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Computed Tomographic Scan Cerebral Asymmetries and Morphologic Brain Asymmetries

Correlation in the Same Cases Post Mortem

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• We examined the relationship between computed tomographic (CT) scan hemispheric asymmetries and postmortem brain asymmetries of the planum temporale region in the same 15 subjects (right-handed men). A significant correlation was found between occipital length asymmetry visible on the CT scan slice at the level of the bodies of the lateral ventricles and planum temporale length asymmetry found at autopsy. We believe that some CT scan asymmetries may be indexes of underlying anatomic brain asymmetries. These anatomic brain asymmetries, in turn, may underlie some functional asymmetries observed in humans, especially those asymmetries related to language.

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In 1968, Geschwind and Levitsky studied the size of the planum temporale (superior surface of the temporal plane) in humans and observed that the outer border of the left planum temporale was longer than the right in 65% of their 100 postmortem cases, while the right planum was longer in only 11%.[1] Witelson and Pallie found that the length of the left planum temporale was greater in 86% of their 14 neonatal cases and in 81% of their 16 adult cases.[2] Similarly, other researchers have noted that a greater left planum temporale is more common than a greater right planum temporale.[3-5] Typically, in the region of the brain posterior to the rolandic fissure, the sylvian fissure is longer and lower on the left, and shorter and higher on the right. This has been observed in human adults,[1,6-8] fetuses, and neonates.[2-5] Similar sylvian fissure asymmetries have been observed in higher primates such as the orangutan[9,10] and chimpanzee.[7] It has been suggested that these asymmetries may underlie human cerebral dominance for language because they are observed in anatomic areas associated with some human language behaviors.

With the advent of computed tomographic (CT) scans, cerebral hemispheric asymmetries were identified and measured in vivo. In 1976, LeMay pioneered in the use of CT scans to measure brain asymmetries.[9,11] In the population of 100 right-handed men she studied, LeMay noted that 78% exhibited greater left than right occipital length (5% showed greater right than left), and 67% exhibited greater left than right occipital width (13.3% showed greater right than left). In 70% of the right-handed men, the right frontal lengths were greater (13% had greater left than right), and in 53%, the right frontal widths were greater (15% had greater left than right). The cerebral asymmetries of left-handed men appeared to be more evenly distributed across asymmetry type (eg, for occipital lengths, 37% had greater left than right, 24% had left equal to right, and 39% had greater right than left). This study was important because it suggested a possible relationship between asymmetry on the CT scan and cerebral dominance implied by handedness.

The relationship between CT scan cerebral hemispheric asymmetries and actual anatomic asymmetries found post mortem has not yet been investigated within the same subjects. The purpose of our study was to investigate the possibility of a direct relationship in the same subjects between (1) the CT scan cerebral hemispheric asymmetries—occipital width and length, posterior parietal width and length, and frontal width and length—and (2) postmortem planum temporale length (PTl) and area (PTa) asymmetries, or (3) sylvian fissure length (SFl) and posterior height (SFh) asymmetries.

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SUBJECTS AND METHODS

Subjects

In this retrospective study, the CT scans of 15 men aged 41 to 76 years who were later examined post mortem were obtained at the Boston Veterans Administration Medical Center. The CT scans had been performed in vivo on each patient to determine whether focal cerebral abnormalities were present. In 11 of the 15 patients, CT scan abnormalities of the following nature were noted: in six patients, prominent sulcal enlargement; in three patients, small left-hemisphere infarcts outside the temporal lobe; and in two patients, small right-hemisphere infarcts outside the temporal lobe. All infarcts occurred in adulthood, as determined by a review of medical records. These patients with focal brain abnormalities were included in the study because it was assumed that these types of focal brain abnormalities could neither account for nor alter the skull asymmetries that were measured from the CT scans, nor could they affect the size of the planum temporale.

Family members of each of the patients were contacted to obtain information regarding (1) the patient's handedness, (2) the family history of handedness, and (3) the patient's occupation for most of his life. In every case, the patient had been right-handed. Two of the 15 were reported to have left-handers in their immediate families.

Methods

CT Scans.—The CT scans were performed at the Boston VA Medical Center from 1977 to 1981 (using an Ohio Nuclear [Solon, Ohio] Delta 50 or Delta 2010 CT scanner). Slices were obtained routinely at an angle of 15° to 25° from the canthomeatal line. Each slice represented a 7- or 10-mm-thick section of the head. The CT scan films were obtained with the following two window settings: (1) the original routine window (w = 130 to 140 Hounsfield units [HU]) and center (c = 30 to 40 HU), and (2) the bone window (w ≈ 400 HU). The second (bone window) setting better visualized the inner table of the skull and thus increased accuracy in measurement of the CT scan asymmetries.

CT Scan Asymmetry Measurements.—Cerebral hemispheric asymmetries were measured on CT scans using the methods of Pieniadz et al,[12] which were modifications of the techniques of LeMay and Geschwind.[10,11]

The widths and lengths of the occipital lobes were measured at two CT slices: slice W, the first slice above the tentorium, and slice SM, one slice higher, where the bodies of the lateral ventricles are close together (Fig 1).[13] Slice W contains, in part, the posterior superior temporal gyrus, a major portion of Wernicke's area. Slice SM contains, in part, the supramarginal and angular gyri.

The widths and lengths of the posterior parietal lobes were measured at slice SM + 1, where the bodies of the lateral ventricles are smaller and separated, and slice SM + 2, the first slice superior to the ventricles.[13]

The widths and lengths of the frontal lobes were also measured at the following two CT slices; slice B, the lowest slice above the sphenoid wing on which the frontal horns appear oval shaped; and slice B/W, the lowest slice on which the frontal horns appear butterfly shaped (Fig 1).[13] Slice B contains, in part, the pars triangularis, an anterior portion of Broca's area. Slice B/W contains, in part, the pars opercularis, a posterior portion of Broca's area, as well as the middle of the superior temporal gyrus, a portion of Wernicke's area.

Width Measurements.—In the first width measurement technique, a transparent millimeter ruler was used. For the occipital and posterior parietal widths, the ruler was placed over the most posterior extension of the interhemispheric fissure, at the posterior junction of the inner table of the skull (Fig 1, top). The ruler was then moved inward with its long edge perpendicular to the longitudinal axis of the skull until either the left or the right inner table of the skull measured 10 mm from the midline interhemispheric fissure. At this point, the widths of both the left and right hemispheres were noted. For the frontal widths, the ruler was placed over the most anterior extension of the interhemispheric fissure and anterior junction of the inner table of the skull (Fig 1, bottom). The ruler was then moved inward toward the frontal horns, with its long edge perpendicular to the longitudinal axis of the skull until either the left or right inner table of the skull measured 10 mm from the midline interhemispheric fissure. At this point, the frontal widths were measured.

Width asymmetries were quantified in the following manner: each asymmetry value greater than zero was quantified in millimeters. The millimeter difference in widths was then multiplied by ten for ease in data manipulation. If the widths of the two hemispheres differed by less than 0.5 mm, they were considered equal, or symmetric, and assigned a value of zero. The difference between the left and right width values was expressed in the form of ratios similar to those described by Eidelberg and Galaburda.[14] These ratios are as follows: occipital and posterior parietal, $(L - R)/[(L + R)/2]$; and frontal, $(R - L)/[(R + L)/2]$, where L is the width of the left hemisphere and R is the width of the right hemisphere. The ratio was positive when asymmetry was in the expected, or typical, direction, and the ratio was negative when the asymmetry was in the unexpected, or atypical, direction. Occipital asymmetries were considered typical if L was greater than R, and frontal asymmetries were considered typical if R was greater than L. The ratio was near zero when there was symmetry between the two hemispheres. The expected directional values were based on the percentage of occurrence of these asymmetries in the right-handed men studied by LeMay.[9,11]

Chui and Damasio[15] and Andreasen et al[16] have measured occipital widths at a point anterior to the occipital pole that represents 16% of the brain's total length. They have taken measurements of frontal widths at a point anterior to the occipital pole that represents 90% of the brain's total length. In our study, for purposes of comparison, the Chui and Damasio occipital width technique (16%) was used, as well as the technique of occipital width measurements recorded at 8% and 5% of the brain's total length. The last two methods were most compatible with the techniques used by LeMay and our group, previously[12] and in this study. The frontal widths were measured at 90% of the brain's total length; this was also most compatible with the point at which we had measured frontal widths in previous studies and in this study.

Length Measurements.—One technique was used in measuring lengths. The lengths of the occipital, posterior parietal, and frontal portions of the hemispheres were measured by positioning a clear plastic polar coordinate overlay over the CT scan slice to be measured (Fig 2). The concentric circles on the overlay permitted the visualization of the curved inner table of the skull at either the frontal or occipital and parietal poles. The hemisphere that extended farther and reached a more distant concentric circle was considered longer.

Each length asymmetry value greater than zero was quantified in millimeters. The millimeter difference in lengths was multiplied by ten for ease in data manipulation. The difference between the left and right length values was expressed in the form of the following ratios: occipital and posterior parietal, $(L - R)/(AP/2)$; and frontal, $(R - L)/(AP/2)$, where $L - R$ (or $R - L$) is the length difference between the left and right (or right and left) hemispheres, and AP is the greatest distance from the anterior pole to the posterior pole on the CT slice where the $L - R$ (or $R - L$) asymmetries were measured (see Chui and Damasio[15] for a more detailed description of AP). The ratio was positive when asymmetry was in the expected, or typical, direction, and was negative when the

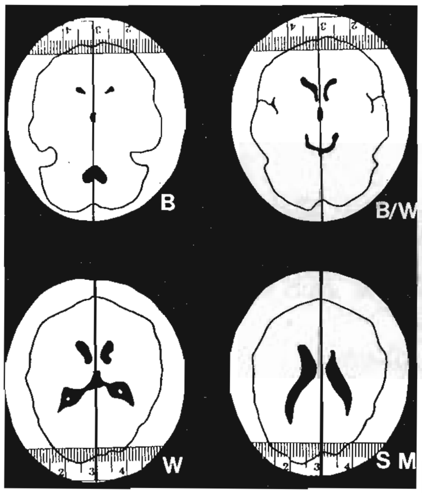

Fig 1.—Method for measuring computed tomographic scan occipital widths (bottom) and frontal widths (top). In this case, occipital width asymmetry on slice W was 3-mm difference, with left greater than right. Asymmetry value was +30. Asymmetry value on slice SM was +10. Similar methods were employed in measurement and calculation of frontal widths on slices B and B/W, and of posterior parietal widths on slices SM + 1 and SM + 2.

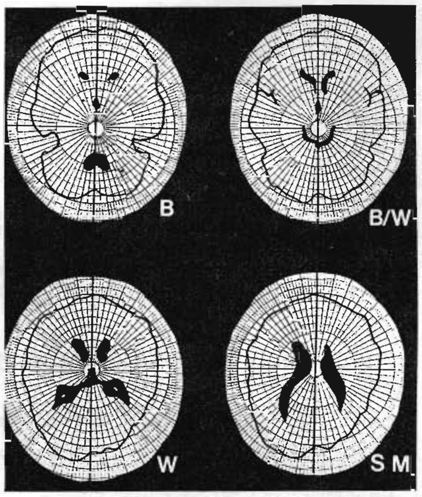

Fig 2.—Method for measuring computed tomographic scan occipital lengths (bottom) and frontal lengths (top). In this case, occipital length asymmetry on slice W was 3-mm difference, with left greater than right. Asymmetry value was +30. Asymmetry value on slice SM was +40. Similar methods were employed in measurement and calculation of frontal lengths on slices B and B/W, and of posterior parietal lengths on slices SM + 1 and SM + 2.

asymmetry was in the unexpected, or atypical, direction. The ratio was zero when there was symmetry between the two hemispheres.

Figures 3 and 4 show CT scans of two patients, patient 8 (Table 1), who had typical (left) occipital length asymmetry on his CT scan, and patient 14 (Table 1), who had atypical (right) occipital length asymmetry on his CT scan.

Interrater Reliability on CT Scans.—Before cutting of the brains, all CT scan asymmetries were measured by two independent raters. There were no disagreements between raters in the direction of asymmetry. A conference between the raters eliminated any disagreements about the degree of asymmetry by forcing the raters to agree after remeasurements of the scans. The conferred-on CT scan data were used in further analyses.

Postmortem Brain Measurements.—All brain specimens had been fixed in 10% formaldehyde solution for approximately one to three months prior to brain cutting. All brains were suspended by the circle of Willis in the formaldehyde solution and were free of any obvious distortion due to fixation.

Planum Temporale Measurements.—The supratemporal surface (planum temporale) of the temporal lobe was exposed after a cut was made in the lengthwise plane at the posterior end of the sylvian fissure. The left and right plana temporale were photographed together to control for equal magnification of the two hemispheres. The lengths and areas of the two plana temporale were then measured from 20 × 25-cm photographs using the following method (Figs 5 and 6).

The length of the outer border of the left planum temporale was measured with a millimeter ruler from the posterior sulcus of Heschl's gyrus (the first transverse gyrus) to the posterior margin of the planum temporale.[1] The length of the outer border of the right planum temporale was measured from the sulcus immediately posterior to Heschl's gyrus to the posterior margin of the planum temporale. These straight-line measurements were taken from the photographs, as shown in Figs 5 and 6. There were two separate transverse gyri on the right in two of the 15 brains; there were no brains exhibiting two separate transverse gyri on the left. When two transverse gyri were present on the right, the second transverse gyrus was included in the measurement of the planum temporale. The difference between the left and right raw measurements for the left and right PTl was also computed into an asymmetry ratio using the formula (L − R)/[(L + R)/2] (described by Eidelberg and Galaburda[14]). This is the same basic asymmetry ratio that had been applied to all the raw data from the CT scan asymmetries.

The areas of the left and right plana temporale were measured with a planimeter, using the anatomic landmarks described (Figs 5 and 6). The asymmetry ratio for the left and right PTa was also computed for each case, using the basic asymmetry ratio described.

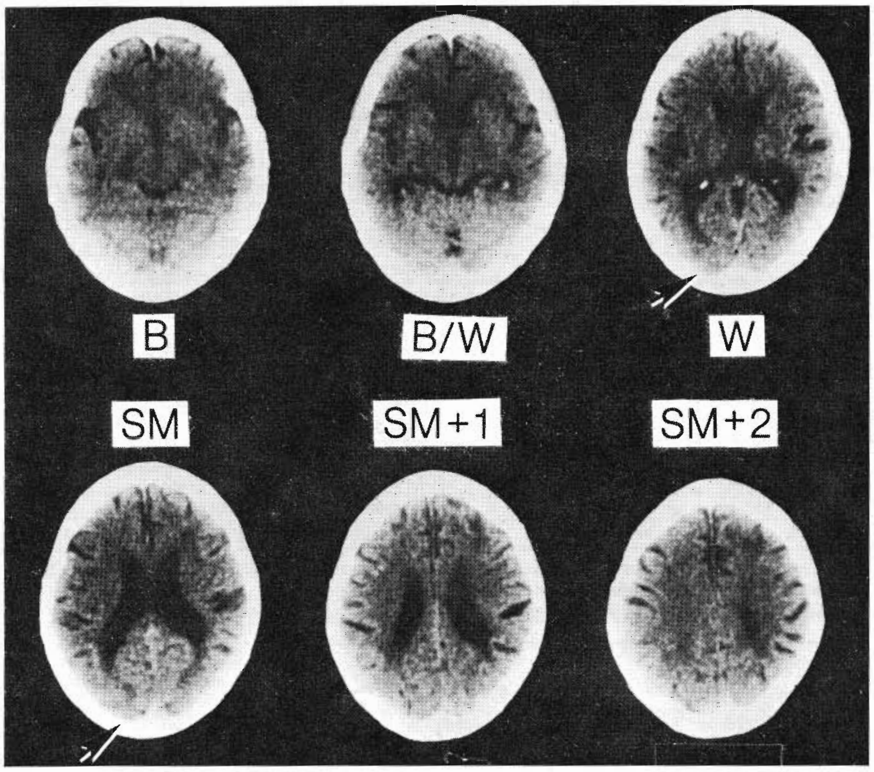

Fig 3.—Patient 8 (see Table 1). Typical left computed tomographic scan occipital length asymmetry (arrows, slice W and slice SM). Occipital length asymmetry value at slice W was +10 (ratio, +0.037), and at slice SM was +10 (ratio, +0.037). Scan is dark because bone windows were used.

Fig 4.—Patient 14 (see Table 1). Atypical right occipital length computed tomographic scan asymmetry (arrows, slice W and slice SM). Occipital length asymmetry value at slice W was −10 (ratio, −0.038) and at slice SM was −15 (ratio, −0.058). Scan is dark because bone windows were used.

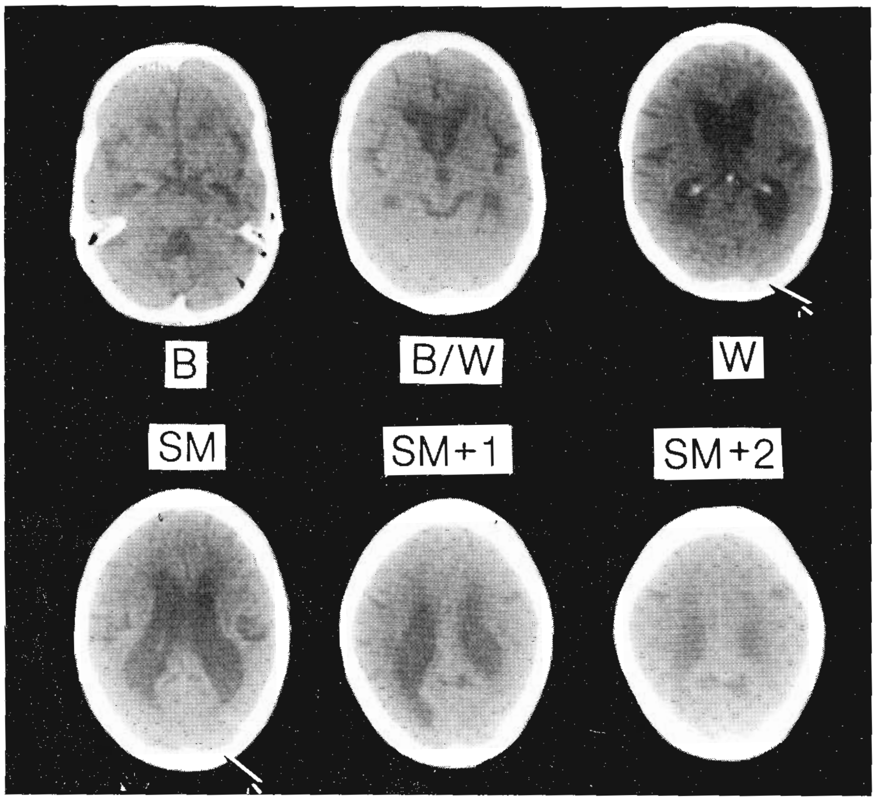

Table 1.—Occipital Length Asymmetries on Computed Tomographic Scans and Postmortem Asymmetry Measurements in the Brains of Right-handed Men*

Patient No.	CT Scan Occipital Length Asymmetries, Value/Ratio		Postmortem Measurements, Raw Data, L/R			
	Slice W	Slice SM	PT1, mm	PTa†	SFl-1, cm	SFh-2, cm
1	−15/−0.059	0/0.000	55.00/33.85	0.02855/0.02220	...	...
2‡	+10/+0.037	+5/+0.019	63.75/49.50	0.02605/0.02100	8.5/6.5	5.7/5.7
3	0/0.000	+5/+0.019	41.25/39.25	0.01740/0.01575	3.8/6.0	...
4	+20/+0.075	+10/+0.038	41.65/36.25	0.01310/0.01435	5.0/6.2	...
5	+10/+0.042	+10/+0.042	66.15/30.00	0.02520/0.01210	10.1/8.2	7.3/6.5
6	+10/+0.037	+10/+0.037	65.20/44.75	0.0250/0.02520	8.6/7.9	6.4/6.0
7	+15/+0.057	+10/+0.039	33.50/17.75	0.00890/0.00820	6.2/6.0	6.8/8.2
8	+10/+0.037	+10/+0.037	38.00/13.15	0.01310/0.00490	10.0/8.7	4.8/6.8
9	+10/+0.035	+10/+0.037	49.25/45.40	0.01990/0.02110	9.1/6.5	5.7/5.7
10‡	+5/+0.024	0/0.000	32.90/29.90	0.01560/0.00890	6.8/5.2	5.3/5.5
11	+15/+0.061	+15/+0.070	53.50/22.40	0.02340/0.01730	7.0/6.3	5.2/6.1
12	+10/+0.038	+5/+0.020	49.50/38.25	0.01610/0.01420	8.6/5.9	5.2/7.5
13	+10/+0.038	+10/+0.038	28.00/30.25	0.01110/0.01210	6.7/6.1	8.1/7.6
14	−10/−0.038	−15/−0.058	17.25/28.00	0.00540/0.01090	5.9/4.8	7.0/5.8
15	...	+10/+0.038	47.25/20.75	0.01630/0.01310	4.9/4.2	7.8/7.8

*PTl indicates planum temporale length; PTa, planum temporale area; SFl-1, sylvian fissure length 1; and SFh-2, sylvian fissure height 2.
†The PTa is given in planimetric units.
‡Sinistrality was present in the subject's immediate family.

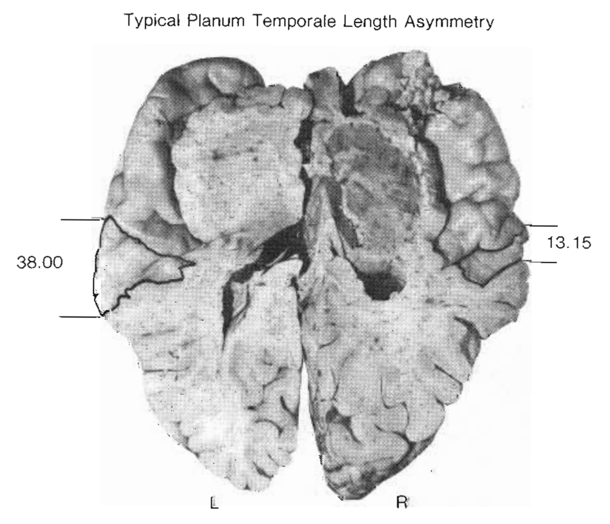

Fig 5.—Method for measuring planum temporale length (PTl) and planum temporale area (PTa). Distance between horizontal black lines on left and right represents length of outer border of left and right plana temporale. In this case of typical left PTl asymmetry (patient 8), left PTl was 38.00 mm, and right PTl was 13.15 mm. Measurements were from 20 × 25-cm photographs of brains. Left and right PTa are outlined in black. Left PTa in this case was 0.0131; right PTa was 0.0049 (planimetric units). Computed tomographic scan for this case (8) is shown in Fig 3, where typical left occipital length asymmetry was observed (slice SM, +10; ratio, +0.037).

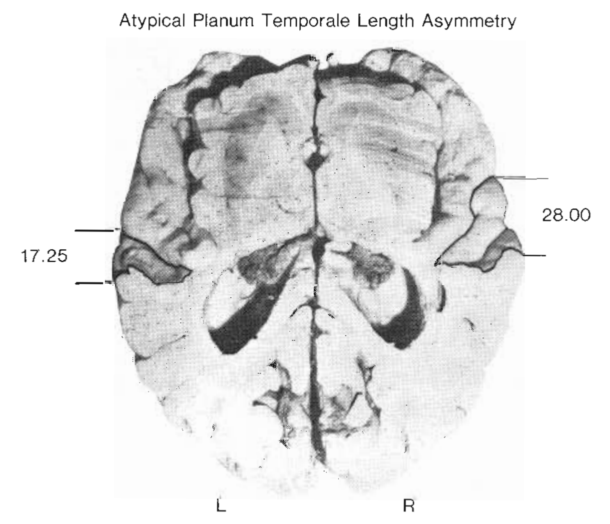

Fig 6.—Atypical right planum temporale length (PTl) asymmetry (patient 14) where left PTl was 17.25 mm and right PTl was 28.00 mm. Left planum temporale area (PTa) was 0.0054 and right PTa was 0.0109 (planimetric units). Computed tomographic scan for this case (14) is shown in Fig 4, where atypical right occipital length asymmetry was observed (slice SM, −15; ratio, −0.058).

Interrater Reliability in Planum Temporale Measurements.—All PTl and PTa asymmetries found post mortem were measured by two independent raters. There were no disagreements between raters on the direction of asymmetry. Pearson's product-moment correlation was $r = .96$ ($P < .001$) for PTl, and $r = .98$ ($P < .001$) for PTa between the two raters' measurements. Because these correlations were high, the means of the two raters' measurements were used in further data analyses.

Sylvian Fissure Measurements.—The following perimetric measurements for the height and length of the left and right sylvian fissures were made directly on the brain post mortem (Fig 7). Dental floss was placed along the curved surface of the brain to measure the following heights and lengths: (1) The SFl from the rostral end of the anterior horizontal ramus (a) to the end of the posterior horizontal ramus (b) (a to b = SFl - 1); (2) the SFl from the rostral end of the anterior horizontal ramus (a) to the end of the posterior ascending ramus (c) (a to c = SFl - 2); (3) the SFh from the end of the posterior horizontal ramus (b) to the most inferior perpendicular point on the lateral aspect of the temporal lobe (d) (b to d = SFh - 1); and (4) the SFh from the end of the posterior ascending ramus (c) to the most inferior perpendicular point on the lateral aspect of the temporal lobe (e) (c to e = SFh - 2). The asymmetry ratios for the left and right SFl and SFh were computed

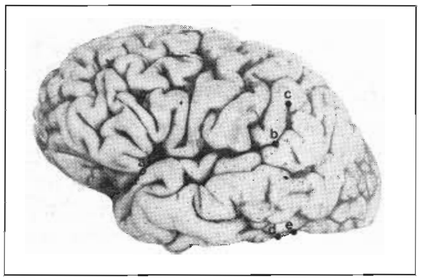

Fig 7.—Method for measuring sylvian fissure lengths (SFl-1, SFl-2) and heights (SFh-1, SFh-2). SFl-1 is distance from a to b, SFl-2 is distance from a to c, SFh-1 is distance from b to d, and SFh-2 is distance from c to e.

using the basic asymmetry ratio previously described.

RESULTS

The CT scan occipital length measurements (asymmetry values and asymmetry ratios) and some of the postmortem brain measurements are presented in Table 1. The distributions for the frontal and occipital width and length CT scan asymmetries (left, equal, and right) and the means for these asymmetry ratios are presented in Table 2. This table shows that the distribution of the CT scan occipital length asymmetries in the fifteen subjects examined is compatible with the distribution previously reported by LeMay,[11] eg, 80% (12/15) had left occipital length in our study, and 78% had left occipital length in the LeMay study (N = 100); 6.6% (1/15) had right occipital length in our study, while 5% had right occipital length in the LeMay study (N = 100).

The distributions for the postmortem brain asymmetry measurements (left, equal, and right) and the means for the asymmetry ratios are presented in Table 3. This table shows that the distribution of the planum temporale length asymmetries in the 15 cases examined post mortem is compatible with the distribution in the study by Geschwind and Levitsky,[1] eg, 73% had greater left PTl (11/15 brains) in our study, and 65% exhibited greater left PTl in the study by Geschwind and Levitsky. It is noteworthy that the single subject with increased right occipital length at CT scan slices W and SM was also the single subject with a greater right PTl and PTa post mortem (Patient 14; Table 1 and Figs 4 and 6).

CT Scan Asymmetry and Postmortem Asymmetry Correlations.—Pearson's product-moment correlation (r) was used to assess the relationship between CT scan asymmetries and

Table 2.—Computed Tomographic Scan Asymmetry Distributions

	Asymmetry*		
	L > R	L = R	R > L
	Width		
Frontal asymmetry			
Slice B (N = 13)			
No. (%)	5 (38.5)	3 (23.0)	5 (38.5)
Mean asymmetry ratio ± SD	−0.185 ± 0.159	−0.013 ± 0.019	0.149 ± 0.136
Slice B/W (N = 15)			
No. (%)	5 (33.3)	5 (33.3)	5 (33.3)
Mean asymmetry ratio ± SD	−0.226 ± 0.202	−0.015 ± 0.024	−0.137 ± 0.031
Occipital asymmetry			
Slice W (N = 14)			
No. (%)	8 (57.0)	4 (28.6)	2 (14.3)
Mean asymmetry ratio ± SD	0.159 ± 0.057	0.01 ± 0.033	0.095 ± 0.025
Slice SM (N = 15)			
No. (%)	10 (66.6)	4 (26.6)	1 (6.6)
Mean asymmetry ratio ± SD	0.176 ± 0.102	−0.01 ± 0.017	−0.12 ± 0.000
Posterior parietal asymmetry			
Slice SM + 1 (N = 14)			
No. (%)	10 (71.0)	0 (0.0)	4 (28.6)
Mean asymmetry ratio ± SD	0.191 ± 0.084	0.0 ± 0.050	−0.271 ± 0.064
Slice SM + 2 (N = 12)			
No. (%)	9 (75.0)	0 (0.0)	3 (25.0)
Mean asymmetry ratio ± SD	0.214 ± 0.116	0.05 ± 0.000	−0.233 ± 0.068
	Length		
Frontal asymmetry			
Slice B (N = 12)			
No. (%)	3 (25.0)	6 (50.0)	3 (25.0)
Mean asymmetry ratio ± SD	−0.029 ± 0.005	0.000 ± 0.000	0.019 ± 0.000
Slice B/W (N = 14)			
No. (%)	1 (7.0)	8 (57.0)	5 (35.7)
Mean asymmetry ratio ± SD	−0.036 ± 0.000	0.000 ± 0.000	0.020 ± 0.003
Occipital asymmetry			
Slice W (N = 14)			
No. (%)	11 (78.6)	1 (7.0)	2 (14.3)
Mean asymmetry ratio ± SD	0.044 ± 0.014	0.000 ± 0.000	−0.048 ± 0.011
Slice SM (N = 15)			
No. (%)	12 (80.0)	2 (13.3)	1 (6.6)
Mean asymmetry ratio ± SD	0.036 ± 0.013	0.000 ± 0.000	−0.058 ± 0.000
Posterior parietal asymmetry			
Slice SM + 1 (N = 14)			
No. (%)	13 (93.0)	1 (7.0)	0 (0.0)
Mean asymmetry ratio ± SD	0.041 ± 0.014	0.000 ± 0.000	0.000 ± 0.000
Slice SM + 2 (N = 12)			
No. (%)	12 (100.0)	0 (0.0)	0 (0.0)
Mean asymmetry ratio ± SD	0.045 ± 0.017	0.000 ± 0.000	0.000 ± 0.000

*L indicates left hemisphere; and R, right hemisphere.

Table 3.—Postmortem Asymmetry Distributions

	Asymmetry*		
	L > R	L = R	R > L
Planum temporale length (N = 15)			
No. (%)	11 (73.0)	3 (20.0)	1 (6.6)
Mean asymmetry ratio ± SD	0.502 ± 0.287	0.017 ± 0.069	−0.470 ± 0.000
Planum temporale area (N = 15)			
No. (%)	9 (60.0)	5 (33.3)	1 (6.6)
Mean asymmetry ratio ± SD	0.373 ± 0.262	−0.031 ± 0.068	0.000 ± 0.000
Sylvian fissure length-1 (N = 14)			
No. (%)	9 (64.3)	3 (21.4)	2 (14.3)
Mean asymmetry ratio ± SD	0.213 ± 0.087	0.067 ± 0.026	−0.330 ± 0.120
Sylvian fissure length-2 (N = 14)			
No. (%)	6 (42.8)	5 (35.7)	3 (21.4)
Mean asymmetry ratio ± SD	0.160 ± 0.055	0.056 ± 0.024	0.233 ± 0.119
Sylvian fissure height-1 (N = 12)			
No. (%)	4 (33.3)	8 (66.6)	0 (0.0)
Mean asymmetry ratio ± SD	−0.115 ± 0.049	0.015 ± 0.000	0.000 ± 0.000
Sylvian fissure height-2 (N = 12)			
No. (%)	2 (16.6)	6 (50.0)	4 (33.3)
Mean asymmetry ratio ± SD	0.155 ± 0.035	0.027 ± 0.027	−0.262 ± 0.088

*L indicates left hemisphere; and R, right hemisphere.

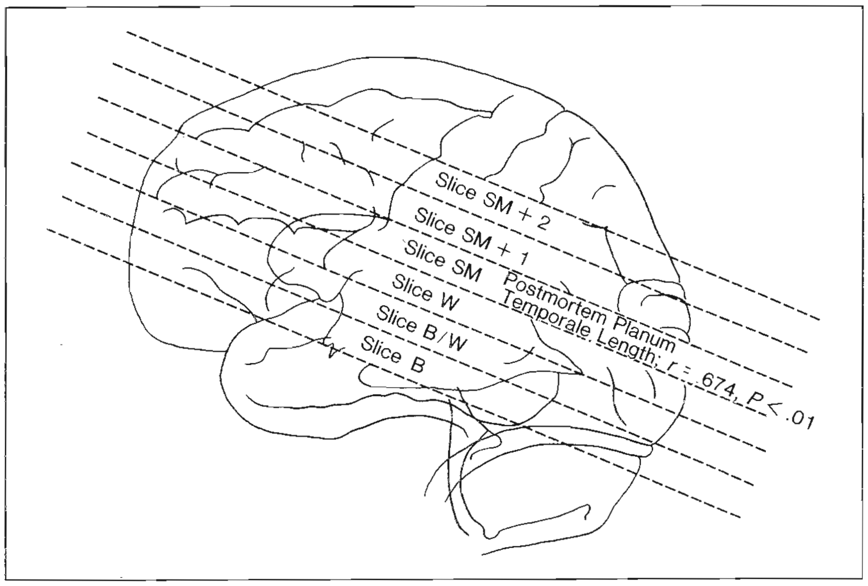

Fig 8.—Lateral diagram of brain showing approximate location of computed tomographic slice SM where computed tomographic (CT) scan occipital length measurements correlated significantly with planum temporale length measurements post mortem. Note measurement at CT slice SM is more directly posterior to planum temporale and angular gyrus than other CT slices.

postmortem brain asymmetries. All correlations were performed using the asymmetry ratio data only.

CT Scan Occipital Width and Length Asymmetries and Postmortem Asymmetries.—There was a significant correlation between the CT scan occipital length on slice SM and the PTl ($r = .674$; $P < .01$; $df = 13$), ie, increased left occipital length on CT scan slice SM was significantly correlated with increased left PTl on postmortem examination. There were no other significant correlations between either slice SM occipital width or slice W occipital width or length and PTl, PTa, SFl-1, SFl-2, SFh-1, or SFh-2 (Fig 8).

CT Scan Occipital Width Asymmetries at Different Percentages of the Brain's Length and Postmortem Asymmetries.—There were no significant correlations between any postmortem and CT scan measurements of occipital width asymmetries taken at different percentages of the brain's total AP length on CT scan. This includes width measurements taken at a point that represented 5% or 8% of the brain's total AP length on CT scan (as in LeMay's[9,11] and our own previous studies[12]), or 16% of the brain's total AP length on CT scan (as in the studies of Chui and Damasio[15] and Andreasen et al[16]).

CT Scan Posterior Parietal Width and Length Asymmetries and Postmortem Asymmetries.—There were no significant correlations between CT scan posterior parietal widths or lengths on slices SM + 1 or SM + 2 with any of these postmortem asymmetries.

CT Scan Frontal Width and Length Asymmetries and Postmortem Asymmetries.—There were no significant correlations between CT scan frontal widths or lengths on slices B or B/W with PTl, PTa, SFl-2, SFh-1, or SFh-2.

There was a significant correlation between frontal width on slice B and SFh-1 ($r = .74$; $P < .01$; $df = 10$), ie, increased right frontal width on CT scan slice B was significantly correlated with increased left SFh on postmortem examination.

Intercorrelation of Postmortem Asymmetries.—The PTl and PTa asymmetry ratios were significantly intercorrelated ($r = .769$; $P < .001$; $df = 13$). No other postmortem asymmetry ratios were significantly intercorrelated.

COMMENT

The finding of a significant correlation between occipital length asymmetry on CT scan slice SM and PTl asymmetry post mortem is noteworthy because it demonstrates that at least one gross CT scan asymmetry measure may help predict an asymmetry of the brain in a language-related region, namely that of the PTl. The correlation of the asymmetry measurements on slice SM (which includes a portion of the angular gyrus) with PTl asymmetry is also interesting in light of the recent findings of Eidelberg and Galaburda.[17] They have observed that the cytoarchitectonic region that constitutes most of the angular gyrus (area PG) is significantly larger in the left hemisphere than in the right in brains with a larger left planum temporale. Thus, the CT scan asymmetry at this level may reflect, in part, the anatomic asymmetry in the area superior and posterior to the temporal lobe. Indeed, slice SM is directly superior to slice W, which contains a portion of Wernicke's area, and probably most of the planum temporale. Because of the 25° angulation of the CT scan slices in our study, however, the most posterior portion (occipital lobe) of slice SM, where the asymmetries were measured, lies directly posterior to the planum temporale and the angular gyrus (Fig 8). Thus, slice SM may be especially important because asymmetries at this slice may reflect asymmetries of the planum temporale and the angular gyrus.

In our previous study of CT scan asymmetries and recovery in global aphasia,[12] the interrater reliability for length measurements was higher than that for width measurements. Thus, it appears that occipital length on slice SM may be the most meaningful CT scan asymmetry measurement of the posterior language areas. This measurement not only correlated significantly with PTl in this study, but also produced the highest interrater reliability in our CT scan laboratory in a previous study.[12]

There was only one correlation between a CT scan width asymmetry (slice B, a frontal width) and a postmortem asymmetry (SFh-1). This correlation is difficult to interpret, because the relationship between the width of a frontal area and the SFh at the posterior horizontal ramus at the junction of the temporal and parietal lobes is not obvious. The direction of the correlation was opposite to the expected direction as well, which contributes to the difficulty in interpretation. This finding, and the significant correlation between slice SM length and planum temporale length, must be interpreted cautiously, since one possible outcome of multiple comparisons is that two biologically unrelated measures may be significantly correlated as a result of random occurrence.

No other CT scan width asymmetry was correlated with postmortem asymmetry. One explanation for this is that the gross CT scan width measurements may inadequately capture the dimension of the anatomic brain asymmetries examined in this study. The brain asymmetries examined were in the spatial dimensions of length (PTl, SFl-1, and SFl-2), height (SFh-1 and SFh-2) and area (PTa). Thus, it is more likely that a CT scan length measurement, rather than a width measurement, would correlate with an anatomic length measurement (eg, PTl). One may speculate that if multiple very thin CT scan slices were obtained in the plane of the planum temporale or sylvian fissure (ie, near 0°), even higher correlations between the CT scan occipital length and postmortem PTl might be obtained.

The CT scan posterior parietal lengths did not correlate with any postmortem asymmetries examined in this study. This is perhaps because some parietal asymmetries may be more pronounced on the superior aspect (convexity) of the skull[18] and be more clearly visualized on coronal CT scans. We suggest that future studies examine these parietal asymmetries on posterior (parietal) coronal CT scans.

In this study, we attempted to verify the usefulness of CT scan asymmetry as an indicator of morphologic brain asymmetry. A significant correlation between CT scan occipital length asymmetry at slice SM and postmortem planum temporale length asymmetry was demonstrated. It has been suggested that anatomic asymmetry of the planum temporale may underlie some functional asymmetry (eg, language).[1-3,7,12,15,19] Thus, in light of the results from this study, at least one CT scan asymmetry (occipital length) may also be an additional index of functional asymmetry for language. Indeed, it appears that this occipital CT scan asymmetry may be more related to functional asymmetry for some language functions rather than handedness, because of the results from our previous study of the relationship between CT scan asymmetries and recovery in right-hand persons with global aphasia.[12] In that study of 14 subjects with global aphasia, the subjects with atypical occipital CT scan asymmetries had test scores that were significantly correlated with improved recovery on "posterior" language functions (single-word comprehension, naming, and repetition). Each of these global aphasics was right-handed, but those with equal or greater right occipital lengths or widths shown on CT scans exhibited better recovery from global aphasia.

One possible explanation for the improved recovery in those right-handed global aphasics with reversed or equal occipital asymmetries is provided by the results from this postmortem study. Occipital length asymmetry on CT scan slice SM was significantly correlated with PTl post mortem. Thus, the subjects with right-handed global aphasia with atypical occipital length on CT scan perhaps also had atypical PTl, ie, possibly there was anomalous dominance for some "posterior" language functions in those subjects.

All the subjects in the global aphasia study (N = 14) and our postmortem study (N = 15) were right-handed, yet not all the subjects exhibited typical left occipital asymmetries. Therefore, it must be assumed that some aspects of language (and hemispheric dominance for those aspects of language) are not always directly tied to handedness (and hemispheric dominance for motor activity). The two may well be separate. In fact, neither of the two subjects in our study (2 and 10) with sinistrality in their family histories exhibited atypical right occipital length on a CT scan or right PTl post mortem. Patient 2 had typical occipital asymmetries and patient 10 had almost equal occipital measurements. Chui and Damasio have recently reported CT scan asymmetry data showing that left occipital lengths and widths were almost equally common among right- and left-handed persons.[15] We encourage future research along the following separate lines: (1) the relationship of language function to CT scan and morphologic brain asymmetries; and (2) the relationship of handedness to CT scan and morphologic brain asymmetries. The relationship between these functions (language and handedness) and various brain asymmetries may be separate and independent.

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