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Cerebral and callosal organisation in a right hemisphere dominant "split brain" patient

Helmi L Lutsep, C Mark Wessinger, Michael S Gazzaniga

Abstract

Patients described in previous reports who have undergone corpus callosotomy for control of seizures have been left hemisphere dominant for language. To determine the hemispheric localisation (and possible coexistence) of language and traditional right hemisphere skills in reversed dominance, the first right hemisphere dominant corpus callosotomy patient was studied. Localisation of callosal functions was also investigated, as MRI showed 1·5 cm of spared callosal body. The patient, KO, a 15 year old girl with familial left handedness, underwent two stage callosotomy in 1988. Lateralised visually presented stimuli requiring same or different comparisons between visual fields showed chance performance. Oral naming and reading showed better performance by the right hemisphere than the left, whereas both hemispheres were proficient in auditory comprehension. Active voice syntax was above chance only in the right hemisphere. Face recognition was significantly better in the right hemisphere than in the left. Tasks requiring tactile comparisons between hands showed above chance performance except in the instance in which the non-dominant right hand was stimulated first in a point localisation task between hands. This case showed hemispheric coexistence of language and traditional right hemispheric skills in a corpus callosotomy patient with reversed language dominance. Tactile transfer was localised to the mid-posterior callosal body.

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Center for Neuroscience, University of California Davis, Davis, CA, USA
H L Lutsep
C M Wessinger
M S Gazzaniga

Correspondence to:
Dr Michael S Gazzaniga, Center for Neuroscience, University of California Davis, Davis, CA 95616, USA.

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The surgical corpus callosotomy procedure for intractable epilepsy has provided a unique opportunity to study the functions of the individual cerebral hemispheres, and has allowed the illucidation of the corpus callosum's role in the interhemispheric transfer of information.[1] Thus far the complete callosotomy or "split brain" patients have all been left hemisphere dominant for language.[2 3] In these patients, visuospatial tasks, face recognition, or line orientation judgment tasks are performed better by the right hemisphere.[4-6] The availability of a callosotomy patient with right hemispheric language dominance allows us to explore the hemispheric localisation of skills when dominance is reversed, and to determine whether language and perceptual skills can coexist in one hemisphere.

The present case has been shown by MRI to have 1·5 cm of callosal body remaining, allowing specific function localisation within the corpus callosum to be investigated. Although animal studies have shown somatosensory interhemispheric fibres to run through the rostral part of the caudal half of the callosal body,[7] in humans the transfer of tactile information has been generally localised by behavioural studies to the portion of corpus callosum posterior to the foramen of Monro.[8-12] More precise correlations of function with MRI localisation can be made in this case. Moreover, reports have suggested that integrity of tactile information transfer depends on direction,[11 13 14] which is further investigated in this study.

In the present report, it is shown that language and perceptual skills may coexist in one hemisphere. Although both hemispheres display certain language capabilities, complex grammatical skills are localised to only one hemisphere. The mid-posterior body of the corpus callosum is shown to be the primary site of transfer of tactile information, and hypotheses for directional variability in tactile performance are proposed.

Patient and methods

PATIENT

The patient, KO, a left handed girl with one left handed sibling, was a 15 year old high school student at the time of testing. She displayed infantile spasms during the first six months of life. These subsided until the age of 6 years at which time she developed staring spells and generalised tonic-clonic and atonic seizures. The seizures became intractable on medical treatment. At the age of 9 KO underwent anterior callosal section, followed eight months later by posterior callosotomy. Although she has developed a new seizure type consisting of unresponsiveness and stiffening of only one side of the body, left or right, her seizure patterns and frequencies have not changed greatly since the operations.

Bedside tests of disconnection showed poor verbal reporting of the right visual field during bilateral simultaneous visual stimulation, which corrected with pointing instead of verbal reporting. She was able to transfer tactile localisation information from one hand to the other with her eyes closed and name items placed in either hand, and she showed no apraxia or agraphia. The remainder of the postoperative general neurological examination was unremarkable. Preoperative psychometric testing with the Wechsler intelligence scale for children-revised (WISC-R) showed a verbal IQ of 70, performance IQ of 78, and full scale IQ of 72. Postoperatively she achieved a verbal IQ of 74, performance IQ of 85, and a full scale IQ of 78. Early EEGs showed a hypsarrhythmic pattern with bihemispheric sharp waves. Postoperative EEGs have shown independent and bisynchronous frontal and generalised spikes on a normal background. Preoperative carotid amytal testing suggested bilateral language. Postoperative three dimensional MRI showed corpus callosum section sparing 1·5 cm of callosal body and occasional splenial fibres (fig 1).

PROCEDURES

Lateralised visual stimuli were generated by a Macintosh II computer. The images were displayed for 0·15 seconds in random order to the right visual field (RVF) or left visual field (LVF) while the subject fixated on a central point on the screen. All pictures were selected from Snodgrass drawings—a series of pictures standardised for consistent naming responses.[15] In tasks that required pointing, the right hand was used to maximise the performance of the left hemisphere.

Language tasks included: (*a*) oral naming of a picture flashed either to the RVF or LVF; (*b*) auditory comprehension of a word spoken by the examiner and assessed with lateralised visual stimuli requiring pointing to one of two pictures flashed to the RVF or LVF; (*c*) reading a three or four letter word flashed to the RVF or LVF and pointing to the corresponding picture in a full field array of 12 pictures, or seeing a picture flashed to the RVF or LVF and pointing to the corresponding three or four letter word in a full field array of 12 words; and (*d*) testing active voice and passive voice syntax by having the subject point to "yes" or "no" flashed into one visual field depending on whether an aurally provided sentence correctly or incorrectly described a full field picture.

The ability to compare visual stimuli between the two fields was tested by flashing one picture to each field (simultaneously and with an interval of 0·15 seconds); the patient stated orally whether they were the same or different. Within field performance was tested as well, by flashing two pictures to a single field. Face recognition was assessed by flashing a picture of a face to the RVF or LVF, and having the patient point to the same image in a full field array of eight pictures. A set of men's faces and a set of women's faces were tested. The ability to compare tactile information between hands was evaluated in two ways. In the first method, a small wooden shape was palpated by one hand out of view, then searched for with the other hand in a bag of 10 similar objects. In the second method, the examiner touched a point proximally or distally along each finger of one hand (a total of nine sites per hand, comprising three sites on the index finger and two each on the other three fingers), and the patient attempted to find the corresponding point on the other hand with the thumb of the opposite hand. Within hand performance was also tested, using the ipsilateral thumb to point to the location touched. No verbal reporting was used in the tactile tasks.

A three dimensional MRI was obtained on a 1·5 Tesla General Electric superconductive scanner. A total of 124 contiguous coronal slices 1·5 mm thick were acquired, encompassing the entire brain. Parameters for the T1 weighted pulse sequence included TR = 34 and TE = 5. Additional T2 weighted axial cuts with parameters TR = 6000 and TE = 88 were used to screen for occult second lesions.

Statistical analyses were performed in each case by the χ^2 method. Significance was determined through the application of standard tables.[16]

Results

Oral naming (P < 0·001) and reading (P < 0·001) showed significantly better performance by the right hemisphere than the left (table 1). The left hemisphere was, however, able to name 50% of items, and displayed reading comprehension above chance performance (P < 0·01). Both hemispheres were

Figure 1 Sagittal MRI of the cerebral hemispheres in patient KO, showing a resected corpus callosum sparing 1·5 cm of callosal body and rare rostral remnants.

Table 1 Language results

	RVF	LVF	RVF v LVF	RVF v chance	LVF v chance
Oral naming	18/36	35/36	P < 0·001		
Reading					
Word flashed, point picture	6/12	11/12			
Picture flashed, point word	4/12	10/12			
Total	10/24	21/24	P < 0·001	P < 0·01	P < 0·001
Auditory comprehension	33/36	36/36	NS	P < 0·001	P < 0·001
Active voice syntax	31/48	38/48	NS	NS	P < 0·005
Passive voice syntax	12/24	15/24	NS	NS	NS

RVF = Right visual field; LVF = left visual field. Chance performance could not be determined for the oral naming and reading tasks. Chance was 18/36 for auditory comprehension; 24/48 for active voice syntax; and 12/24 for passive voice syntax.

Table 2 Perceptual task results

	RVF	LVF	Bilateral	Bilateral v chance	RVF v LVF
Picture comparison					
Non-simultaneous	30/32	32/32	22/32	NS	NS
Simultaneous	15/16	16/16	8/16	NS	NS
Face recognition	6/32	20/32		P < 0·001	

RVF = Right visual field; LVF = left visual field. Chance performance was 16/32 for the non-simultaneous and 8/16 for the simultaneous picture comparison tasks; for the face recognition task chance was 4/32.

proficient in auditory comprehension of single words (P < 0·001). Active voice syntax (P < 0·005) was above chance only in the right hemisphere. Passive voice syntax tasks could not be mastered even after multiple practice trials and full field training, rendering comparisons of the two hemispheres unhelpful in this condition.

Face recognition was significantly better in the right hemisphere than the left (P < 0·001; table 2). Tasks requiring picture same or different comparisons between visual fields showed chance performance (P > 0·10).

Tactile object comparison tasks between hands showed above chance performance in each direction (P < 0·001; table 3). In the point matching task between hands, stimulation of the left hand and finding the corresponding point with the right showed above chance performance (P < 0·005); stimulation of the right hand and matching with the left showed chance performance. There was no significant difference between the two directional conditions of point matching. Within hand performance was above chance in each hand (P < 0·001), although more accurate within the left hand.

Discussion

The language data (oral naming, auditory comprehension, reading, and active voice syntax) indicate that patient KO is right hemisphere dominant for language. Although the left hemisphere seems to have some capability for speech production and comprehension, only the dominant right hemisphere performs active voice syntax. Face recognition is also significantly better in the right hemisphere. Between field picture comparisons show visual disconnection. Most of the between hand tactile comparisons (object comparisons and point matching) do not show tactile disconnection, although performance deteriorates in the case in which the right hand is stimulated and the left hand finds the corresponding point of stimulation.

This and previous studies suggest that unlike other language functions, complex grammar skills are localised to only one hemisphere. Whereas callosotomy patients LB and NG have shown comprehension for nouns and the affirmative or negative distinction with their non-dominant right hemispheres, active, passive, and future tenses as well as plurals are not recognised.[17] Callosotomy patients VP and JW both have complex right hemisphere lexicons, and VP's right hemisphere is also able to carry out verbal commands and access speech.[18 19] On the other hand VP's right hemisphere is not able to perform the active and passive sentence task described in this paper, and JW's right hemisphere achieves an above chance performance only in the active condition.[20] As in VP, the present case illustrates the ability of the non-dominant, in this case left, hemisphere to access speech and to comprehend single words. Moreover, whereas the dominant hemisphere performs the active sentence grammar task, the non-dominant hemisphere does not. The non-redundant, fundamental nature of grammar is further supported by tantalising evidence of its genetic inheritability, provided by the discovery of an autosomal dominant pattern of inheritance in a family with poor grammar but otherwise generally intact language functions.[21 22] Left hemidecortication also results in a deficiency in manipulation of grammatical structure by the isolated right hemisphere, which shows basic lexical capabilities.[23] Comprehension of passive negative constructions, as well as use of morphological markers and other grammatical structures, are impaired in hemidecortication patients. Performance on passives may, however, be a misleading measure of linguistic capabilities, as chance performance on reversible passives in neurologically intact adolescents has been shown to be associated with low mental age to the degree seen in patient KO.[24] The chance performance of both of her hemispheres on this task is thus not surprising.

It is of interest to learn whether cognitive functions characteristically associated with the non-dominant hemisphere in patients with

Table 3 Tactile task results

	Within R hand	Within L hand	Stimulate L, find R	L– > R v chance	Stimulate R, find L	R– > L v chance
Object comparison	3/3	3/3	9/10	P < 0·001	10/10	P < 0·001
Point matching	13/18	18/18	10/18	P < 0·005	6/18	NS

R = Right; L = left. Chance performance for the object comparison task was 1/10; for the point matching task, chance was 2/18.

left hemisphere language reside in the non-dominant hemisphere in right language dominant subjects as well. A left handed patient with posterior section of the corpus callosum for tumour of the third ventricle displayed language in the right hemisphere and visuospatial drawing abilities in the left hemisphere.[10] Although limited by the inability to confirm all lesion locations with modern brain scanning capabilities, Hécaen *et al*, however, found a right hemispheric lesion dependence for production of spatial function deficits as well as cerebral ambilaterality of language representations in left handers with familial sinistrality.[25] Interestingly, in non-familial left handers, lesions causing spatial function deficits were not right hemisphere dependent. Patient KO has a clear right hemispheric superiority for face recognition, a traditional right hemispheric specialised skill,[6] which places this function in her dominant (right) hemisphere along with language. Thus it seems that, especially in those subjects with familial left handedness, language and perceptual skills may reside in the same hemisphere. Geschwind and Galaburda[26] have suggested that certain right hemispheric skills rarely shift to the left because the right hemisphere develops earlier in utero. The right hemispheric functions may then be joined by language, which is more flexibly lateralised.[27] Studies in hemidecorticated patients also provide evidence that language and visuospatial functions may coexist in the isolated right hemisphere.[23] Likewise, only one of four studied patients with right hemidecortication after disease acquired in childhood or later showed

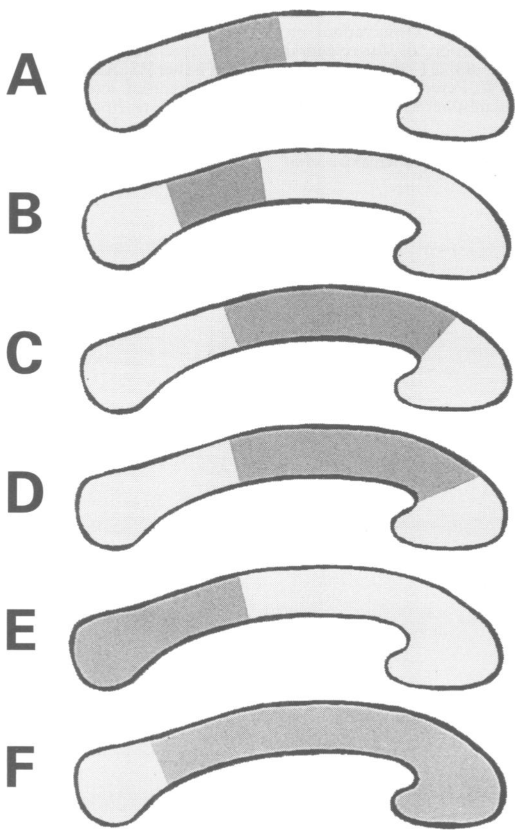

Figure 2 Callosal lesion data representing patients with poor tactile transfer from the following studies: (A) Bentin and Sahar;[8] (B) Dimond et al;[9] (C) Jeeves et al;[11] (D) Leiguarda et al;[12] (E) Gazzaniga;[13] (F) Satomi et al.[14] The rostrum of the callosum, or anterior, is on the right side of each drawing. Note that except for one report including MRI (study F) and another CT (study D), imaging was not available and lesions were reconstructed solely from surgical descriptions.

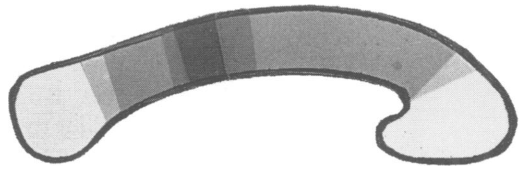

Figure 3 Localisation of tactile transfer within the corpus callosum based on combined reconstruction of all lesions (studies A-F) in fig 2. The rostrum of the callosum, or anterior, is on the right side of the drawing.

the presence of prosopagnosia, supporting the co-occurrence of language and face recognition abilities in isolated left hemispheres.

Patient KO also allows us to investigate transfer of tactile functions via the corpus callosum, as she has sparing of 1·5 cm of callosal body as well as almost intact transfer of tactile information. Although Bentin and Sahar[8] have suggested that tactile information is transferred in the anterior corpus callosum, posterior to the foramen of Monro, combining all available data (only one with MRI corroboration) from lesioned humans[8 9 11–14] better localises tactile transfer to the mid-posterior body of the corpus callosum (figs 2 and 3). This finding is consistent with animal studies reporting somatosensory interhemispheric fibres in the rostral part of the caudal half of the body of the corpus callosum.[7] The MRI findings in KO support the mid-posterior body of the callosum as the site of tactile transfer (fig 1).

In addition to function location, an interesting question is posed regarding the mechanisms of tactile transfer. Information about point locations on the hands is capably transferred from left to right, but not from right to left in patient KO. This phenomenon has been described in two patients with probable left hemispheric dominance as well, but in the reverse direction.[13 14] In reviewing each of these cases, it is notable that the information that passes more accurately begins in the dominant hemisphere. In KO and in one of the other patients, within hand performance was better in the dominant than the non-dominant hand. In KO, no other lateralising signs were seen either on neurological examination or on the MRI to explain this discrepancy. Elicitation of a mild form of neglect or poorer internal verbal strategies generated by the non-dominant hemisphere could be postulated, and could also have contributed to deficient transfer of tactile information originating there. Despite the possibility that there may have been sparing of those callosal fibres responsible for the integration of information moving from the dominant to non-dominant hemisphere,[13] the cortical origins of the tactile information, especially input from the dominant hemisphere, may be of ultimate importance.

Although it has been argued that epileptic patients do not have brains representative of the normal population and caution should be exercised in applying data from these patients too generally, we can nevertheless learn from them the range of possible cerebral organisational patterns. This case suggests that whereas some language functions can be found redundantly in the non-dominant hemisphere, complex grammar skills seem to be localised to one hemisphere only. Gazzaniga[28] makes the point that certain word strings may be learned by rote, obviating the need to understand the underlying grammar. The rote learning, representing lexical memory, most likely has a diffuse representation in the brain. Thus the non-dominant hemisphere has the appearance of being able to perform simpler grammar tasks; however, true grammatical manipulations are displayed only by the hemisphere with "the grammar organ".[28 29]

This case shows that language and perceptual skills may coexist in one hemisphere. Tactile transfer, it seems, occurs through the mid-posterior body of the corpus callosum. Moreover, tactile localisation information seems to be passed more accurately when it originates from the dominant hemisphere in the callosotomy patient, a finding with implications for the role of the dominant hemisphere in integration of tactile information.

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