In addition, age appears to be a significant risk factor since a higher probability of a vascular accident exists in patients aged 45 and older (Wada, personal communication).

A relation between carotid amytal results and anatomical asymmetries has been reported by Ratcliff et al.,(1980). Patients with left hemisphere speech dominance, as determined by carotid amytal testing,tend to have a narrower left-sided middle cerebral arterial arch whereas in patients with atypical speech representation, this asymmetry is significantly less marked. However, Strauss et al (1985) were unable to find a relation between cerebral speech dominance and Sylvian arch asymmetry. In the latter study however, the number of cases with unilateral right hemisphere speech dominance was very small (N=2).

b)Handedness

Investigators have studied the relations between hand preference and speech dominance as assessed via the carotid amytal test (Rasmussen & Milner,1977; Strauss & Wada,1983) Approximately 95 percent of right handers have speech localized in the left hemisphere while the incidence of left hemisphere speech dominance in left-handers is reported to be in the 50-70 percent range (Branch, Milner, & Rasmussen,1964; Rasmussen & Milner,1977; Strauss & Wada,1983).

There is also evidence of an association between handedness and morphological asymmetry (LeMay & Culebras,1972; Hochberg & LeMay,1975). LeMay (1976,1977,1978) examined anatomical asymmetries on CT scans. The measures involved both the forward (fronto-petalia) or backward (occipito-petalia) extension of one cerebral hemisphere beyond the other, resulting in an impression on the inner table of the cranial vault. LeMay reports in a series of papers(1976,1977,1978), a relation between handedness and these anatomical measures.

See Table 1

As Table 1 shows, LeMay & Kido (1978) found a wider left parieto-occipital region,an area important for language function, and a left occipito-petalia, in the majority of the right-handed patients. With regard to the frontal region, the right side tended to be wider and there was a trend for right frontal petalia. In contrast, no consistent width asymmetries were observed in the CT scans of left handers, consistent with the notion that this population is more likely to show atypical patterns of cerebral organization. It is also worth noting that left occipito-petalia has been documented in fetal and newborn brains (LeMay & Geschwind,1978).

One study, however, found no relation between handedness and CT asymmetries. As shown in Table 1, the data fom Chui & Damasio's study (1980) suggest that the variables of handedness and cerebral asymmetries are unrelated. In contrast to LeMay & Kido (1978), no significant differences were found between the right handers and non-right handers. They did however confirm the presence of a left occipital petalia in 60 percent of the right handers. However, significant asymmetries for the frontal petalias were not found on the scans for the right handers, although there was a trend for a right frontal petalia.

Significant differences were found in the non-right-handed group where 64 percent were found to have larger left than right occipital widths. No significant differences in frontal or occipital petalias existed for this group.

The reason for the discrepant findings between the LeMay and the Chui and Damasio studies is not known.

Perhaps methodological differences can account for the inconsistencies. LeMay measured the widths of the frontal and occipital portions of the hemispheres approximately 5 mm from the ends of the hemispheres. The extension of one hemisphere beyond the other, determined the petalia measures. In contrast, Chui and Damasio took their CT measurements for the occipital widths at a point that was anterior to the occipital pole by a distance that represented 16 percent of the brain's total length. The frontal widths were measured at a point anterior to the occipital pole representing 90 percent of the brain's total length.

Based on their findings, Chui and Damasio (1980) suggest that CT asymmetries are possibly better predictors of language dominance than hand preference. The discrepancy between Chui and Damasio's distribution of handedness and CT measures(the presence of L > R occipital petalia in only 60 percent of their right handers), and the previous documentation of speech dominance and handedness (95 percent of right handers have left cerebral dominance) does not support their contention that the CT asymmetries are better predictors of language dominance than hand preference. Nonetheless, a stronger argument could possibly have been made if Chui & Damasio had had results from language laterality tests on their patients such as carotid amytal test results.

Pieniadz and Naesar (1984) have also suggested that occipital CT scan asymmetries are probably related more to some aspect of language function than to handedness. They found a significant correlation between CT occipital length asymmetry and postmortem planum temporale asymmetry in right handers. Pieniadz and Naesar's (1984) documentation of occipital length asymmetries are similar to those reported by LeMay (1977), suggesting that at least one CT scan measure of asymmetry, occipital length, may be an index of language laterality. Their measuring procedure was a modification of that reported in LeMay (1977) and LeMay and Geschwind (1977).

There is some additional evidence that occipital length asymmetry may index some aspect of language laterality. Pieniadz et al. (1983) found better recovery of some language functions in those right-handed global aphasics who had atypical occipital CT scan asymmetries (equal or right larger than left). Based on their study of 14 right-handed patients, they suggest that cases with atypical occipital asymmetries do not necessarily manifest atypical patterns of handedness. Pieniadz and Naesar (1984) speculate that the occipital CT scan asymmetry is related more to some aspect of language function than to hand preference. They point out, however, that occipital asymmetry does not predict language laterality per se. (See also Henderson, 1984). It does, however, appear to predict the hemispheric side of lesion producing aphasia, only when there is some potential for language recovery.

c)Dichotic Listening

Kimura (1961a) was the first to propose that, on a dichotic listening task, a right ear advantage for verbal stimuli implied left hemisphere speech dominance while a left ear advantage suggested right hemisphere specialization. Her proposal was based on the idea that there are more efficient neural connections of the auditory pathways from each ear to the contralateral than to the ipsilateral, hemisphere. She supported her suggestion by giving a verbal dichotic listening test to patients who had undergone carotid amytal testing (Kimura, 1961b). Kimura found a right ear advantage for those patients with left hemisphere speech dominance and a left ear advantage for her small group of patients with right hemisphere speech dominance.

Numerous studies with normal and clinical populations have used the dichotic listening procedure as a behavioral technique to investigate hemispheric asymmetry with auditory input. Kimura's 1975 review summarized the literature at that time, and indicated that a right ear advantage, implying left hemisphere dominance, exists for the perception of speech sounds in the form of nonsense syllables, consonant-vowel syllables, backward speech, and real words. A recent review by Springer and Deutsch (1982) reports that approximately 80% of right-handed subjects show a right- ear advantage for the perception of verbal stimuli. This estimate correlates closely with the reports of a larger left posterior Sylvian region found in 75% to 80% of right handers (Strauss, Kosaka, & Wada,1983). A right ear advantage has also been reported as early as age 3 years of age (Nagafuchi,1970; Ingram,1975) indicating the usefulness of the dichotic listening technique in studying the development of functional brain asymmetry.

Although the validity of the dichotic listening technique appears well established, a controversy remains regarding the reliability of this procedure. The procedure appears sensitive to attentional factors,individual strategies, as well as to the methodologies used for determining ear advantage (Bryden,1982; Clark & Spreen,1983). Berlin (1977) also points out that while the dichotic listening test appears to be an index of laterality, it cannot be interpreted as an index of magnitude of laterality. That is, a large right ear advantage does not necessarily imply a larger left hemisphere superiority.

Studies have shown relations between ear advantage on a dichotic listening test and anatomical asymmetries

(Witleson, 1982). Strauss, et al. (1985) report a wider left posterior Sylvian region is more common in those individuals who show a right ear - left hemisphere advantage on a verbal dichotic listening test. A wider right posterior Sylvian region is more typical of a left ear - right hemisphere advantage. However, the small number of subjects limits the conclusion for those with left ear advantage.

d)Divided Visual Field Technique

The divided visual field (DVF) technique involves the presentation of stimuli to the right and left visual hemifields and has been used to investigate hemispheric asymmetry with visual input. The use of this technique in studies of cerebral organization is based on the rationale that information falling in the left visual field (LVF) is initially projected to the right cerebral hemisphere while information in the right visual field (RVF) is initially projected to the left cerebral hemisphere. A RVF advantage has been reported for language related stimuli (e.g. words, letters) and a LVF advantage has been shown for non-language stimuli (e.g. line orientation,faces) (Beaumont, 1982; Bryden, 1982). In addition, reduced or reversed laterality effects have been reported for left-handers (Bryden, 1982; Bradshaw & Nettleton, 1983). These results provide indirect support for the idea that DVF studies are related in some way to hemispheric asymmetry. More direct evidence comes from a recent study by Strauss, Wada, & Kosaka (1985). They report that patients with speech in the left hemisphere,as determined by amytal testing, were more likely to show a RVF superiority on a visual verbal half-field task. Patients with atypical speech representation showed a bias toward the LVF.

Rationale:

The purpose of the present study was to investigate further the relations between anatomical asymmetries as visualized by CT scans, and a variety of functional laterality indices. The anatomical measures included width measurements of the frontal, occipital, and parietal areas. Frontal and occipital petalia measurements were also included in the anatomical indices. The functional laterality indices were speech dominance as determined by carotid amytal testing, handedness, performance on a verbal dichotic listening task, and performance on a verbal visual half-field task. Previous studies using CT scan measures were unable to report carotid amytal, dichotic listening, or visual half-field findings on their patients, and few studies have attempted to correlate functional measures to anatomical CT measures in the same cases.

Due to the retrospective nature of this research (the CT scans had been done prior to this study), and the small number of scans that could be retrieved, it was predicted that a low subject/variable ratio would exist. In the event of a low subject/variable ratio, the study would be exploratory and would generate hypotheses regarding the relations between morphological and functional measures.

The following were the a priori hypotheses for this study:

1.The strongest associations would be between the CT measures of occipital widths and/or lengths and performance on the dichotic listening task. This speculation was based on the literature regarding the importance of the posterior language zone to the perception of language. (Geschwind & Levitsky,1968; Goodglass & Kaplan,1972).

2.Since carotid amytal findings have been linked to the results of dichotic listening testing (Kimura 1961a) and anatomical asymmetries (Ratcliffe, et al., 1980; but see Strauss, et al , 1985), it was hypothesized that an association may also exist between carotid amytal results and parietal,occipital widths and/or lengths.

3.In light of the conflicting results from various studies (LeMay & Kido, 1978; Chui & Damasio,1980; Piendiaz & Naesar,1984)'it is somewhat difficult to predict what the association would be between handedness and any of the anatomical variables measured on the CT scans. This study used measurement techniques similar to Chui & Damasio (1980) and Pieniadz and Naesar (1984). Given their negative findings,it is was hypothesized that there would be no associations between handedness and any of the anatomical measurements.

4.Since performance on the divided visual field task is, like the dichotic listening task, a test of language reception, the prediction is made that a relation may exist between the posterior occipital lengths and/or widths and performance on this task.

In summary, this study allowed for the unique opportunity to investigate the possible relations between an unequivocal measure of speech dominance (carotid amytal findings), behavioral measures of laterality (handedness, dichotic listening,divided visual field testing) and morphology (measurements from CT scans).

METHOD

Subjects

The neurological population was composed of epileptic patients with medically refractory seizures who had undergone in-depth investigation for possible surgical treatment at the University of British Columbia's Health Sciences Centre Hospital. The protocol for possible surgical candidates includes a series of electroencephalograms, carotid amytal testing to determine speech dominance, carotid arteriograms and CT scans to obtain structural information. In addition, patients receive neuropsychological testing that includes a verbal dichotic listening task, an inventory to determine handedness, and a verbal visual half-field task.

A list of possible patients who had undergone carotid amytal tests and CT scanning consisted of 95 names. When the retrieval of scans was completed and files were checked for relevant neuropsychological information, the final sample size was 48. Some of the CT scans could not be located and others were omitted due to technical inadequacies. Eleven cases were omitted because the only available neuropsychological information was post-operative. The CT scans included in this study were either interpreted as normal (38) or had non-significant findings (10) such as minimal ventricle enlargement. In the case of the latter, the neuroradiologist decided whether these cases should be included in this study. Any cases with neoplastic or atrophic processes were omitted (14).

The final sample consisted of 24 males and 24 females. In 34 patients (70.8%), speech was exclusively mediated by the left hemisphere and in 6 patients (12.5%), speech was in the right hemisphere. Eight patients (16.7%) had bilateral speech representation (left hemisphere more than right). At the time of scanning, the ages of the patients ranged from 12 to 58, with a mean age of 29.10 years of age.

PROCEDURE

Laterality Indices

Speech dominance was established in the patients following the procedures of Wada & Rasmussen (1960). Patients were classified as having either left, right, or bilateral speech representation. The carotid amytal results were coded so that bilateral and right hemisphere speech representation were classified as degrees of left hemisphere dominance. This ranking allowed for the correlation analyses (see Results).

To determine handedness, patients completed a behaviorally validated lateral preference inventory (Coren & Porac, 1978; Coren,Porac, & Duncan, 1979; Porac & Coren,1981). A score was tabulated from the inventory, with 0 or a negative value signifying left handedness. A score greater than 0, signified right handedness.

The dichotic listening test was developed by Hayden and Spellacy and consists of 22 trials. Each trial contained three dichotic pairs of mono-syllabic nouns, matched in terms of their initial phoneme (e.g. port, pack). The subject is instructed to repeat as many of the 6 words as possible on each trial. A laterality score ((R-L)/(R+L))was derived for each subject, where R represents the number of words correctly reported from the right ear and L, the total correct from left ear presentations. A negative score or a score of 0 represented a left ear advantage and a positive score represented a right ear advantage.

The stimuli for the verbal visual half-field test consisted of forty-eight four-letter real words (e.g. what, then, like). A bilateral stimulation procedure,with a central number at fixation was used (Strauss, Wada, and Kosaka, 1985). The subjects were told that words would appear on the screen with one word appearing to the right and another word appearing to the left of a central fixation number. They were to report the number first and then the words in any order. A laterality score of (R-L)/(R+L) was derived for each subject where R represents the number of words correctly reported from the right visual field and L, the total correct for the left visual field. A negative score or a score of 0 represented a left visual field advantage and a postive score, represented a right visual field advantage.

CT Scan Measurements

The CT scans were performed at two hospitals. Scans were done at the Vancouver General Hospital from 1976 to 1982 using either an EMI 1010 or GE 8800. Slices were obtained at an angle of 0 or 20 degrees to the canthomeatal line.

Insert Figure 1 about here

Each slice done on the EMI represented a 8 mm thick section of the head, whereas the GE slices represented a 10mm section. From 1982 to 1984, scans were also done at the Health Sciences Centre Hospital at the University of British Columbia,using a Siemans Somatome DR2. Slices were obtained at 0 degrees to the canthomeatal line (see Figure 1) and each slice represented an 8mm thick section of the head. Since there are magnification differences between scanners, minification factors were applied to the data so that the measurements from each scanner were directly comparable to each other. A minification factor of 3.5 was used on EMI scans, 2.9 for GE scans, 3.0 for the Siemans scans having 4 images per film, and a 2.0 factor was applied for those Siemans scans with 6 images per film.

The CT slices chosen for analysis were as close to the descriptions offered by Pieniadz et al (1984). For example, the widths and lengths of the occipital lobes were measured on 2 CT slices . Slice "0" was the first slice above the tentorium and contained the image of the posterior temporal lobe. The second slice for occipital measurements, "O1", was one slice higher and showed the bodies of the lateral ventricles. Meaurements were made for the parietal areas on slices P and P1. Slices F and F1 designated the slices where frontal measurements were made (See Figure 1). All slices were double checked by the two raters to ensure that the appropiate slices were chosen and used.

Width Measurements

To make the results from this study comparable to the results of previous studies in this area, 2 methodologies were initially proposed to measure the possible CT asymmetries. One method was similar to that developed by LeMay (1977) and later modified by Piendiaz et al, (1983). The width measurement was to be made by moving a clear plastic ruler from the occipital pole along the posterior falx until either the left or right inner table of the skull measured 10mm from the midline of the interhemispheric fissure. The widths of both the left and right hemispheres would be recorded. The frontal widths were to be measured in the same way starting from the frontal pole. Since the scans for this study were from 2 different scanners with different magnifications, this method was not used.

The procedure that was used to measure widths was based on that used by Chui and Damasio (1980). A midline axis was drawn down the interhemispheric fissure as a centre guideline using more than one of the following elements as landmarks: third ventricle, pineal gland, anterior falx, or the septum pellucidum. Perpendicular lines were then drawn to the midline axis at the most posterior and anterior ends of the hemispheres. The distance between these two perpendicular lines was designated as the AP, the greatest distance from the anterior pole to the posterior pole. Occipital widths were measured at a point that was anterior to the occipital pole and represented 16% of the brain's total length. The frontal widths were measured at a point anterior to the occipital pole representing 90% of the brain's total length. Chui and Damasio chose the 16% and 90% points because they would traverse the occipital lobes and the middle inferior frontal gyrus respectively. Since their scans were angulated at 15 degrees, while ours were at 0 and 20 degrees, two additional width measures were done. To maximize the chances of the width measurements traversing across anterior and posterior language zones, width measurements were also taken at 30 percent and 80 percent of the brain's total length. In short, left and right side measurements for the occipital and parietal areas on slices O, O1, P, P1 were made at 16 percent and 30 percent of the brain's total length, whereas the frontal measurements were done at 80 percent and 90 percent on slices F, and F1 (see Figure 2). For each patient, a total of 6 AP measurements and 24 width measurements were made.

Insert Figure 2 about here

A ratio for the occipital differences was derived from the formula (L-R)/(L+R/2). The formula (R-L)/(R+L/2) was used to determine the difference between the frontal lobes. These equations are taken from Pieniadz and Naesar (1984), and this study also used their criteria for quantifying width measurements. If the widths of the two hemispheres differed by less than 0.5 mm, they were considered as equal or symmetrical, and were assigned a value of 0. When the ratio is a positive number, the asymmetry is in the expected, or typical direction whereas a negative number represents atypical or unexpected direction. The normative directions are based on data from LeMay's studies (1976,1977). Occipital asymmetries are considered typical if L>R, and frontal asymmetries are considered typical if R>L.

Length Measurements

A clear plastic polar coordinate overlay was provided by Dr. M. Naesar and was used to measure lengths (Piendiaz and Naesar 1984). Length asymmetries occurred when one hemisphere extended further than the other and reached a more distant concentric circle. For each patient, a total of 6 length measurements, one for each slice (O,O1,P,P1,F,F1), were made. A ratio for the occipital differences in length was derived from the formula, (L-R)/(AP/2), where AP is the greatest distance from the anterior to the posterior pole. The equation (R-L)/(AP/2) provided a ratio for frontal differences.

Inter-rater Reliability And Experimenter Bias

All CT scans were measured by two independent raters. There were no discrepencies regarding the direction of any of the asymmetries. Since the only differences were in the rounding off of numbers, each scan was reviewed again by both raters and any differences were conferenced. The agreed upon measurements were used for subsequent analyses.

To control for experimenter bias regarding the expected asymmetries, measurements were made on a random selection of half the CT scans on reversed images. Both raters were blind as to which scans had a reversed image.

RESULTS

The results will be presented in three sections. Section I provides a brief overview of the relations between the functional and anatomic data in terms of frequency distributions. The analyses for this section used the Chi-square test (SAS, 1982; Stats Plus,1982). The Yates Correction Factor was applied to those contingency tables where the expected cell frequencies were less than 5. Only those significant levels below .05 will be reported. The second section reports the results for the main objectives of this study: the relations between the morphological and functional measures using canonical correlation analyses. Finally, section III, includes additional data analyses.

SECTION I FREQUENCY DISTRIBUTIONS

A. Distribution Of Widths And Petalias By Carotid

Amytal Results

Table 2 shows the distribution of width asymmetry by carotid amytal results (speech dominance).

Insert Table 2 about here

Regardless of speech representation, the majority of subjects showed no left-right asymmetries. However,when asymmetries did emerge on occipital slices, they tended to favor the left side (Chi-square(1)=16.49,p<.001) for both the left and right speech groups. The difference appears less marked, though not significantly so,for patients with bilateral speech. The same pattern emerges on the parietal slices. Left (Chi- square(1)=4.9,p<.03) and right (Chi-square(1)=8.3,p<.004) speech groups showed a bias toward a left-sided asymmetry. Patients with bilateral speech showed no bias. Right and bilateral speech groups differ significantly in their pattern of asymmetries (Chi-square (1)=3.9, p<.05). When frontal asymmetries occurred, the right side was favoured again, independent of speech group (Chi-square(1)=5.07,p<.02).

Insert Table 3 about here

Table 3 shows the petalia (lengths) distribution by carotid amytal results. Again, the largest distribution type was the L=R for occipital, parietal, and frontal petalias. When an asymmetry existed for either occipital and parietal petalias, for any of the speech groups, it was in the direction of L>R (occipital: Chi- square(1)=29.0,p<.001; parietal: Chi-square(1)=5.14, p<.02). When asymmetries for the frontal petalias were considered, they favoured the right side, regardless of side of speech representation (Chi- square(1)=14.0,p<.001).

B. Distribution of Widths and Petalias by Handedness

Insert Table 4 about here

Table 4 shows the left-right measurements by handedness for our epileptic population. Again, the majority of subjects showed no asymmetries. However, when asymmeties did occur among right-handers, they showed the pattern described by LeMay & Pieniadz. That is, among right-handers, occipital and parietal lobe asymmetry favoured the left side (occipital Chi-square(1)=12.19,p<.001; parietal Chi-square(1)=5.4,p<.02). There was a trend, albeit non-significant, for the frontal width asymmetry to favour the right side.

Although the number of left-handers in our sample is very small, a similar pattern emerged in this group. The majority of subjects showed no left-right asymmetries. When occipital or parietal asymmetries emerged, they favoured the left side. Similarly, when frontal asymmetries emerged, they favoured the right side.

Insert Table 5 about here

Petalia distribution by handedness is shown in table 5. Again, the majority of left and right-handed subjects showed no left-right asymmetries. When occipital or parietal asymmetries were evident, they were biased toward the left side regardless of handedness (occipital Chi-square(1)=29.0,p<.001; parietal Chi-square(1)=5.14,p<.02). When the frontal asymmetries occurred, they favoured the right side regardless of handedness(Chi-square(1)=14,p<.001).

C. Distribution of Widths and Petalias By Dichotic Listening Results

The distribution of width asymmetries by dichotic listening results are shown in Table 6.

Insert Table 6 about here

Regardless of ear advantage, the majority of the subjects showed no left-right asymmetries. Again, when asymmetries emerged for the occipital slices, they tended to favour the left side regardless of ear advantage (Chi- square(1)=18.75, p<.001). If a frontal width asymmetry was present, it favoured the right side (frontal Chi- square(1)=5.07;p<.02).

It is worth noting that ear differences exist in terms of the overall pattern of parietal measures (Chi- square(2)=9.79,p<.007). This is largely due to differences on slices P30 and P130 (Chi-square(2)=8.99,p<.01). People who had a REA showed left-sided or no asymmetries. Patients who had a LEA showed no asymmetries.

The distribution of petalia (lengths) asymmetries by dichotic listening results are shown in Table 7

Insert Table 7 about here

The majority of subjects showed no asymmetries. If an asymmetry occurred, it was in the expected direction; that is left-sided on occipital and parietal measures, right-sided on frontal measures.

D. Distribution of Widths and Petalias by Visual Half-field results

Table 8 shows the distribution of width asymmetries by visual half-field results.

Insert Table 8 about here

Again the majority of subjects showed no asymmetries. When occipital asymmetries emerged, they favoured the left side regardless of visual field (Chi-square(1)=16.07,p<.001) When parietal asymmetries emerged, they also favoured the left side regardless of visual field (Chi-square(1)=15.25,p<.001) Frontal asymmetries tended albeit nonsignificantly, to favour the right side.

The petalia (length) distributions are shown in Table 9.

Insert Table 9 about here

The largest distribution type was L=R for occipital, parietal, and frontal petalias. If an asymmetry for occipital or parietal petalia existed, it was always in the L>R direction independent of visual field. With regard to the asymmetry of frontal petalias, the right side was favoured.

SECTION II RELATIONS BETWEEN MORPHOLOGICAL AND FUNCTIONAL MEASURES

The following section reports the results addressing the apriori hypotheses of this study, using the statistical procedure of canonical correlation.

Canonical correlation is a multivariate statistical analysis that determines the linear relations between two data sets that do not necessarily have the same number of variables. Table 10, shows the two data sets used in this study.

Insert Table 10 about here

Although it is usual procedure with canonical correlations to assign one data set as predictor variables and the other set as criterion or outcome variables, this is not necessary when one is looking at the associations between two data sets (Rosenblood, 1984). Intuitively, one may want to call the CT measurements as the predictors assuming that anatomical structures provide the necessary substrate for the behavioral measures (e.g. handedness). In this study, the measurements from the CT scans were designated as data set one. The canonical correlations look at the associations between this data set and data set two, which includes the results from the carotid amytal testing, handedness, dichotic listening task, and the visual half-field task. Briefly, two linear composites are formed (one for each variable) and the correlation between these two composites (known as the canonical correlation) is calculated. The canonical correlation measures the first pair of canonical variates with the highest intercorrelation possible. Following this, a second set of canonical variates accounting for the residual variance is produced and so forth. The square of the canonical correlation (Eigenvalue) is an estimate of the variance sharedby the two composites.

The a priori hypotheses for this study considered the full multivariate relations between the two data sets and examined the significance of individual dimensions. Therefore, Harris's procedure (1976) for testing significance in canonical correlation was chosen. The procedure involves determining first if Wilks' Lambda (1-p) is significant. If significant, one then determines if the Greatest Characteristic Root is significant, and if so, one can then declare the first canonical correlation as being significant. This procedure continues until non-significance occurs in either Wilks' Lambda or the Greatest Characteristic Root. Any remaining correlations are considered as non-significant. Also, if the overall mulitivariate is significant in canonical correlation, then, and _only_ then, can the simple correlations can be examined. Finally, canonical correlation immediately drops any subjects with missing data. For this current study, not all subject's files included scores from the visual half-field task. Therefore canonical correlations were performed on the data, both with (N=34) and without (N=48) visual half-field scores.

Table 11 shows the results of the canonical correlation analysis between the complete anatomical and functional variables.

Insert Table 11 about here

The first a priori hypothesis suggests that the strongest association might be found between the anatomical variables of occipital widths and/or lengths and the functional variable of dichotic listening. No significant relations were found for either widths and lengths using Harris's procedure. Due to the exploratory nature of this study, examination of the canonical structure was done for several of the analyses to examine for possible trends in the data.

For example, Table 12 shows the correlations between the individual anatomical variables and the functional variate (W1) as well as the individual functional variables and the anatomical variate (V1).

Insert Table 12 about here

Since the Greatest Characteristic Root was near significance ($p<.0535$), only the first canonical correlation was examined. The correlation ($r=.8465$) between the dichotic listening scores (DICHT) and the anatomical variate suggest this task has the strongest association to the anatomical variate. However, the lack of any high correlations between the individual anatomical measures and the functional variate suggest no clear, distinct associations for any individual anatomical area.

Table 13 shows the results from the canonical correlation analysis between the complete anatomical data set and the functional variables excluding the visual half-field scores.

Insert Table 13 about here

Canonical correlation analysis omitting visual half-field scores (N=48), again revealed non-significance using Harris's procedure.

Table 14 presents the correlations between the variables, omitting the visual half-field scores and the variates.

Insert Table 14 about here

The correlation between the dichotic listing scores and the anatomical variate remains the strongest association to the anatomical variate, but is somewhat lower (r=.6871)

The second a priori hypothesis suggested that relations might exist between occipital widths and/or lengths and speech dominance as determined by carotid amytal results. Canonical correlation analysis with visual half-field scores (see Table 11) or without visual half-field scores (see Table 13) revealed no significant relations.

The third apriori hypothesis suggested that there would be no significant associations between handedness and any of the anatomical measurements. Canonical correlation analyses confirmed this (see Tables 11 and 13).

Table 15 shows the individual correlations between the anatomical and functional variables using Pearson Product Correlation.

Insert Table 15 about here

However, when individual correlations (Pearson Product Correlation Coefficients) are done, a small but significant relation is seen between occipital width measures (WIO130) and handedness (r=.3344, N=48, p<.0202).

The final hypothesis suggested that possible relations may exist between occipital widths or lengths and visual half-field results. No significant relations were found(See Table 11).

SECTION III FURTHER ANALYSES

Due to the low subject-to-variable ratio in this study, and the fact that in canonical correlation, the variance is shared among the total number of variables in each data set, further canonical correlation analyses were done using width variables only, length variables only, and an analysis of the variables used in the Chui & Damasio study (1980). The following results addressed issues that were not apriori and were again, exploratory in nature.

A. Widths Only

Table 16 shows the results from canonical correlation analysis using only the width measurements and all the functional variables.

Insert Table 16 about here

Harris's procedure revealed nonsignificance for canonical correlation using the widths only. Although statistically inappropiate, since Wilks' Lambda was not significant, examination of the Greatest Characteristic Root revealed significance ($p<.0258$).

Table 17 shows the standardized canonical coefficients for this analysis.

Insert Table 17 about here

The numbers represent the weightings for each variable in the composite equation describing the dimension. Although uninterpretable (e.g. there are no established rules for cut-off criteria of a significant standardized canonical coefficient), the larger numbers represent variables contributing more to the linear equations. When visual half-field scores (TSCPE) are included (N=34) the standardized canonical coefficients suggest that relations possibly exist between an anatomical variate composed of posterior widths (slices O,P,P1) at 30 percent (WIO30,WIP130) and 16 percent (WIP16) of total brain length and anterior widths (slices F,F1) measured at 80 percent of total brain length and a functional variate composed of handedness and dichotic listening scores.

Table 18 shows the results from canonical correlation analysis between the width measurements only and the functional variables excluding the visual half-field scores.

Insert Table 18 about here

However, when visual half-field scores are omitted, both Wilks' Lambda and the Greatest Characteristic Root are not significant.

B. Lengths Only

Table 19 shows the results from canonical correlation analysis between length measurements only and all functional variables.

Insert Table 19 about here

Canonical correlation analysis for length measurements only, did not reveal any significant relations, using Harris's procedure. However, the Greatest Characteristic Root was significant ($p<.0136$).

Examination of the standardized canonical coefficients in Table 20 suggest that relations possibly exist between an anatomical variate composed of occipital and parietal lengths (LENOC1,LENPA) and the functional variate of dichotic listening scores.

Insert Table 20 about here

Table 21 shows the results from canonical correlation analysis between the length measurements only and the functional variables excluding the visual half-field scores.

Insert Table 21 about here

When visual half-field scores are omitted, the Greatest Characteristic Root remained significant ($p<.0186$)

Table 22 shows the standardized canonical coefficients for lengths only and functional variables excluding the visual half-field scores.

Insert Table 22 about here

The standardized canonical coefficients suggest the same anatomical variate composed of LENOC1 and LENPA and the functional variate composed of dichotic listening scores.

C. Chui & Damasio (1980) Variables Only

Table 23 shows the results using Chui & Damasio's anatomical variables and all the functional variables. The canonical correlation analysis in Table 24 uses the same anatomical variables and the functional varibles exclude the visual half-field scores.

Insert Tables 23 & 24 about here

In the original study by Chui & Damasio (1980), their width measurements were at 16 percent (WIO16,WIO116) and 90 percent (WIF90,WIF190) of the brain's total length. Using their measures , there were no significant relations using canonical correlation with or without visual half-field scores.

Table 25 shows the Pearson Correlation Coefficients between Chui & Damasio's anatomical variables and all the functional variables.

Insert Table 25 about here

An exploratory examination of the univariate correlations between these anatomical and functional variables revealed no significant individual correlations.

DISCUSSION

This invivo study allowed for the unique opportunity to investigate,in epileptic patients, the possible relations between anatomical measurements from CT scans and functional laterality indices of handedness, dichotic listening, and visual half-field results as well as the results from carotid amytal testing, an unequivocal measure of speech dominance. The findings showed that the majority of subjects showed no asymmetries in either widths or lengths (petalias) measures. However, when asymmetries occurred, they were in the predicted direction. For example, when asymmetries were evident in the parietal or occipital slices,they were in the L>R direction. When asymmetries on the frontal slices were examined,they were in the direction of R>L. There were,however, no strong relations between the anatomical measures and the laterality indices. We will consider each of these points in greater detail.

Reduction in incidence of asymmetries

The results show a lower incidence of left-right asymmetries relative to other studies (Lemay & Kido, 1978; Pieniadz & Naesar,1984). The reason for this lower incidence is not clear but may reflect methodological or sampling differences. It should be pointed out again that the original procedure by LeMay & Kido to measure widths could not be used in this study (see methods) due to the magnification difference between scans used in this study. This study used Chui & Damasio's (1980) technique where width measurements are taken at 16 percent and 90 percent total brain's length. Also, additional measures at 30 percent and 80 percent of the total brain's length were taken (see Figure 2) to maximize the chances of the width measurements traversing across the anterior (Broca's) and posterior (Wernicke's) language zones. Nonetheless, compared to Chui & Damasio, there is a lower incidence in overall asymmetries. Thus, methodological issues cannot account for the whole story. Population differences may also be a factor (see below).

Speech Dominance (Carotid Amytal Results)

The findings suggest that there are no clear width or length asymmetries in an epileptic population that reliably predict speech dominance. The Chi-square analyses revealed a significant difference between right and bilateral speech groups on parietal slices. The samples however are small (N=8 and N=6, respectively) and this finding needs to be replicated.

It is quite possible that relations exist;for example, frontal widths and lengths and carotid amytal results since the amytal test is mainly a test of speech production, a function that presumably depends primarily on frontal regions. However, simple width and length measures of the sort used in this study may not be sensitive enough to show a relation. Wada et al., (1975) have suggested that the total cortical surface area of the frontal operculum (Broca's region) is not apparent because of the tightly packed gyral pattern on the left side. Histological or cytoarchitectonic methods (Galaburda, 1980) may be required for a more accurate area measurement of this anterior language zone.

Clinically, carotid amytal testing is typically performed on medically refractory epileptic patients to determine speech dominance before surgical intervention. Future studies must determine whether the negative findings reported here are due to the idiosyncratric nature of our patient population (epileptics) or to the fact that the carotid amytal test is basically measuring speech production as opposed to speech perception (comprehension).

Handedness

Chui & Damasio's contention that CT criteria (widths and lengths) are not related to handededness is supported by the nonsignificant canonical correlations. The significant univariate correlation between a posterior width measurement (WI0130) and handedness ($r=.3344$, $p<.0202$) is small and requires further replication.

Dichotic Listening Results

Pieniadz & Naesar (1984) suggested that occipital length may be the best CT index of functional (language) asymmetry. The exploratory examination of canonical correlation using lengths only, supports this suggestion. Although there are severe limitations to the statistical interpretation of this finding, the trend suggests that occipital length (LENOC1) might be related in some way to the functional variable of performance on a verbal dichotic listening task. Intuitively, it would make sense that a task involving the perception of verbal material (dichotic listening task) could be related to measurements in the posterior language zones.

Visual Half-field Results

A relation between the divided visual field task and posterior anatomical measures (i.e.occipital lengths and widths) would have been expected to have existed since the task is basically a test of verbal reception. However,the lack of a relation between this functional variable and posterior anatomical measures may be due to the the lack of sensitivity for both the anatomical measures and visual half-field task.

Several additional possibilities exist for explaining the results of this study and the discrepancies between present and previous findings:1)low-subject-to-variable ratio, 2) differences in patient population 3) CT scanning angulation and 4) differences in measurement techniques.

1. Low-subject-to-variable ratio

Due to the small sample size, this study must be considered exploratory and further replication with a larger sample of its findings is necessary. Although a sample size of 48 patients appears small, in a retrospective study where various criteria had to be achieved (e.g. scans must be of patients who have had carotid amytal testing and neuropsychological testing), 48 patients would seem respectable. No previous study has reported this large a sample of patients with carotid amytal test results.

Henderson et al (1984) who used similar CT measurements on aphasics (including 15 cases of crossed aphasics,) also found tht CT measures failed to predict language laterality. He also determined,through statistical power analysis, that a sample size of approximately 9000 right-handed aphasics would be required to insure the probability of a Type II as well as a Type I error of less than .05. Power analysis was not performed for this study, but using the simple criterion of at least 10 subjects per variable, would suggest that at least 220 patients would be required as a minimum sample size. This would be clinically difficult to achieve.

2. Differences in Patient Populations

The previous studies using CT measures were performed on either nonneurological or aphasic stroke patients as well as normals. The study with aphasics would suggest that any abnormalities that existed were within the aphasic patient's vascular system and that this pathology would not account for asymmetries in the brain or skull. In this present study, patients with histories of medically refractory epilepsy, typically of early onset, could be of higher risk for changes in cortical volume and/or shape.

Table 26 provides a breakdown of the patients and the age of seizure onset or insult.

Insert Table 26 about here

In more than half of the sample, the onset or insult occurred early in life, before the age of 7.

Another important influence could be the long-term effects of being on an anticonvulsant regime. Although the long-term effects of epilepsy or anticonvulsants on developing brain morphology remains unknown, there does appear to be some some association between the long-term use of Dilantin and cerebellar atrophy although the issue has been raised that frequent status epilepticus may be the key factor (Purves,et al,1986;Dolman, 1986). Preliminary results of another study currently in progress (O'Kusky, et al., 1986), examining the anatomical measures from MRI scans, suggest a trend for the overall corpus callosum size in an epileptic population to be approximately seven percent smaller in comparison to a normal population.

In short, Pieniadz's suggestion that CT asymmetries are related to some aspect of language may be true. However, this interpretation may only be appropiate to populations where there is relatively normal morphological development. Moreover, it may also apply to some aspect of language that was not measured by the functional tasks used in this study.

3. Differences in CT Angulation

A review of the previous studies reveals that various angles of scanning have been used and that the anatomical areas measured may be different. For example, LeMay and Kido's scanning routine (1978) was at 20 degrees above the orbitomeatal line. Chui & Damasio's study (1980) involved 15 degrees whereas Pieniadz et al (1983) used 15 to 30 degrees to the canthomeatal line or 15 to 25 degrees (Pieniadz & Naesar, 1984).

This current study included scans done at 0 and 20 degrees. Zero degrees had been chosen in the clinical protocal to provide optimal images of the temporal areas. Although Figure 1 suggests that different areas are being imaged, the width measurements closely correspond to similar cortical areas. The anterior and posterior width measurements traverse language-related zones (e.g. Broca's and Wernickes).

Kertesz et al (1984) recently reported relations between a visual field task and right parietal and left occipital widths at 30 percent total brain's length. However, his images were obtained from MRI scanning at an angle of 30 degrees to the orbitomeatal line and may be reflecting not only differences in angulation but also influences from a different imaging technique. In addition, the relations between specific laterality indices and particular anatomical areas may be maximized at particular angles of scanning(e.g. 30 degrees for visual field tasks).

4. Differences in Measurement Techniques

Variations in methods of measurements may also be contributing to the different results. LeMay's technique (1978) involved measurements at approximately 5mm from the ends of the hemispheres. Chui & Damasio (1980) took their measurements at 16 percent and 90 percent of the total brain's length. Pieniadz and Naesar (1984) included a modification of LeMay's method and also took width when either the left or right inner table of the skull measured 10mm from the midline of the interhemispheric fissure. This current study included measurement techniques by Chui & Damasio (1980) and part of the Pieniadz & Naesar (1984) protocal. The results from this study did not replicate previous findings. Consequently, while we cannot rule out procedural differences, population differences seem a more plausible explanation for the descrepant results.

One also cannot ignore the fact that the simple measures of widths and lengths may not be sensitive enough to individual variation in gyral size and sulcal demarcation, which may account for some of the conflicting results.

Suggestions for Future Studies

Future clinical studies may also be plagued with the problem of small sample size. If associations between morphological and laterality indices are to be investigated, one consideration would be to use a small, select number of variables. The results from this study suggest that the occipital measures (WIO30 and LENOC1) and dichotic listening test results and handedness have the most potential to be related. Parietal and frontal measures may be of little value but again, this may be due to the angles of scanning used in this study.

The findings from this current study as well as others (Henderson, et al., 1984) suggest that CT measurements and asymmetries may be poor predictors of laterality indices. In turn, the results suggest that simple width and length measurements are poor predictors of the possible neuroanatomic substrates of language. Clinically, these simple measures do not represent a reliable, non-invasive method to predict language laterality. However, replication of these findings is needed. Future studies must address the questions concerning the of angle of scanning, the anatomical measurement technique, and the aspects of language that are to be assessed. There is also some suggestion that the type of clinical population (aphasic,epileptics, vs nonneurological and normals) may influence the presence and degree of cerebral asymmetries.

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Table 1. Summary of CT Asymmetries from Previous Studies- Percentages

LeMay & Kido (1978)

WIDTHS	OCCIPITAL			FRONTAL		
	L>R	L=R	R>L	L>R	L=R	R>L
Right-handers	71.3	20	8.8	12.5	30	57.5
Left-handers	34.1	34.1	31.8	30.5	34.1	35.3
PETALIAS						
Right-handers	75	13.7	7.5	12.5	51.3	28.7
Left-handers	42.3	40	14.1	18.8	54.1	18.8

Chui & Damasio (1980)

WIDTHS	OCCIPITAL			FRONTAL		
	L>R	L=R	R>L	L>R	L=R	R>L
Right-handers	36	44	20	22	42	36
Left-handers	64	32	4	20	32	48
PETALIAS						
Right-handers	60	20	20	8	56	36
Left-handers	44	36	20	16	56	28

Pieniadz & Naesar (1984)

WIDTHS	OCCIPITAL				FRONTAL		
Right-handers (N=15)	L>R	L=R	R>L		L>R	L=R	R>L
slice W (N=14)	57.1	28.6	14.3	slice B (N=13)	38.5	23	38.5
slice SM (N=15)	66.6	26.6	6.6	slice B/W (N=15)	33.3	33.3	33.3
PETALIAS							
slice W (N=14)	78.6	7	14.3	slice B (N=12)	25	50	25
slice SM (N=15)	80	13.3	6.6	slice B/W (N=14)	7	57	35.7

Table 2 Width Asymmetry by Carotid Amytal Results (percent)

OCCIPITAL				
Left	slice	L>R	L≈R	R>L
(N=34)	O16	11 (32.4)	18 (52.9)	5 (14.7)
	O116	13 (38.2)	18 (52.9)	3 (8.82)
	O30	10 (29.4)	22 (64.7)	2 (5.88)
	O130	6 (17.7)	27 (79.4)	1 (2.9)
	Total	40 (29.4)	85 (62.5)	11 (8.1)
Bilateral	O16	1 (12.5)	6 (75)	1 (12.5)
(N=8)	O116	3 (37.5)	4 (50)	1 (12.5)
	O30	1 (12.5)	4 (50)	3 (37.5)
	O130	2 (25)	6 (75)	0
	Total	7 (21.9)	20 (62.5)	5 (15.6)
Right	O16	2 (33.3)	4 (66.6)	0
(N=6)	O116	3 (50)	2 (33.3)	1 (16.7)
	O30	1 (16.7)	4 (66.6)	1 (16.7)
	O130	2 (33.3)	4 (66.6)	0
	Total	8 (33.3)	14 (58.3)	2 (8.3)
FRONTAL				
Left	F80	5 (14.7)	23 (67.6)	6 (17.7)
	F180	6 (17.7)	22 (64.7)	6 (17.7)
	F90	5 (14.7)	18 (52.9)	11 (32.4)
	F190	9 (26.5)	13 (38.2)	12 (35.3)
	Total	25 (18.4)	76 (55.9)	35 (25.7)
Bilateral	F80	0	5 (62.5)	3 (37.5)
	F180	1 (12.5)	4 (50)	3 (37.5)
	F90	2 (25)	3 (37.5)	3 (37.5)
	F190	4 (50)	2 (25)	2 (25)
	Total	7 (21.9)	14 (43.8)	11 (34.4)
Right	F80	0	4 (66.7)	2 (33.3)
	F180	0	5 (83.3)	1 (16.7)
	F90	1 (16.7)	1 (16.7)	4 (66.7)
	F190	0	5 (83.3)	1 (16.7)
	Total	1 (4.2)	15 (62.5)	8 (33.3)

Table 2 (continued)

PARIETAL	slice	L>R	L=R	R>L
Left	P16	12 (35.3)	17 (50)	5 (14.7)
	P116	12 (35.3)	16 (47.06)	6 (17.7)
	P30	7 (20.6)	22 (64.7)	5 (14.7)
	P130	7 (20.6)	22 (64.7)	5 (14.7)
	Total	38 (27.9)	77 (56.6)	21 (15.4)
Bilateral	P16	3 (37.5)	1 (12.5)	4 (50)
	P116	2 (25)	4 (50)	2 (25)
	P30	1 (12.5)	6 (75)	1 (12.5)
	P116	3 (37.5)	3 (37.5)	2 (25)
	Total	9 (28.1)	14 (43.8)	9 (28.1)
Right	P16	3 (50)	3 (50)	0
	P116	2 (33.3)	4 (66.7)	0
	P30	3 (50)	3 (50)	0
	P130	3 (50)	2 (33.3)	1 (16.7)
	Total	11 (45.8)	12 (50)	1 (4.2)

Table 3 Length (Petalia) Asymmetry by Carotid Amytal Results (percent)

OCCIPITAL		L>R	L=R	R>L
	slice			
Left	OC	10 (29.4)	24 (70.6)	0
(N=34)	OC1	10 (29.4)	24 (70.6)	0
	Total	20 (29.4)	48 (70.6)	0
Bilateral	OC	3 (37.5)	5 (62.5)	0
(N=8)	OC1	3 (37.5)	5 (62.5)	0
	Total	6 (37.5)	10 (62.5)	0
Right	OC	2 (37.3)	4 (66.7)	0
(N=6)	OC	1 (16.5)	5 (83.3)	0
	Total	3 (25)	9 (75)	0
FRONTAL				
Left	FR	0	29 (85.3)	5 (14.7)
	FR1	0	30 (88.2)	4 (11.8)
		0	59 (86.8)	9 (13.2)
Bilateral	FR	0	7 (87.5)	1 (12.5)
	FR1	0	6 (75)	2 (25)
	Total	0	13 (81.3)	3 (18.7)
Right	FR	0	5 (83.3)	1 (16.7)
	FR1	0	5 (83.3)	1 (16.7)
	Total	0	10 (83.3)	2 (16.7)
PARIETAL				
Left	PA	3 (8.8)	31 (91.2)	0
	PA1	2 (5.9)	32 (94.1)	0
	Total	5 (7.4)	63 (92.6)	0
Bilateral	PA	1 (12.5)	7 (87.5)	0
	PA1	1 (12.5)	7 (87.5)	0
	Total	2 (12.5)	14 (87.5)	0
Right	PA	0	6 (100)	0
	PA1	0	6 (100)	0
	Total	0	12 (100)	0

Table 4 Width Asymmetry by Handedness (percent)

	slice	L>R	L=R	R>L
OCCIPITAL				
Right-handers (N=42)	O16	11 (26.2)	25 (59.5)	6 (14.3)
	O116	16 (38.1)	22 (52.4)	4 (9.52)
	O30	11 (26.2)	26 (61.9)	5 (11.9)
	O130	11 (26.2)	26 (61.9)	5 (11.9)
	Total	49 (29.2)	99 (58.9)	20 (11.9)
Left-handers (N=6)	O16	3 (50)	3 (50)	0
	O116	3 (50)	2 (33.3)	1 (16.7)
	O30	1 (16.7)	4 (66.7)	1 (16.7)
	O130	1 (16.7)	4 (66.7)	1 (16.7)
	Total	8 (33.3)	13 (54.2)	3 (12.5)
FRONTAL				
Right-handers	F80	5 (11.9)	27 (64.3)	10 (23.8)
	F180	7 (16.7)	27 (64.3)	8 (19.04)
	F90	8 (19.04)	20 (47.6)	14 (33.3)
	F190	12 (28.6)	16 (38.1)	14 (33.3)
	Total	32 (19.1)	90 (53.6)	46 (27.4)
Left-handers	F80	0	5 (83.3)	1 (16.7)
	F180	0	4 (66.7)	2 (33.3)
	F90	0	2 (33.3)	4 (66.7)
	F190	1 (16.7)	4 (66.7)	1 (16.7)
	Total	1 (4.2)	15 (62.5)	8 (33.3)
PARIETAL				
Right-handers	P16	16 (38.10)	18 (42.9)	8 (19.04)
	P116	15 (35.7)	19 (45.2)	8 (19.04)
	P30	9 (21.4)	27 (64.3)	6 (14.3)
	P130	11 (26.2)	23 (54.8)	8 (19.04)
	Total	51 (30.4)	87 (51.8)	30 (17.9)
Left-handers	P16	2 (33.3)	3 (50)	1 (16.7)
	P116	1 (16.7)	5 (83.3)	0
	P30	2 (33.3)	4 (66.7)	0
	P130	2 (33.3)	4 (66.7)	0
	Total	7 (29.2)	16. (66.7)	1 (4.2)

Table 5 Length (Petalia) Asymmetry by Handedness (percent)

OCCIPITAL		L>R	L=R	R>L
Right-handers	slice			
(N=42)	OC	14(33.3)	28(66.7)	0
	OC1	13(30.9)	29(69.04)	0
	Total	27(32.1)	57(67.9)	0
Left-handers	OC	1(16.7)	5(83.3)	0
(N=6)	OC1	1(16.7)	5(83.3)	0
	Total	2(16.7)	10(83.3)	0
FRONTAL				
Right-handers	FR	0	36(85.7)	6(14.3)
	FR1	0	36(85.7)	6(14.3)
	Total	0	72(85.7)	12(14.3)
Left-handers	FR	0	5(83.3)	1(16.7)
	FR1	0	5(83.3)	1(16.7)
	Total	0	10(83.3)	2(16.7)
PARIETAL				
Right-handers	PA	4(9.5)	38(90.5)	0
	PA1	3(7.1)	39(92.6)	0
	Total	7(8.3)	77(91.7)	0
Left-handers	PA	0	6(100)	0
	PA1	0	6(100)	0
	Total	0	12(100)	0

Table 6 Width Asymmetry by Dichotic Listening Results (percent)

			L>R	L=R	R>L
	OCCIPITAL				
		slice			
REA		O16	12(28.6)	24(57.1)	6(14.3)
(N=42)		O116	16(38.1)	21(50)	5(11.9)
		O30	11(26.2)	28(66.7)	3(7.1)
		O130	9(21.4)	32(76.2)	1(2.4)
		Total	48(28.6)	105(62.5)	15(8.93)
LEA		O16	2(33.3)	4(66.7)	0
(N=6)		O116	3(50)	3(50)	0
		O30	1(16.7)	2(33.3)	3(50)
		O130	1(16.7)	5(83.3)	0
		Total	7(29.2)	14(58.3)	3(12.5)
	FRONTAL				
REA		F80	5(11.9)	27(64.3)	10(23.8)
		F180	7(16.7)	26(61.9)	9(21.4)
		F90	8(19.04)	18(42.9)	16(38.1)
		F190	12(28.6)	16(38.1)	14(33.3)
		Total	32(19.04)	87(51.8)	49(29.2)
LEA		F80	0	5(83.3)	1(16.7)
		F180	0	5(83.3)	1(16.7)
		F90	0	4(66.7)	2(33.3)
		F190	1(16.7)	4(66.7)	1(16.7)
		Total	1(4.2)	18(75)	5(20.8)
	PARIETAL				
REA		P16	16(38.1)	18(42.9)	8(19.04)
		P116	15(35.7)	19(45.2)	8(19.04)
		P30	11(26.2)	25(59.5)	6(14.3)
		P130	13(30.9)	21(50)	8(19.04)
		Total	55(32.7)	83(49.4)	30(17.9)
LEA		P16	2(33.3)	3(50)	1(16.7)
		P116	1(16.7)	5(83.3)	0
		P30	0	6(100)	0
		P130	0	6(100)	0
		Total	3(12.5)	20(83.3)	1(4.2)

Table 7 Length (Petalia) Asymmetry by Dichotic Listening Results (percent)

OCCIPITAL	slice	L>R	L=R	R>L
REA (N=42)	OC	14(33)	28(67)	0
	OC1	13(31)	29(69)	0
	Total	27(32)	57(68)	0
LEA (N=6)	OC	1(17)	5(83)	0
	OC1	1(17)	5(83)	0
		2(17)	10(83)	0
FRONTAL				
REA	FR	0	35(83.3)	7(16.7)
	FR1	0	35(83.3)	7(16.7)
	Total	0	70(83.3)	14(16.7)
LEA	FR	0	6(100)	0
	FR1	0	6(100)	0
	Total	0	12(100)	0
PARIETAL				
REA	PA	3(7.14)	39(92.8)	0
	PA1	3(7.14)	39(92.8)	0
	Total	6(7.14)	78(92.8)	0
LEA	PA	1(16.7)	5(83.3)	0
	PA1	0	6(100)	0
	Total	1(8.3)	11(91.7)	0

Table 8 Width Asymmetry by Visual Half-Field Results (percent)

OCCIPITAL	slice	L>R	L=R	R>L
RVF	O16	9(42.9)	8(38.1)	4(19.04)
(N=21)	O116	10(47.6)	8(38.1)	3(14.3)
	O30	6(28.6)	12(57.1)	3(14.3)
	O130	5(23.8)	16(76.2)	0
	Total	30(35.7)	44(52.4)	10(11.9)
LVF	O16	3(23.1)	9(69.2)	1(7.7)
(N=13)	O116	3(23.1)	9(69.2)	1(7.7)
	O30	4(30.8)	8(61.5)	1(7.7)
	O130	3(23.1)	10(76.9)	0
	Total	13(25)	36(69.2)	3(5.8)
FRONTAL				
RVF	F80	2(9.5)	16(76.2)	3(14.3)
	F180	3(14.3)	13(61.9)	5(23.8)
	F90	3(14.3)	10(47.6)	8(38.1)
	F190	8(38.1)	7(33.3)	6(28.6)
	Total	16(19.04)	46(55.76)	22(26.19)
LVF	F80	2(15.4)	7(53.8)	4(30.8)
	F180	4(30.8)	7(53.8)	2(15.4)
	F90	4(30.8)	5(38.5)	4(30.8)
	F190	3(23.1)	5(38.5)	5(38.5)
	Total	13(25)	24(46.2)	15(28.9)
PARIETAL				
RVF	P16	7(33.3)	11(52.4)	3(14.3)
	P116	8(38.1)	11(52.4)	2(9.5)
	P30	5(23.8)	15(71.4)	1(4.8)
	P130	5(23.8)	13(61.9)	3(14.3)
	Total	25(29.8)	50(59.5)	9(10.7)
LVF	P16	8(6.15)	3(23.1)	2(15.4)
	P116	7(53.9)	3(23.1)	3(23.1)
	P30	3(23.1)	8(61.5)	2(15.4)
	P130	4(30.8)	9(69.2)	0
	Total	22(42.3)	23(44.2)	7(13.5)

Table 9 Length (Petalia) Asymmetry by Visual Half-Field Results (percent

		slice	L>R	L=R	R>L
	OCCIPITAL				
RVF		OC	6 (28.6)	15 (71.4)	0
(N=21)		OC1	6 (28.6)	15 (71.4)	0
		Total	12 (28.6)	30 (71.4)	0
LVF		OC	4 (30.8)	9 (69.2)	0
(N=13)		OC1	4 (30.8)	9 (69.2)	0
		Total	8 (30.8)	18 (69.2)	0
	FRONTAL				
RVF		FR	0	18 (85.7)	3 (14.3)
		FR1	0	17 (80.9)	4 (19.04)
		Total	0	35 (83.3)	7 (16.7)
LVF		FR	0	10 (76.9)	3 (23.1)
		FR1	0	10 (76.9)	3 (23.1)
		Total	0	20 (76.9)	6 (23.1)
	PARIETAL				
RVF		PA	1 (4.8)	20 (95.2)	0
		PA1	2 (9.5)	19 (90.5)	0
		Total	3 (7.1)	39 (92.9)	0
LVF		PA	2 (15.4)	11 (84.6)	0
		PA1	1 (7.7)	12 (92.3)	0
		Total	3 (11.5)	23 (88.5)	0

Table 10

DATA SETS USED FOR CANONICAL CORRELATIONS

DATA SET ONE
(ANATOMICAL VARIABLES)

LENGTHS*

LENOC - OCCIPITAL
LENOC1 - OCCIPITAL
LENPA - PARIETAL
LENPA1 - PARIETAL
LENFR - FRONTAL
LENFR1 - FRONTAL

WIDTHS*

WIO16 - OCCIPITAL @ 16% of brain's total length
WIO116 - OCCIPITAL @ " " " " "
WIO30 - OCCIPITAL @ 30% " " " "
WIO130 - OCCIPITAL @ " " " " "

WIP16 - PARIETAL @ 16% of brain's total length
WIP116 - PARIETAL @ " " " " "
WIP30 - PARIETAL @ 30% " " " "
WIP130 - PARIETAL @ " " " " "

WIF80 - FRONTAL @ 80% of brain's total length
WIF180 - FRONTAL @ " " " " "
WIF90 - FRONTAL @ 90% " " " "
WIF190 - FRONTAL @ " " " " "

DATA SET TWO
(FUNCTIONAL VARIABLES)

HANDEDNESS SCORE (HAND)
DICHOTIC LISTENING SCORE (DICHT)
VISUAL HALF-FIELD SCORE (TSCPE)
SPEECH DOMINANCE - CAROTID AMYTAL RESULTS (DOM)

*SEE METHODS SECTION FOR THE EQUATIONS USED TO DERIVE THESE SCORES

Table 11 Canonical Correlation Analysis: Complete Anatomical and All Functional Variables (including visual half-field scores) N=34

	Canonical Correlation	Eigenvalue	Approx F	Num DF	Den DF	p
1.	.857372	2.7748	.7867	72	49.5436	.8256
2.	.785070	1.6064	.5826	51	39.5089	.9652
3.	.615641	.6103	.3738	32	28.	.9960
4.	.457672	.2650	.2650	15	15.	.9928

	Value	F	p
Wilks' Lambda	.04989506	.787	.8256
Roy's Greatest Characteristic Root	2.77483	2.312	.0535

Table 12 Canonical Structure: Correlations Between Variables and the Variates (including visual half-field scores)
N=34

Correlations between the anatomical variables and the canonical variate of the functional (W1) variables

	W1	W2	W3	W4
LENOC	.1242	-.0135	.0218	.2480
LENOC1	.3084	-.0306	.0463	.1354
LENFR	.3805	.0065	.2408	-.0240
LENFR1	.3261	-.0652	.2265	-.0258
LENPA	.0448	-.1293	.0132	.0046
LENPA1	.0894	-.1642	.0950	-.0425
WIO16	.0599	.1953	.1852	-.0149
WIO116	.0537	.1672	.9885	.1591
WIO30	.3553	.0135	.0048	.0292
WIO130	.1447	.2550	.2562	-.0583
WIP16	.1389	-.0084	.0567	.1024
WIP116	.0432	.0759	.1828	.1610
WIP30	.1165	.1083	.3032	.0591
WIP130	.2418	.1166	.2047	-.0779
WIF80	-.2712	-.2085	.1617	-.1573
WIF180	-.1125	.2029	.1261	.0844
WIF90	-.3285	.1648	.1578	-.0719
WIF190	-.0552	.0135	.1612	.0034

Correlations between the functional variables and the canonical variate of the anatomical (V1) variables

	V1	V2	V3	V4
HAND	-.0697	.6943	.2513	.0967
DICHT	.8465	-.1006	-.0406	-.0307
DOM	-.2042	-.0574	.5720	-.1253
TSCPE	.1628	.4111	.0575	.3777

Table 13 Canonical Correlation Analysis: Complete Anatomical and Functional Variables (excluding visual half-field scores) N=48

	Canonical Correlation	Eigenvalue	Approx F	Num DF	Den DF	p
1.	.720879	1.0819	.8619	54	81.2658	.7179
2.	.568160	.4767	.5939	34	56.	.9470
3.	.449821	.2537	.4598	16	29.	.9476

	Value	F	p
Wilks' Lambda	.2594625	.862	.7179
Roy's Greatest Characteristic Root	1.081885	1.743	.0887

Table 14 Canonical Structure: Correlations Between Variables and the Variates (excluding visual half-field scores)
N=48

Correlations between the anatomical variables and the canonical variate of the functional (W1) variables

	W1	W2	W3
LENOC	-.0191	-.1145	.0449
LENOC1	.1753	-.0864	.0389
LENFR	.2257	.0823	.0899
LENFR1	.2108	.0670	.1409
LENPA	-.1208	-.1495	-.0566
LENPA1	.0452	-.0561	.1112
WIO16	-.0139	.2444	-.0227
WIO116	-.0873	.1729	.0548
WIO30	.2351	-.0231	-.0841
WIO130	-.0259	.3625	.0459
WIP16	-.0969	.0448	.0839
WIP116	-.1299	.0961	.1285
WIP30	-.0958	.2292	.0949
WIP130	.0064	.2242	.1120
WIF80	-.2947	.0123	.1652
WIF180	-.0530	.1379	.0086
WIF90	-.2328	.1649	-.0739
WIF190	-.0394	.0550	.0115

Correlations between the functional variables and the canonical variate of the anatomical (V1) variate

	V1	V2	V3
HAND	-.0714	.5408	-.1304
DICHT	.6871	-.0169	.1355
DOM	-.2994	.2926	.3373

Table 15 Pearson Correlation Coefficients Between Anatomical and Functional Variables

(Pearson Correlation Coefficients/p level/ Number of Observations)

	HAND	DICHT	DOM	TSCPE
LENOC	-.12015	-.00128	-.01742	.22319
	.4160	.9931	.9064	.2045
	48	48	48	34
LENOC1	-.11086	.18138	-.08811	.15858
	.4532	.2173	.5515	.3704
	48	48	48	34
LENFR	.02989	.23977	.01600	.07838
	.8402	.1007	.9141	.6595
	48	48	48	34
LENFR1	.00205	.24133	.05257	.02765
	.9889	.0985	.7227	.8766
	48	48	48	34
LENPA	-.11393	-.12777	-.06921	-.05414
	.4407	.3868	.6402	.7610
	48	48	48	34
LENPA1	-.09018	.07827	.03571	-.09522
	.5422	.5969	.8096	.5922
	48	48	48	34

Table 15 (continued) Pearson Correlation Coefficients Between Anatomical and Functional Variables

	HAND	DICHT	DOM	TSCPE
WIO16	.24057	-.02731	.11457	.11871
	.0995	.8538	.4381	.5037
	48	48	48	34
WIO116	.15730	-.07181	.16637	.23730
	.2856	.6276	.2584	.1766
	48	48	48	34
WIO30	-.02089	.19939	-.17258	.09905
	.8879	.1743	.2408	.5773
	48	48	48	34
WIO130	.33440	-.02255	.23226	.13682
	.0202	.8791	.1122	.4404
	48	48	48	34
WIP16	.02789	-.06847	.12620	.11181
	.8507	.6438	.3927	.5290
	48	48	48	34
WIP116	.06710	-.08793	.19977	.19789
	.6504	.5523	.1734	.2619
	48	48	48	34
WIP30	.19914	-.06945	.22845	.15605
	.1748	.6391	.1183	.3782
	48	48	48	34
WIP130	.18031	.3314	.19678	.06183
	.2200	.8231	.1801	.7283
	48	48	48	34
WIF80	-.00703	-.23147	.25262	-.27545
	.9622	.1134	.0832	.1149
	48	48	48	34
WIF180	.13398	-.05197	.09947	.16631
	3640	.7257	.5012	.3472
	48	48	48	34
WIF90	.20144	-.24899	.12626	-.02065
	.1698	.0879	.3926	.9077
	48	48	48	34
WIF190	.05384	-.03574	.05381	.01442
	.7163	.8094	.7164	.9355
	48	48	48	34

Table 16 Canonical Correlation Analysis: Width Measurements and All Functional Variables (including visual half-field scores) N=34

	Canonical Correlation	Eigenvalue	Approx F	Num DF	Den DF	p
1.	.774218	1.4963	.9340	48	71.3766	.5947
2.	.629832	.6575	.6639	33	56.6815	.8963
3.	.485941	.3091	.5140	20	40.	.9438
4.	.414069	.2069	.4828	9	21.	.8698

	Value	F	p
Wilks' Lambda	.1529571	.934	.5947
Roy's Greates Characteristic Root	1.49634	2.619	.0258

Table 17 Standardized Canonical Coefficients for Widths Only and All Functional Variables (including visual half-field scores)

N=34

Standardized Canonical Coefficients for the Widths

	V1	V2	V3	V4
WIO16	-.1986	.4781	-.1879	.2045
WIO116	-.0682	-.0403	.2283	-.8601
WIO30	.7773	-.8839	-.3015	.0792
WIO130	.6981	.1415	-.6357	.3396
WIP16	-.7170	-.6209	-.7279	-.0883
WIP116	-.4636	.3854	.8839	-.1571
WIP30	-.4368	.5242	1.5154	.1078
WIP130	.7055	.2715	.2036	.5588
WIF80	-.9183	-.3225	.0940	.3467
WIF180	.9376	.2367	.0094	-.4462
WIF90	-.2627	.5437	1.0777	.0186
WIF190	-.1978	-.5170	.6660	.3021

Standardized Canonical Coefficients for the Functional Variables

	W1	W2	W3	W4
HAND	.7190	.6211	-.7393	.2203
DICHT	.7367	-.4025	.3193	.5374
DOM	-.3813	.2725	.9516	.5635
TSCPE	.0972	.1987	.9162	-.6533

Table 18 Canonical Correlation Analysis: Width Measurements Only and Functional Variables (excluding visual half-field scores) N=48

	Canonical Correlation	Eigenvalue	Approx F	Num DF	Den DF	p
1.	.598984	.5595	.9412	36	98.2299	.5696
2.	.533025	.3969	.7437	22	68.	.7785
3.	.303980	.10108	.3563	10	35.	.9572

	Value	F	p
Wilks' Lambda	.4166211	.941	.5696
Roy's Greatest Characteristic Root	.5595323	1.632	.1275

Table 19 Canonical Correlation Analysis: Length Measurements Only and All Functional Variables
N=34

	Canonical Correlation	Eigenvalue	Approx F	Num DF	Den DF	p
1.	.652876	.7429	.8166	24	84.936	.7065
2.	.333130	.1248	.2918	15	69.4154	.9948
3.	.184218	.0351	.1684	8	52.	.9942
4.	.128379	.0168	.1508	3	27.	.9283

	Value	F	p
Wilks' Lambda	.4846484	.817	.7065
Roy's Greatest Characteristic Root	.7429123	3.343	.0136

Table 20 Standardized Canonical Coefficients for Lengths Only and All Functional Variables
N=34

Standardized Canonical Coefficients for the Lengths

	V1	V2	V3	V4
LENOC	-.3088	1.0495	.3066	.8880
LENOC1	1.0582	.1806	-.0003	-.1401
LENFR	.5309	-.2130	-.7268	.5078
LENFR1	.3216	-.0811	.5475	.0551
LENPA	-1.0683	-.5043	.4238	-.1401
LENPA1	.4955	-.3513	.4507	.1886

Standardized Canonical Coefficients for the Functional Variable

	W1	W2	W3	W4
HAND	.0321	-.2442	-1.1883	-.1583
DICHT	.9815	-.1889	- .0299	-.3090
DOM	.4819	-.2549	.5163	.9374
TSCPE	.2844	.9452	.2732	.5159

Table 21 Canonical Correlation Analysis: Length Measurements Only and Functional Variables (excluding visual half-field scores) N=48

	Canonical Correlation	Eigenvalue	Approx F	Num DF	Den DF	p
1.	.546459	.4258	.9366	18	110.794	.5371
2.	.165439	.0281	.1859	10	80.	.9969
3.	.134247	.0184	.1881	4	41.	.9422

	Value	F	p
Wilks' Lambda	.6698911	.937	.5371
Roy's Greatest Characteristic Root	.4257554	2.909	.0186

Table 22 Standardized Canonical Coefficients for Lengths Only and Functional Variables (excluding visual half-field scores) N=48.

Standardized Canonical Coefficients for the Lengths

	V1	V2	V3
LENOC	-.3300	.6115	.5044
LENOC1	.9354	.2784	-.9369
LENFR	.4225	-.6232	-.0249
LENFR1	.2379	.3235	.1619
LENPA	-1.1665	-.1141	-.4470
LENPA1	.4868	.5320	.5896

Standardized Canonical Coefficients for the Functional Variables

	W1	W2	W3
HAND	.2243	-1.0434	-.0247
DICHT	1.0273	.0510	-.0764
DOM	.1944	.3295	.9908

Table 23 Canonical Correlation Analysis: Chui & Damasio's Anatomical Variables and All the Functional Variables (including visual half-field scores) N=34

	Canonical Correlation	Eigenvalue	Approx F	Num DF	Den Df	p
1.	.500471	.3342	.7742	16	80.0689	.7092
2.	.281255	.0859	.0859	9	65.8615	.8903
3.	.224595	.0531	.4896	4	56.	.7433
4.	.129791	.0171	.4969	1	29	.4865

	Value	F	p
Wilks" Lambda	.644379	.774	.7092
Roy's Greatest Characterist Root	.3341716	2.423	.0708

Table 24 Canonical Correlation Analysis: Chui & Damasio's Anatomical Variables and All the Functional Variables (without visual half-field scores) N=48

	Canonical Correlation	Eigenvalue	Approx F	Num DF	Den DF	p
1.	.373422	.1620	.7150	12	108.767	.7340
2.	.192506	.0385	.3594	6	84	.9025
3.	.113382	.0130	.2800	2	43	.7572

	Value	F	p
Wilks' Lambda	.8180121	.715	.7340
Roy's Greatest Characteristic Root	.1620397	1.742	.1583

Table 25 Pearson Correlation Coefficients Between Chui & Damasio's Anatomical Variables and All Functional Variables

(Pearson Correlation Coefficients/p level/ Number of Observations)

	HAND	DICHT	DOM	TSCPE
WIO16	.24057	−.02731	.11457	.11871
	.0995	.8538	.4381	.5037
	48	48	48	34
WIO116	.15730	−.07181	.16637	.23730
	.2856	.6276	.2584	.1766
	48	48	48	34
WIF90	.20144	−.24899	.12624	−.02065
	.1698	.0879	.3926	.9077
	48	48	48	34
WIF190	.05384	−.03574	.05381	.01442
	.7163	.8094	.7164	.9355
	48	48	48	34

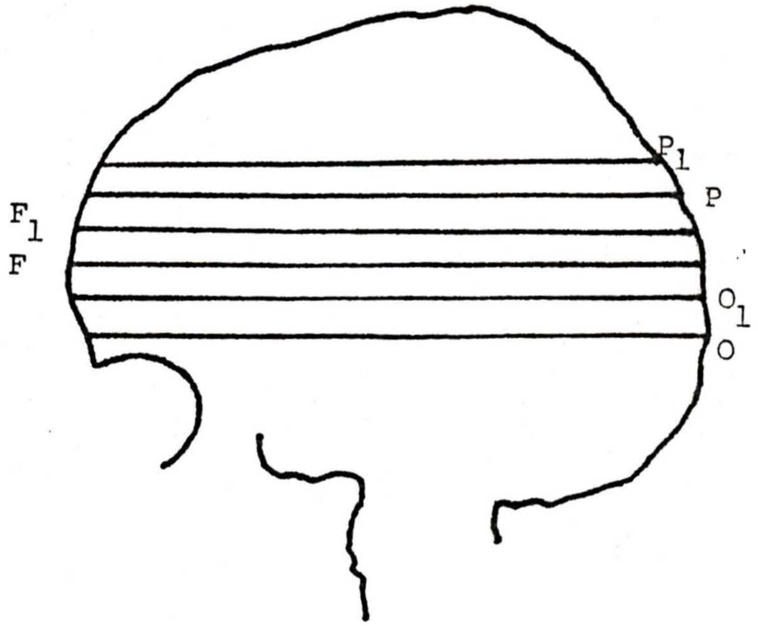
Table 26

Distribution of Etiology by Age of Seizure Onset or Insult

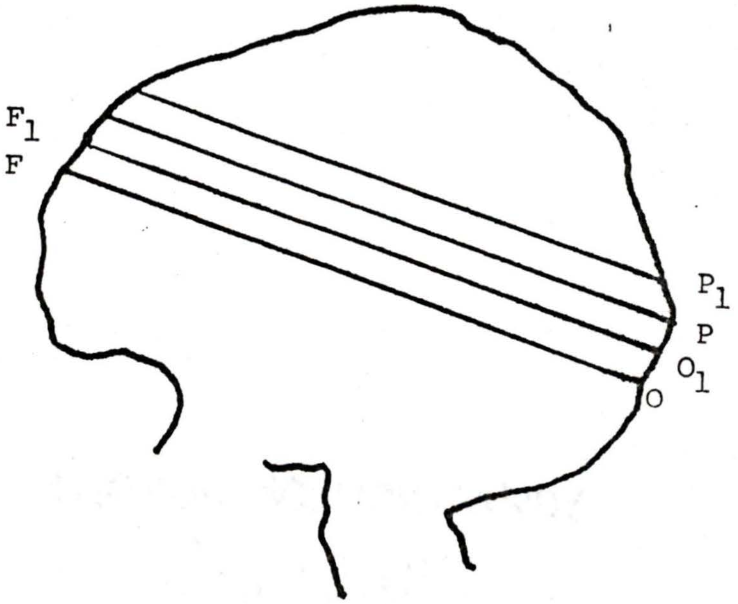
TYPE OF INSULT AGE (YEARS)	Idiopathic	Head Injury	Prenatal	Difficult Birth	High Fever	Encephalitis	Spinal Meningitis	Other
00*		1	1	7	1		1	
01	1		1		2			1
02		1		1	2			
04	1							
06	1	1	1	1	1			
07	1							
08		1		1				
09						1		
11		1						
12	1				1			
13		1						1
14	2				1			
15	1			1				
16	1	1						
17				1				
18		1						
19	1	1						
28		1						
34						1		

(*00 - designates an age less than 12 months)

Figure 1 Location of CT Slices

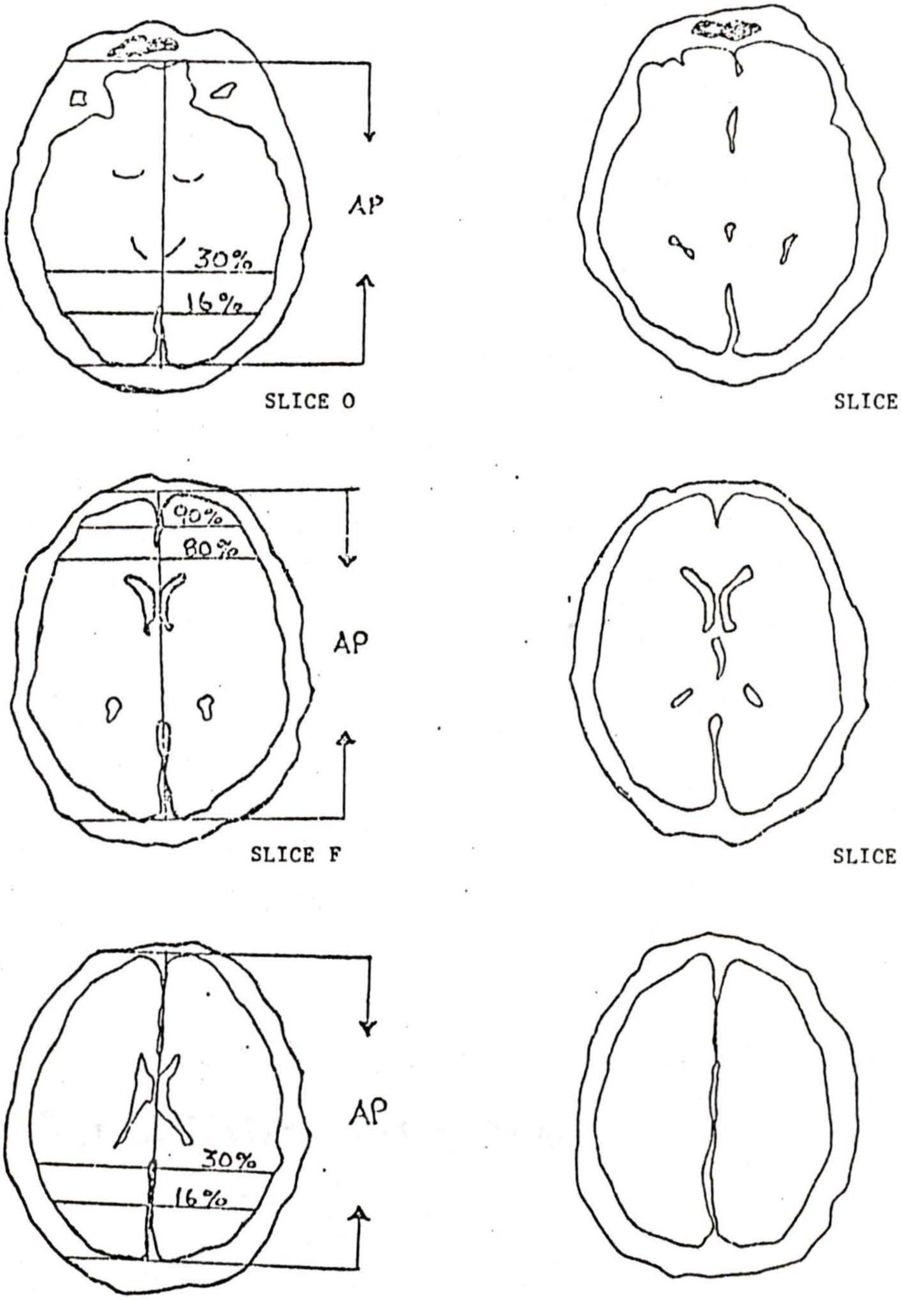


0 Degrees



20 Degrees

FIGURE 2 EXAMPLES OF CT SLICES AND MEASUREMENT TECHNIQUES



SLICE O

SLICE O_1

SLICE F

SLICE F_1

SLICE P

SLICE P_1

Vita

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Relations Between Anatomical and Functional
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