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A dissociation between spatial and identity matching in callosotomy patients

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ALTHOUGH they are structurally similar, the two hemispheres of the human brain have many functional asymmetries. Some of these, such as language and motor control, have been well characterized. Others, such as visuospatial asymmetries, are less well understood. Many researchers have noted that the right hemisphere appears to be specialized for visuospatial processing. We investigated the abilities of the divided cerebral hemispheres of two callosotomy patients to perform discriminations based on spatial or identity information. The data revealed a robust right-hemisphere superiority for spatial judgments. In contrast, the left hemisphere was somewhat better than the right at making identity judgments. These results suggest that the right hemisphere is specialized for spatial processing, and the left is specialized for pattern recognition. *NeuroReport* 10:2183–2187 © 1999 Lippincott Williams & Wilkins.

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Introduction

It has been known for many years that the two hemispheres of the human brain differ in their ability to process information. Hemispheric specialization can be seen as adaptive because it allows for more efficient allocation of cortical space. If a region of one hemisphere becomes specialized for a particular function, the homologous region in the other hemisphere can be dedicated to other processes. This arrangement allows for development of more functions without requiring an increase in cortical size. The result is more, and more complex, functional capabilities. The popular notion of hemispheric asymmetries is that the left hemisphere is specialized for verbal and symbolic processing and the right is specialized for visuospatial processing. More recent evidence suggests that the two hemispheres each play a role in both types of processing but that the hemispheres differ in the nature of that processing. In terms of linguistic function, it has been well established that the right hemisphere plays a role in the processing of linguistic information [1], although the left hemisphere is clearly dominant. Data from patients with unilateral brain damage, callosotomy patients, patients undergoing Wada testing and behavioral testing on neurologically normal subjects all converge on the conclusion that the left hemisphere is dominant for linguistic processing in a majority of the population.

For visuospatial processing, studies of patients with unilateral brain damage provide evidence that the right hemisphere is superior to the left, but the nature and limits of that specialization remain unclear. Recent investigations of visuospatial asymmetries have focused on the search for dichotomies between the processing styles of the two hemispheres. Several researchers have proposed dichotomies suggesting that the two hemispheres are biased toward processing different aspects of a visual stimulus. For example, Sergent [2] has proposed that the left hemisphere selectively processes high spatial frequency information, and the right hemisphere selectively processes low spatial frequency information. Similarly, Robertson *et al.* [3] have suggested that the left hemisphere is biased toward processing the local details of a stimulus, whereas the right hemisphere is biased toward processing its global layout (see [4] for a discussion of the computational advantages of such a double filtering of visual inputs). Kosslyn and colleagues [5] have taken a slightly different approach, and proposed that the left hemisphere tends to represent visuospatial information categorically (representing the relationships between stimuli descriptively: above, below, left, right, and so forth). The right hemisphere, by contrast, appears to represent visuospatial information in a finer grained, coordinate framework. The implication of each of these dichotomies is that the analysis of a visual input may be, to some extent, divided between the two hemispheres, with each contributing its expertise to the final percept. It is unclear which, if any, of these dichotomies accurately represents the processing differences between the hemispheres. Each dichotomy has received a moderate amount of empirical support, although none is unequivocally supported by all the available data (see [6] for a review). Hellige suggests that each dichotomy may reflect different manifestations of the same underlying cause.

We hypothesize that the underlying cause of these observed visuospatial dichotomies might be a left hemisphere specialization for pattern recognition and a right hemisphere specialization for processing spatial relationships. The left hemisphere must have highly developed pattern recognition abilities in order to recognize and name visually presented objects and for letter recognition and reading. Objects and letters can appear in a variety of positions and orientations, so it may be advantageous for the left hemisphere's pattern recognition system to be at least somewhat oblivious to spatial information [7]. A right hemisphere specialization for processing spatial relationships would compensate for any left hemisphere deficit in this domain. In an intact brain, inter-hemispheric transfer of information via the corpus callosum would mask any hemispheric asymmetries in spatial processing or pattern recognition. In callosotomy patients, however, this pathway is severed and hemispheric differences can be directly observed by testing each hemisphere in isolation.

We investigated the abilities of the divided hemispheres of two callosotomy patients to match lateralized stimuli based on identity or spatial location. The stimuli were pairs of vertically aligned squares, each containing a small icon in one corner. In the spatial matching condition, the subjects judged whether or not the two icons were in the same corner of the squares. In the identity matching condition, the subjects judged whether or not the two icons were the same, regardless of their relative locations (see Fig. 1).

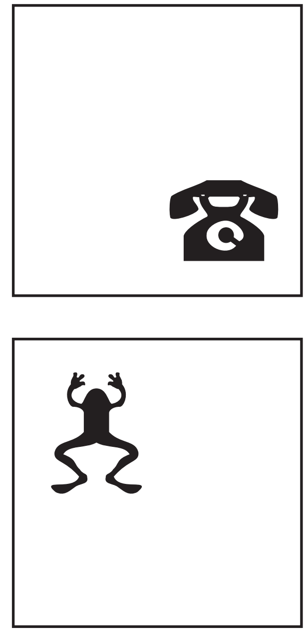

FIG. 1. An example of the stimuli used in the spatial matching and identity matching conditions. The stimuli were presented to the right or left of visual fixation for 150 ms. In the spatial matching condition the patients judged whether or not the icons appeared in corresponding corners of the squares, regardless of their identities. In the identity matching condition, the patients judged whether or not the icons were the same, regardless of their relative locations.

Materials and Methods

The Committee for the Protection of Human Subjects at Dartmouth College approved all experimental procedures.

Two right-handed callosotomy patients, J.W. and V.P., participated in this experiment. J.W. is a 46-year-old man; V.P. is a 47-year-old woman. Both patients underwent two-stage resection of the corpus callosum for the relief of intractable epilepsy in 1979. MRI subsequently confirmed the completeness of J.W.'s callosal section. Postsurgical MRI scans of V.P. revealed some spared fibers in the splenium and rostrum of the corpus callosum [8]. Despite this sparing, V.P.'s performance on perceptual tasks reveals no evidence of interhemispheric transfer of visual information [9,10]. Further details of both patients' are reported elsewhere [11]. J.W. and V.P. are both experienced laboratory subjects and were familiar with the testing procedures employed. Both patients gave informed consent prior to their participation in the study.

There were two experimental conditions: identity matching and spatial matching. The stimuli were presented to either the left or right visual hemifields (centered approximately five degrees to one side of a central fixation point), for 150 ms (nine screen refreshes) on a 19 inch AppleVision monitor refreshed at 60 Hz. The stimuli consisted of pairs of vertically aligned squares, each of which subtended $\sim 5°$ of visual angle on each side. The squares were separated by approximately 2° of visual angle. A small black icon (subtending about 1.5° of visual angle) was placed in one corner of each square. There were nine different icons: airplane, flower, frog, heart, house, musical note, star, telephone, and tree.

In the identity matching condition, each subject was required to judge whether the two icons were the same or different and respond via a keypress. The icons were the same on half of the trials and different on the other half. In the spatial matching condition, the stimulus pairs were again presented to the left or right of fixation, and each subject was required to judge whether or not the two icons were in the same relative position in the square (e.g. top left corner) and respond via a keypress. The icons were in the same relative location on half of the trials and in different relative locations on the other half. In both the identity matching and spatial matching conditions, J.W. and V.P. completed four blocks of 72 trials.

There were two control conditions. The first was a replication of the spatial matching condition, but with the icons replaced by small black circles (subtending 1.5° of visual angle). The task and stimuli were otherwise identical to the spatial matching condition. Each subject completed four blocks of 48 trials. In the second control condition, pairs of icons were presented vertically aligned, centered approximately 4° of visual angle from fixation. The icons were identical to those used in the experimental conditions; the squares were omitted. The subjects' task was identical to the identity matching condition. In this condition, J.W. and V.P. completed four blocks of 72 trials.

In all four conditions, the hand used to respond was counterbalanced across blocks. In blocks with left-handed responses, stimuli presented to the left visual field were used for analysis and responses to stimuli presented to the right visual field were discarded. Similarly, in blocks with right-handed responses, stimuli presented to the right visual field were used for analysis and responses to stimuli presented to the left visual field were discarded. Because these experiments involve analysis of single-subject data in which each hemisphere serves as a control for the other, the accuracy data were analyzed using multidimensional χ^2analyses [12].

Results

In the spatial-matching condition, J.W.'s right hemisphere performed significantly better than his left hemisphere ($\chi^2(1) = 4.63$, $p < 0.05$). This difference was qualitatively similar in patient V.P., although it did not quite reach statistical significance ($\chi^2(1) = 3.28$, $p = 0.07$). In the identity matching condition, the right and left hemispheres of both patients were relatively accurate and neither patient demonstrated a significant hemispheric difference (J.W.: $\chi^{2(1)} = 2.78$, $p = 0.10$; V.P.: $\chi^2(1) = 0.13$, n.s). These results are shown graphically in Fig. 2. These findings confirm the prediction that the right hemisphere is specialized for spatial processing. The prediction that the left hemisphere would be superior for identity matching is not supported, although there was a trend in that direction for patient J.W. The data suggest that both hemispheres are adept at pattern recognition.

Although the spatial matching data are consistent with a right hemisphere superiority for spatial processing, an alternative explanation is that the left hemisphere deficit in this condition was due to interference between the spatial and identity components of the task. The instructions in the spatial matching condition were to ignore the identity of the icons and base responses only on spatial position, but the left hemisphere may have been unable to inhibit the tendency to verbally identify the icons. This, in turn, could have interfered with performance of the spatial matching task. To address this possibility, a control version of the task was constructed. This task was identical to the spatial matching condition described above, but the icons were replaced with black circles, which should mitigate the tendency for automatic naming processes to interfere with spatial judgments. The instructions were to report whether the two circles appeared in the same location in the two squares (Fig. 3). As in the previous experiment, the right hemisphere was superior to the left for both patients (J.W.: $\chi^2(1) = 6.27$, $p < 0.05$; V.P.: $\chi^2(1) = 7.59$, $p < 0.01$). The pattern of performance in the two hemispheres was virtually identical in the experimental and control conditions, although accuracy levels in this control condition were slightly higher (Fig. 4). This indicates that the hemispheric asym-

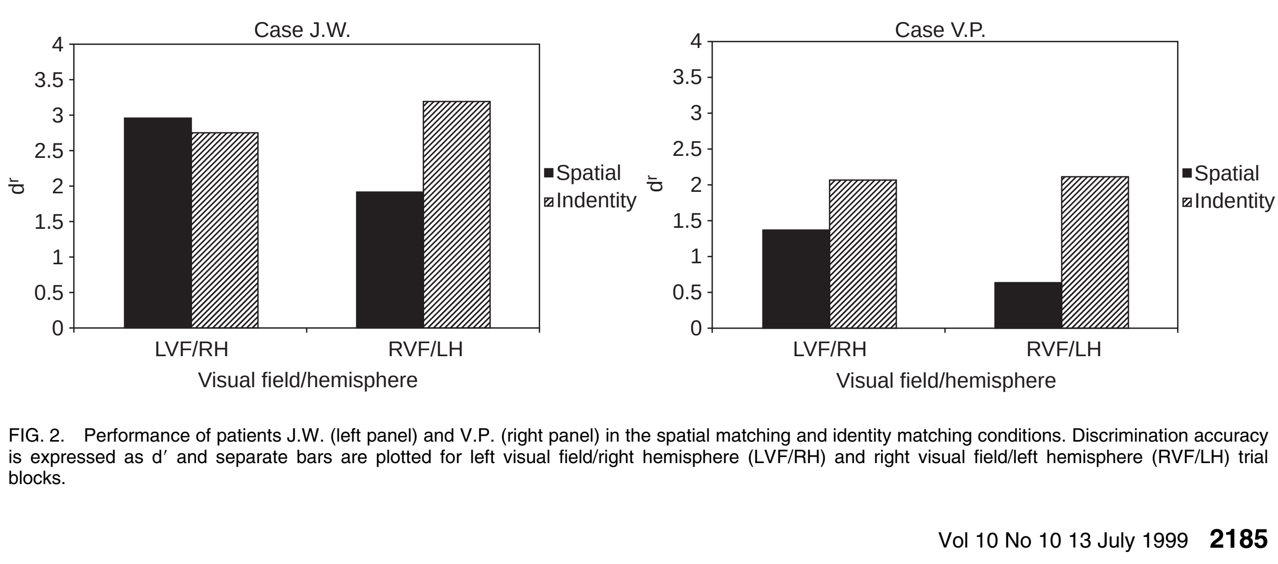

FIG. 2. Performance of patients J.W. (left panel) and V.P. (right panel) in the spatial matching and identity matching conditions. Discrimination accuracy is expressed as d′ and separate bars are plotted for left visual field/right hemisphere (LVF/RH) and right visual field/left hemisphere (RVF/LH) trial blocks.

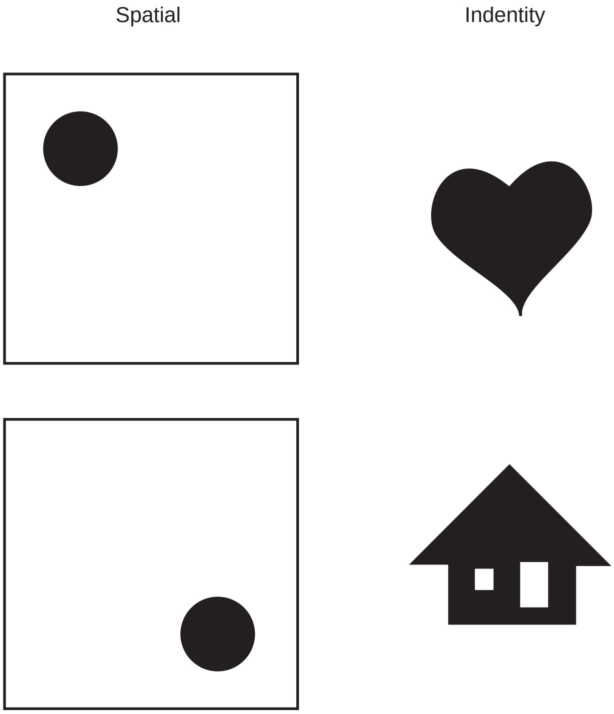

FIG. 3. Examples of the stimuli used in the control tasks (left panel: spatial control task; right panel: identity control task). The stimuli were presented to the right or left of visual fixation for 150 ms, and the patients judged whether or not the black circles were in corresponding corners of the squares.

metry found in the experimental conditions was not the result of interference between hemispheric function and task demands.

A control version of the identity matching condition was also constructed. It is possible that the right hemisphere is superior for any visual judgment task, but that its performance in the identity matching condition may have been depressed by a tendency to preferentially encode spatial, rather than identity, information. This could lower the right hemisphere's accuracy and account for the pattern of performance seen in the identity matching condition. To test this possibility in the control condition, the squares were omitted and the two icons in each pair were presented vertically aligned (Fig. 3). The patients were instructed to judge whether or not the two items in each pair were the same. As in the original identity matching condition, there was a tendency for the left hemisphere to out-perform the right for both patients (Fig. 4). Although this trend was not statistically significant for patient J.W. ($\chi^2(1) = 1.01$, n.s), it was for patient V.P. ($\chi^2(1) = 8.75$, $p < 0.01$). As evidenced by performance on the identity matching tasks, both hemispheres are adept at pattern recognition and there is a suggestion that the left hemisphere might be superior to the right.

Discussion

The purpose of this investigation was to test the hypothesis that visuospatial processes in the left hemisphere are specialized for pattern recognition while those in the right hemisphere are specialized for spatial processing. We reasoned that it would be adaptive to have a pattern recognition system that is at least somewhat oblivious to spatial information in order to recognize visual stimuli presented in different positions, orientations and distances [7]. At the same time, a system capable of performing subtle spatial discriminations is necessary for such functions as sensorimotor integration and navigation. The experiments presented in this paper were designed to test the prediction that these two systems would be lateralized to different hemispheres.

Our data reveal a robust right hemisphere superiority for spatial judgments. This was found regardless of whether the spatial judgments related to nameable icons or simple circles. Our prediction that the left hemisphere would outperform the right on identity matching was only partially confirmed. V.P. showed a left hemisphere advantage in the control condition but not in the original identity

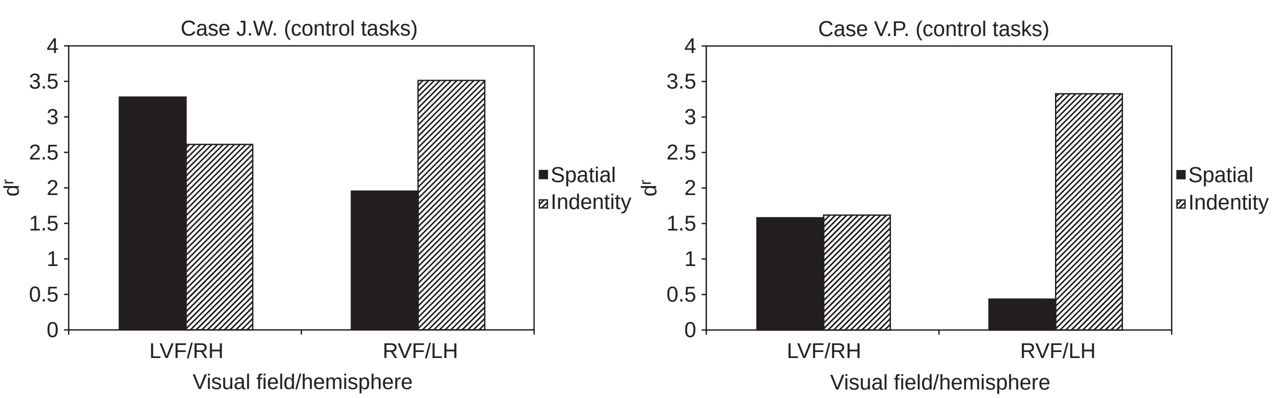

FIG. 4. Performance of patients J.W. (left panel) and V.P. (right panel) in the spatial matching and identity matching control tasks. Discrimination accuracy is expressed as d′, and separate bars are plotted for left visual field/right hemisphere (LVF/RH) and right visual field/left hemisphere (RVF/LH) trial blocks.

matching condition. J.W. showed the opposite pattern, but the left hemisphere advantage in the latter condition failed to reach statistical significance. The relatively good performance of both patients in the identity matching conditions suggests that both hemispheres are capable of reasonably sophisticated pattern recognition. This is consistent with research suggesting that both hemispheres are capable of identifying common objects [13]. It could be argued that it is adaptive for both hemispheres to be equally capable of pattern recognition so objects in either visual field could be rapidly identified.

Although we predicted a left hemisphere superiority for identity matching, there is evidence that the right hemisphere is also capable of sophisticated pattern recognition. For example, several studies have suggested a special role for the right hemisphere in face recognition [14]. Face recognition clearly requires the ability to detect subtle differences between patterns. Tasks like face recognition, however, rely heavily on subtle spatial differences because all faces have essentially the same basic features. Face recognition, therefore, may reflect the operation of a qualitatively different pattern recognition process from those underlying object naming and reading [15]. This raises the possibility that each hemisphere is specialized for different aspects of pattern recognition. The left hemisphere may employ a part-based system for representing visual patterns which is relatively insensitive to minor spatial distortions [16]. In contrast, the right hemisphere may rely on its superior spatial abilities to discriminate between visual stimuli.

Conclusion

Hemispheric asymmetries in visuospatial processing have been observed for many years [17,18]. Although the right hemisphere outperforms the left in many visuospatial tasks, the left hemisphere does appear to be specialized for some aspects of visuospatial processing. A number of dichotomies have been proposed to account for the hemispheric differences in visuospatial processing. Although each of these hypotheses accounts for some of the experimental findings, none appear to be consistent with all of the observed asymmetries [6]. We suggest that the fundamental difference between the two hemispheres is spatial and that this is the underlying cause of hemispheric differences in visuospatial tasks.

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