Human cerebral asymmetries evaluated by computed tomography

H CHANG CHUI AND A R DAMASIO

From the Department of Neurology (Division of Behavioral Neurology), University of Iowa College of Medicine, Iowa City, Iowa

SUMMARY The handedness of seventy-five persons without evidence of neurological disease, was assessed with a standardised test. An analysis of the CT scans of the same persons was performed to determine (1) presence and lateralisation of frontal and occipital "petalia," (2) width of frontal and occipital lobes of each hemisphere, (3) direction of straight sinus deviation. Results suggest that handedness and cerebral asymmetries are independent variables. There were no significant differences between right-handers and non-right-handers. Also there were no significant differences between strongly left-handed and ambidextrous individuals, nor were there differences between right-handers with or without family history of left-handedness. Irrespective of handedness, left occipital "petalia" was more common than right ($p < 0.01$), right frontal petalia was more common than left ($p < 0.01$), and straight sinus deviation was more commonly toward the right. The study does not support the concept that cerebral "symmetry" or "reverse asymmetry" are associated with left-handedness or ambidexterity. The noted asymmetries are more likely to be direct correlates of cerebral language dominance, than of handedness. Furthermore, the possibility that outside forces acting on the bone contributes to the asymmetries cannot be excluded. CT scan may be of value as a direct predictor of cerebral dominance.

Since Geschwind and Levitsky¹ first called attention to the asymmetry of the planum temporale in the human brain, further evidence has been marshalled to the effect that the two cerebral hemispheres are generally not the mirror images of each other.²⁻¹³ Possibly such structural differences relate to the functional specialisation of the hemispheres and further knowledge about these relations may be important for the understanding of normal and abnormal higher behaviour in humans. As a consequence the possibility that anatomical cerebral asymmetry might be evaluated in vivo by means of computed tomography was considered. The fact that an apparent pattern to asymmetries of the human skull had been identified strengthened the rationale for such an investigation.

Hadziselimovic and Cus² examined 250 skulls for local impressions, known as "petalias," formed by cerebral imprinting upon the inner

table of the skull. In the posterior region, left occipital petalia was present in 36.8%, right occipital petalia was noted in 19.2%, and symmetrical poles were found in 44%. Associations between left occipital petalia and right frontal petalia on the one hand, and between right occipital petalia and left frontal petalia on the other, were also described. Looking at the skull and brain by means of CT scan imaging, LeMay⁹ noted the presence of left occipital petalia in 69% of her 158 right-handed subjects, right occipital petalia in 9% and occipital symmetry in 22%. Frontal asymmetries, although less striking, were also noted: right and left frontal petalia being observed respectively in 30% and 7%. When the width of the frontal and occipital lobes was considered, similar asymmetries were noted. In the occipital region, 64% showed wider left hemispheres, and 16% showed wider right hemispheres. On the other hand, measurement in 62 left-handed individuals while showing a similar pattern of petalias, revealed a reversed pattern of asymmetry in the occipital area with regard to width. Predominance of the right side was present in 46% and predominance

Address for reprint requests: Dr AR Damasio, MD, Department of Neurology, University of Iowa Hospitals and Clinics, Iowa City, Iowa 52242, USA.

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of the left was measured in 22%, while for the frontal regions the pattern was similar to that seen in right-handers albeit less pronounced.

In an attempt to replicate LeMay's findings and to find potential new clues of cerebral asymmetry we undertook a study of normal CT scans in right-handed and non-right-handed subjects assessed with a handedness questionnaire, and in whom family handedness was also investigated.

Materials and methods

Seventy-five Mark III EMI computed tomograms of the head (160×160 matrix) were used in the study. Each patient had received an inventory enquiring into the strength of their own handedness and the similar preferences of their first degree relatives.¹⁴ Fifty patients had always used their right hand for most skilled activities and constituted the right-handed group. Twenty-five persons utilised their left hand in a variety of daily activities and composed a group of non-right-handers. Twelve among the latter group were classified as strongly left-handed on the basis of a sinistral preference in most skilled activities. Thirteen persons who could use either hand for a number of skilled activities formed the ambidextrous subset of the non-right-handed group. Mean ages of the right- and non-right-handed groups were comparable: 44.2 and 39.3 years, respectively.

Sixty-two of the 75 CT scans were read as completely normal. Thirteen scans, in which there were no focal findings but in which cerebral atrophy, cerebellar atrophy, and small ventricles were noticed, were also included. These changes were not considered likely to have affected the configuration of the inner table of the skull or the midline structures

which represent the crucial determinants for the symmetry measurements.

The scans were generally obtained in a set of parallel planes angulated 15 degrees to the orbito-meatal line. The lowest section disclosing both the frontal horns and trigone was chosen for the assessment of hemispheric asymmetries. In all but seven of the cases, the CT scans were permanently recorded on transparent films. Using an overhead viewer, these were projected to approximately 80% original head size, and the contours of the inner table of the skull and the midline identifying structures were traced. In the seven cases in which the scans were recorded on 3×4 inch Polaroid prints, the above features were traced directly.

The sagittal line was drawn through the anterior falx, septum pellucidum and pineal gland (fig 1). Not infrequently, the straight sinus or posterior falx or both angulated to either side of the midline. Hence these posterior structures could not be reliably included in the sagittal line determination.

Perpendiculars to the sagittal plane were then drawn at the most anterior and posterior extents of the inner table, thereby defining the antero-posterior diameter of the skull (AP). Where there was asymmetry in the frontal or occipital protuberances, the degree of petalia (PET) was quantified by dividing the differences in the antero-posterior projection ($L_R - L_L$) by the AP diameter of the skull: $PET = (L_R - L_L) / AP$. Thus right-sided petalia was indicated by positive PET values and left-sided petalia was represented by negative PET values.

Note was also made of straight sinus deviation. These observations were annotated as follows: S=E (no angulation); S=R (angulation to the right posteriorly); and S=L (angulation to the left posteriorly).

Fig 1 Principal measurements used to assess petalia and degree of cerebral asymmetry. AP=antero-posterior diameter. 0.16 AP and 0.90 AP=levels at 16% and 90% of AP length (measured from most posterior point) used to determine transverse diameter. TL and TR=left and right transverse diameters of cerebrum (occipital TL and TR are determined at 0.16 AP; frontal TL and TR at 0.90 AP). LL and LR=length of left and right hemisphere, used to determine petalia.

Additional lines were drawn perpendicular to the sagittal line at points lying at distances 16% and 90% of the total posterior to anterior diameter of the skull. These points were selected so that their respective perpendiculars would traverse the occipital lobes and the region of the middle inferior frontal gyrus respectively. The right and left transverse dimensions were compared in each region by dividing their differences by their sums:

$$W = \frac{(T_R - T_L)}{(T_R + T_L)}$$

Again positive values signifies right-sided predominance and negative values indicated left-sided predominance. Differences were recorded if the absolute value of W was equal or greater than 0.02, which corresponded to a measured difference of approximately 1 mm (accuracy of the millimeter rule).

Within group differences were evaluated using a two-tailed sign test. Between group differences were assessed by means of the chi-squared test.

Inherent in the methodology described above are several limitations of accuracy and reliability. There is variability in the planes of section. In persons with limited neck mobility planes of section may parallel the orbito-meatal line (that is, zero degree inclination). Various degrees of horizontal tilt (for example, left side positioned higher or lower than the right) also introduce error. Furthermore, there are individual variations in overall skull proportions.

These differences were minimised by using relative rather than absolute points for measurement. For example, the anterior hemispheric widths were estimated at points lying 90% of the distance from the occipital to the frontal pole, and not at a fixed distance from one pole. Obviously there was also possible error in tracing the inner table of the skull and determining the sagittal plane. For this reason we estimated the reliability of measurements by comparing duplicate sets of measures independently obtained on a separate occasion. Overall reproducibility was good. Differences were, in this sample, always in determining the presence or absence of significant asymmetry. No gross discrepancies, such as finding predominance of the right side on one occasion and predominance on the left side on another, were ever encountered. Reliability was also assessed in relation to level of CT cut, in regard to direction of asymmetry. This proved reliable, the direction of asymmetry being the same regardless of the cut chosen to investigate it.

Results

A Cerebral asymmetries in right-handers

Table 1 and fig 2 summarise the pertinent data. In 56% of 50 right-handers no frontal petalia was found. However, right frontal petalia was more common (36%) than left (8%) ($p<0.01$). At the posterior pole, left occipital petalia was present in over half of the cases (60%). The

Table 1 Distribution of cerebral asymmetries in right-handers and non-right-handers

	Frontal petalia			Occipital petalia			Sinus deviation			Frontal width			Occipital width		
	R	L	E	R	L	E	R	L	E	R	L	E	R	L	E
Right-handers N = 50	36	8	56	20	60	20	20	8	72	36	22	42	20	36	44
Non-right-handers N = 25	28	16	56	20	44	36	24	0	76	48	20	32	4	64	32

R = right L = left E = equal

Fig 2 Histogram depicts relative percentage of frontal and occipital petalia, direction of sinus deviation, and frontal and occipital width predominances in the overall population of right-handers and non-right-handers. R=right; L=left; E=equal; NS=non-significant difference between right-handers (crossed bars) and non-right-handers (black bars).

remaining cases were equally distributed (20% each) between right occipital petalia and occipital symmetry. Asymmetry of occipital petalia reached statistical significance ($p < 0.01$). It should be noted that occipital petalia was more apparent than frontal petalia on gross inspection.

Usually (72%) the straight sinus assumed a fairly straight antero-posterior course. When deviation was present, however, it was more frequently found directed toward the right (20%), a significant value (one-tailed t test, $p < 0.05$).

The pattern of asymmetries for anterior and posterior hemispheric width was similar to but less marked than for petalia. In 42% of the scans the frontal lobes were symmetrical in width. The right side was wider in 36%, and the left side was greater in 22%. Reversed findings characterised the occipital region. The hemispheres were symmetrical in 44% of the cases. But here left-sided predominance of the left side was more common than of the right (36% versus 20% respectively). Neither of the hemispheric width differences were statistically significant.

B Cerebral asymmetries in non-right-handers

Table 1 and fig 2 summarise the data. In the majority (56%) of 25 non-right-handed persons, no significant frontal petalia was present. However, right frontal petalia was slightly but not significantly more common (28%) than left-sided petalia (16%). Left occipital petalia was found in 44% and was absent in 36%. Right occipital petalia was seen in 20% of the cases. These differences were not significant.

Sinus deviation was absent in three-quarters of the cases. When present in this sample of non-right-handers, deviation was invariably to the right, posteriorly ($p < 0.05$).

The right frontal hemispheric width was larger than the left in 48%. The opposite was true in

20%. No frontal width asymmetry was found in 32% (non-significant findings). In the occipital area, the left hemisphere measured wider in 64% of non-right-handers. In only one case (4%) was the right side predominant. These differences are significant for $p < 0.001$. No asymmetry was seen in 32% of the cases.

C Comparison of asymmetries in right-handers versus non-right-handers

Applying the chi-squared test with two degrees of freedom, a comparison of cerebral symmetries was undertaken for right-handed and non-right-handed subjects. The null hypothesis was formulated as follows: Handedness and CT cerebral asymmetries are independent.

In only one set of comparisons could the null hypothesis be rejected: Left occipital width predominance was found more frequently in non-right-handers than in right-handers ($p = 0.05$). This is at variance with findings previously reported in the literature.⁹ Frontal and occipital petalia, frontal hemispheric width, and direction of straight sinus deviation did not differ significantly between right-handers and non-right-handers (p values ranging from 0.35 to 0.60).

D Cerebral asymmetries in relation to strength of handedness

A chi-squared comparison of cerebral asymmetries between 12 strongly left-handed individuals and 13 ambidextrous persons revealed no significant differences. A summary of pertinent data is presented in table 2.

E Cerebral asymmetries in relation to familial handedness

Among the 50 right-handers, 33 had a strong family history of right-handedness (all first degree relatives were right-handers). In 17, at least one first degree relative was not right-handed. A

Table 2 Distribution of asymmetries in ambidextrous and strongly left-handed persons

	Frontal petalia			Occipital petalia			Sinus deviation			Frontal width			Occipital width		
	R	L	E	R	L	E	R	L	E	R	L	E	R	L	E
Ambidextrous N = 13	4	3	6	3	5	5	2	0	11	5	3	5	1	8	4
Strong LH N = 12	3	1	8	2	6	4	4	0	8	7	2	3	0	8	4

Table 3 Cerebral asymmetries in right-handers with and without family history of non-right-handedness

	Frontal petalia			Occipital petalia			Sinus deviation			Frontal width			Occipital width		
	R	L	E	R	L	E	R	L	E	R	L	E	R	L	E
With Non-RH N = 17	8	1	8	4	10	3	4	2	11	6	4	7	4	6	7
Without Non-RH (i.e. all RH) N = 33	11	3	19	6	20	7	6	2	25	12	7	14	6	12	15

Table 4 Cerebral asymmetries in males and females (right-handers)

	Frontal petalia			Occipital petalia			Sinus deviation			Frontal width			Occipital width		
	R	L	E	R	L	E	R	L	E	R	L	E	R	L	E
Male N = 28	11	2	15	3	14	5	7	3	18	12	6	10	8	11	9
Female N = 22	7	2	13	5	18	5	3	1	18	7	4	11	2	7	13

chi-squared comparison of CT cerebral asymmetries between these two groups identified no significant differences. Table 3 summarises the data.

F Cerebral asymmetries: in relation to sex

From the group of 50 right-handers with CT scans read as completely normal, there were 28 males and 22 females. A chi-squared test with two degrees of freedom revealed no significant differences in the findings of frontal petalia, sinus deviation, frontal hemispheric width or occipital hemispheric width predominance (table 4).

G Interassociation of asymmetries

Petalia occurred infrequently on the same side at both occipital and frontal poles (six cases). That is, in general either no petalia or contralateral petalia was found at opposite cerebral poles. Similarly, the side of hemispheric predominance usually did not concord for occipital and frontal regions.

On the other hand, in all but three cases petalia was associated with ipsilateral or absent hemispheric predominance for either occipital or frontal widths. Sinus deviation was associated with contralateral or absent petalia and occipital width predominance.

Similar interassociations of asymmetries were found in the 25 non-right-handed subjects.

In conclusion: (1) The noteworthy cerebral asymmetries found in our population were as follows: (a) Left occipital petalia was more common than right occipital petalia ($p < 0.01$). (b) Right frontal petalia was more common than left frontal petalia ($p < 0.01$), although the most common finding was no frontal petalia. (c) Straight sinus deviation, if present, was more commonly toward the right. (2) Handedness and cerebral asymmetries were found to be independent. (a) There were no significant differences between right-handers and non-right-handers. (b) There were no significant differences between strongly left-handed and ambidextrous individuals. (c) There were no significant differences in right-handers with or without a family history of non-right-handedness. (3) Cerebral asymmetries in right-handers were independent of sex.

Discussion

Our findings confirm the existence, in the majority of subjects in our study, of a pattern of cerebral asymmetry detectable with CT, as described by LeMay.⁹ There is a consistent trend demonstrating that the posterior region of the left hemisphere is more often larger than the right. Similar trends of asymmetry have been noted by macroscopic measurements of the planum temporale^{1 5 6 7 11} and of the occipital horn of the lateral ventricles,³ as well as by cytoarchitectonic comparisons of Wernicke's area.¹³ However, the pattern of CT asymmetry was seen irrespective of individual hand preference, the same being true for the lack of asymmetry or for the reversed asymmetry. Consequently, our study lends no support to the concept that cerebral "symmetry" or the presence of "reverse asymmetry" are, in some way, associated with left-handedness or ambidexterity.⁹

It is of note that the finding of "reverse asymmetry" in the CT scans of some right-handers is not as paradoxical as would first appear. It may correspond to right hemisphere language dominance in dextrals, a rare but well documented disposition which is at the origin of crossed aphasia in dextrals^{15 16} and which has been noted by Milner¹⁷ in studies using the Wada test.

The significance of these asymmetries is an unresolved question. They are more likely to be direct correlates of cerebral language dominance (or of its potential lateralisation) than of handedness. This would appear to be one more circumstance in which handedness may not reflect cerebral dominance for language as accurately as previously presumed. In fact, there is little doubt that the majority of individuals, regardless of hand preference, have left cerebral dominance for language (cf clinical neurological evidence from observation of the aphasias^{18 19} as well as classic studies using the Wada test^{20 21}). Secondly, even in exclusively right-handed persons, the degree of language lateralisation which can be inferred from behavioral assessment is variable (cf Shankweiler and Studdert-Kennedy's study on handedness and speech lateralisation with dichotic listening).²² It may be that the organic substrate

for such variation of degree of language dominance and for discrepancy between dominance and handedness, is reflected by the relative sizes of the posterior hemispheres. CT imaging would thus provide an index of language lateralisation more direct and accurate than handedness.

Should the CT scan provide a direct indication of language lateralisation, important assistance may be given to the calculation of neurosurgical risk and to the formulation of prognosis in aphasic syndromes. Early results regarding the latter, warrant some optimism, as Naeser and associates²¹ have shown that right-handed global aphasics with "reverse asymmetry" seem to enjoy greater improvement than those with "regular" left hemisphere predominance, as had been suggested by Geschwind and associates.¹²

Finally, it should be noted that outside forces acting on the bone may contribute independently to the pattern of symmetry or asymmetry of the skull and cerebrum. Factors such as sleeping posture, particularly in infancy, and prolonged recumbency, may be of importance. In other words, it appears reasonable to conclude that the combined shapes of brain and skull are the result of a compromise between the (a) spatial demands of the brain (in itself influenced by genetical factors and by presence or absence of brain disease capable of modifying macroscopic structure) and (b) forces acting on the bone from the outside.

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