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DEXTRALS with right cerebral hemisphere dominance for language are rare. Eight neurologically intact dextrals underwent BOLD-fMRI while being presented auditory and visual words. Fortuitously, in one subject, right hemisphere activations with visually presented words were seen in the inferior frontal, premotor regions together with predominantly left cerebellar activation. These were a mirror image of activations obtained from the seven other dextrals. Also mirrored was temporal activation from auditory words which extended more posteriorly on the right side than the left. These results showing mirror organization of language were replicated in another scanning session and also by using a second word task. Although rare, mirrored organization of language can occur in normal dextrals without penalizing language function. *NeuroReport* 9: 3499–3502 © 1998 Lippincott Williams & Wilkins.

Right hemisphere language in a neurologically normal dextral: a fMRI study

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Introduction

Language frequently, but not invariably, lateralizes to the left hemisphere in dextrals. It was reported that 60% of right handers but only 32% of non-right handers developed aphasia after left hemisphere lesions.¹ Only 2% of right-handed patients but 24% of non-right-handed persons developed aphasia after right hemisphere insult. In a study in which 103 patients undergoing surgery for epilepsy were evaluated with intracarotid anobarbital (IAP),² two patients had exclusively right hemisphere language, while 22 had bilateral representation. Dextrals with right hemisphere dominant language have rarely been discovered during intra-operative electrical stimulation. However, electrical stimulation gives only a limited functional map of the brain. In contrast, fMRI demonstrates activation of several anatomically separate areas involved in word processing. Previous studies using fMRI to determine hemispheric dominance for language^{3,4} have identified sinistrals with right hemisphere language but have not reported dextrals with almost total right hemisphere language dominance. We fortuitously discovered such an

individual and describe his functional anatomy, bearing in mind that cerebral dominance for language is not a dichotomous variable but a graded continuum.

Materials and Methods

G.O.C. is a 29-year-old graduate student with no history of head trauma and is neurologically intact. He has two siblings who are right handed and one who is left handed. He has two left handed cousins. He is strongly right handed as determined by a modified Edinburgh handedness inventory⁵ (a score of 21 out of 24 points). Structural MR of the brain was normal. There was no asymmetry of occipital lobe length; an occipital hook was not present. We did not measure the planum temporale. He was one of eight neurologically intact, native English speaking dextrals who were studied to evaluate brain activation related to semantic processing of words.⁶

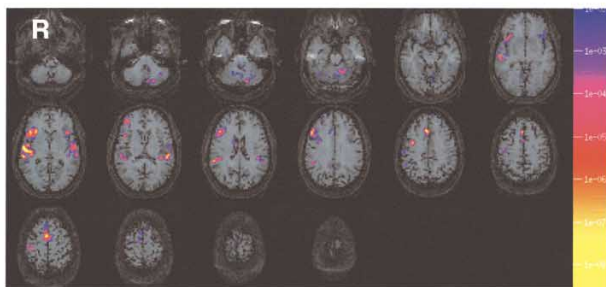
Whole brain fMRI was performed while subjects performed a semantic decision task.⁷ Auditory and visual words were presented in separate scans. For visually presented stimuli, single words were

presented every 2 s. The task (abstract/concrete) was the same for auditory and visual words. Subjects determined whether the word presented was concrete or abstract. Responses were indicated by pressing one of two buttons with the left hand. Words were arranged in blocks of 15 and the tasks were interleaved with periods of fixation. Performance of each task lasted 30 s and fixation intervals lasted 20 s. Each scan took 220 s and eight scans were performed on each subject. The order of tasks was counterbalanced across runs. Whole-brain fMRI was performed on an EPI-capable 1.5 T scanner. Sixteen slices, 7 mm thick, parallel to the intercommissural line, covering the whole brain were obtained. The in-plane resolution was 1.57 mm for anatomical images and 3.125 mm for the functional asymmetrical spin echo images. Four hundred and forty functional images per slice were considered for each subject (220 per modality). Images were motion corrected and transformed into Talairach space. Kolmogorov–Smirnov (KS) statistical maps of signal change in individual functional image voxels were generated. A conservative threshold of $p < 1 \times 10^{-5}$ was used. GOC's activations were compared with activation maps obtained by averaging activations from seven other subjects.⁶

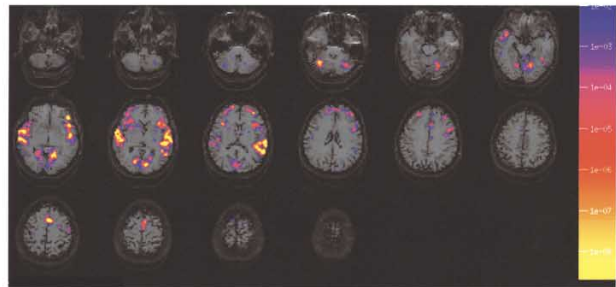
Results

GOC's reaction times and accuracy of responses were comparable to those of the other seven subjects showing left hemisphere language activations. In the visual word abstract/concrete task and fixation comparison, there was activation of the right inferior prefrontal region (Talairach coordinates 50, 12, 28; BA 45), right premotor area (46, -3, 50; BA 6) and left cerebellar hemisphere (-12, -69, -25). In contrast, the corresponding activations in the averaged data of seven other dextrals showed activation in the left inferior frontal (-40, 12, 31), left premotor (-40, -6, 56) areas and the right cerebellar hemisphere (12, -63, -37). The asymmetry index for frontal activations was -1 (totally right hemisphere dominant). In the auditory abstract/concrete task compared to fixation, the asymmetries described above were also seen. In addition, activation of the right superior temporal gyrus extended more posteriorly on the right ($y = -42$ mm) than on the left side ($y = -36$ mm). In the data averaged from the other seven subjects, superior temporal gyrus activation extended to $y = -48$ mm on the left but to $y = -42$ mm on the right. The asymmetry index³ was -1 (fully right lateralized) with both

G.O.C.

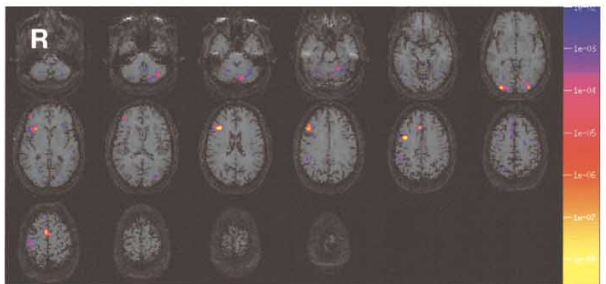


H.C.

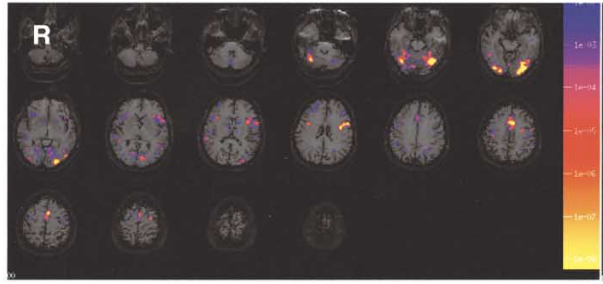


Auditory word task vs. fixation

G.O.C.



H.C.



Visual word task vs. fixation

FIG. 1. Axial activation maps showing activations in the abstract/concrete decision task compared to fixation with visual (upper panel) and auditory (lower panel) word presentation. Subject GOC's activations are displayed on the left and a representative subject, HC, from seven other dextrals is shown on the right. An asymmetry index for GOC's frontal activations was calculated by counting pixels above the $p < 0.00001$ level and applying the formula $(\text{pixels}_L - \text{pixels}_R) / (\text{pixels}_L + \text{pixels}_R)$.

auditory and visual word tasks compared to fixation. These two sets of activations were a mirror image of activations seen in averaged data collected from seven other dextrals (Fig. 1).

We repeated the evaluation using visual words and then added a word stem-completion task where GOC was shown word stems like 'cou' and completed a word silently (e.g. 'courage'). Prior studies using this stem completion task on other dextrals⁸ showed predominantly left IFR activation. Again, GOC showed predominantly right IFR activation with an asymmetry index of -0.5 (Fig. 2).

Discussion

The extent to which GOC's language related brain areas are mirrored is impressive. Most normal individuals presented with auditory word stimuli activate the superior temporal gyrus more extensively (in the posterior direction) on the left side;⁹ in this case we observed the reverse. Greater activation of the left cerebellum in GOC while performing word tasks is also the reverse of what has been observed in other dextrals.⁸

Given that at least 98% of dextrals are left hemisphere dominant for language, it is reasonable to exclude secondary causes for right hemisphere language dominance. Transfer of language to the right hemisphere may occur with destructive lesions^{10,11} or hemispheric surgical resections sustained in early childhood.¹² Developmental lesions or indolent

childhood tumors tend to displace language within the left hemisphere. Sinistrals are more likely to have bilateral representation of language.² As GOC is right handed and has no known basis for a shift of language areas to the right hemisphere, it is probable that this state existed from a very young age.

Mirror activations with both auditory and visual word semantic decision and a visual word generation task suggest that the organization of language functions in the right hemisphere is a laterally reversed representation of the usual pattern. Such right hemisphere language organization can occur without cognitive or linguistic penalties, unlike the reorganization or aberrant organization observed following brain lesions.¹³⁻¹⁵ An individual such as GOC could be expected to sustain severe 'crossed' aphasia should he sustain an infarct of the right frontal region.¹⁶

BOLD contrast fMRI affords a non-invasive means of determining cerebral dominance for language lateralization. In contrast, prediction of language dominance using anatomical asymmetries (such as the relative lengths of the occipital lobes, the direction of the occipital hook, the length of the planum temporale) and handedness may be helpful at the level of group data but are not conclusive in individuals¹⁷. Further, even when several anatomical asymmetries are present, cerebral dominance for language may not be affected,¹⁸ suggesting that the determinants of the lateralization of structure and function are more complex than previously supposed.

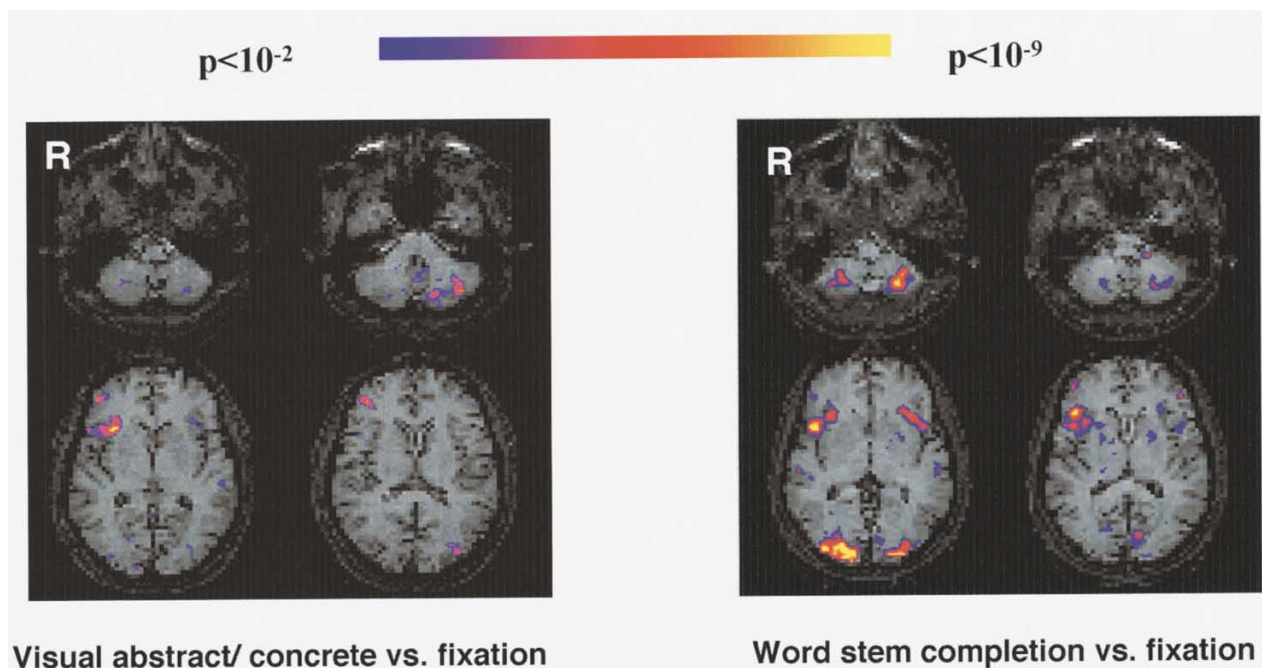


FIG. 2. Axial images showing the results of the repeat experiment. In the visual word task (abstract/concrete) compared to fixation, there is activation in the right inferior frontal region and the left cerebellar hemisphere. In the stem completion task compared to fixation, a similar pattern is seen although the asymmetry is less pronounced.

Conclusion

Although rare, mirrored organization of language can exist in neurologically intact dextrals without obvious penalty to language function.

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