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ERP and RT signs of a rightward bias for spatial orienting in a split-brain patient

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NEUROPSYCHOLOGICAL data have shown that the two cerebral hemispheres differ in the control of spatial attention. The present study investigated hemispheric asymmetries and visuomotor integration in a split-brain patient and three control subjects. Simple reaction times (RTs) and event-related potentials (ERPs) were recorded to lateralized stimuli presented at different eccentricities in the left and right visual hemifields. Both electrophysiological and behavioural data showed that, unlike controls, the split-brain patient showed a strong rightward attentional bias resulting in shorter RTs and larger P300 potentials to stimuli falling in the rightmost space. Furthermore, ERPs also showed that while the RH has a bilateral control of visual space, the LH spatial orienting capability is most restricted to the contralateral hemifield.

Key words: Spatial attention; Event-related potentials; Cerebral hemispheres; Human split-brain; Rightward bias in spatial orienting; Right hemisphere bilateral control over attention to space; P300 component; RTs

Introduction

A long history of neuropsychological studies on humans with focal neurological damage has provided consistent findings on the role of the right hemisphere (RH) in spatial attention and vigilance.[1–3] A consistent finding has been that whereas lesions of either cerebral hemisphere can lead to hemispatial neglect and/or extinction, lesions of the RH produce more dramatic and severe neglect and with a greater frequency than do similar lesions in the left hemisphere (LH). These observations led to the hypothesis that the two hemispheres differ in their control over attention to locations, in that the RH can produce orienting responses to stimuli in either hemispace whereas the LH can only control orienting to contralateral visual space.[4] Kinsbourne[5] proposed that such a pattern may be explained by a directional imbalance in opponent systems that control lateral orienting of attention. In particular, the LH would have a stronger rightward attentional bias, so that when the RH is impaired a severe neglect of the leftmost space would occur, the opposing leftward bias of the RH being considerably weaker. Conversely, if the LH is impaired, the resulting deficit would be quite mild because the intact RH could compensate in its bilateral control, thus producing less severe neglect symptoms.

If this hypothesis is true, one would expect to find a strong difference in the attentional capabilities and directional biases of the two cerebral hemispheres in split-brain patients, whose hemispheres are completely disconnected at the cortical level. In order to test this hypothesis, ERPs and RTs to lateralized stimuli presented at different eccentricities of the visual space were recorded in a split-brain patient and three healthy control subjects. We studied the amplitude and topographical distribution of the P300 component and related these data to the behavioural results. The P300 component is a widely studied late positive deflection typically elicited by task relevant stimuli that require a decision from a subject.[6] Thus, it is a useful tool in investigating cognitive processes related to orienting of attention to spatial locations. Multichannel recording of brain activity over each hemisphere in response to the unilateral stimuli was used in the present study for investigating hemispheric asymmetries in spatial orienting.

Material and Methods

Subjects: Split-brain patient J.W. served as the subject in the present experiment. He is a right-handed 40-year-old alert male with normal vision who underwent a two-stage callosotomy at the age of 25 years in an effort to control otherwise intractable epileptic seizures. Investigation by magnetic resonance imaging (MRI) confirmed complete section of the corpus callosum with sparing of anterior commissure in this patient.[7] Three control subjects (two females and one male, mean age 37 years) also participated in the experiment. All were right-handed and had normal or corrected-to-normal vision.

Stimuli and procedure: Subjects were seated at 57 cm from a colour computer screen. A luminance-modulated square-wave grating (1 c/deg) subtending 3° of visual angle was randomly presented for 100 ms at four peripheral locations on the horizontal meridian of the visual field. Stimulus location eccentricities were 6° and 10° in the left and right hemifields. The interstimulus interval (ISI) randomly varied between 1400 and 2800

ms. Gratings were presented in random blocks, superimposed on the darkened background of the video monitor. Each stimulus block consisted of a total of 44 trials, for a duration of about 2 min. Twelve blocks were administered yielding a total of 132 trials for each stimulus location. Short rest periods were given between each block of stimuli.

Subjects were instructed to maintain eye fixation on a 1/4° circular red dot in the centre of the computer screen, and to avoid ocular or body movements and blinks. To ensure that fixation was maintained, the horizontal and vertical electro-oculogram (EOG) was monitored. Subjects' eyes were monitored by an infrared video-camera.

The subject's task was to push a button as fast as possible to all stimuli. For each block subjects pressed the button with the index finger of the left or right hand. The order of the hand was counterbalanced across the blocks and subjects. During the task, the subjects' arms separately rested on the arms of the easy-chair in which they were seated.

ERPs to the flashed stimuli were recorded from 61 scalp sites using tin electrodes mounted in an elastic cap. Electrode impedance was kept below 5 kΩ. These electrode sites were referred to a balanced non-cephalic sterno-vertebral lead. Blinks and vertical eye movements were monitored with an electrode below the right eye. Horizontal eye movements were recorded from electrodes placed at the outer canthi of the eyes (bipolar lead). EOG signals were amplified with a band pass of 0.01–100 Hz, and EEG signals with a band pass of 0.1–100 Hz. ERPs were computed by averaging epochs of continuous EEG beginning 400 ms prior to, and lasting 1000 ms after stimulus onset; they were aligned to the mean amplitude of the 100 ms prestimulus baseline. Separate average waveforms were computed for each stimulus location. Trials containing artifacts due to ocular movements, blinks or amplifier saturation were excluded from the averaged ERP waveforms. In addition to this rejection procedure, epochs associated with RTs < 170 ms or > 800 ms were also excluded from the ERP averages. Behavioural responses associated with EEG or EOG artifacts, late responses and anticipations were also excluded from RT analysis. Rejection rate was on average < 10% of trials.

Quantification of the late latency P3b complex in the waveforms was accomplished by measuring the mean amplitude in the 350–550 ms post-stimulus range for J.W., and the 250–500 ms range for all control subjects. All measures within the specified latency range were automatically quantified by computer. To investigate the topographical distribution of P300 component, isocontour maps of the superficial brain voltage were also computed.

In the present paper, only the data from trials in which the target appeared in the visual field ipsilateral to the response hand (uncrossed responses) were considered. For analysis purposes, RT and ERP data from J.W. for each experimental condition were randomly averaged in three separate sub-blocks. The RT data were analysed using analysis of variance (ANOVA) with blocks as the random factor: the independent variables of interest were visual field (left = LVF,

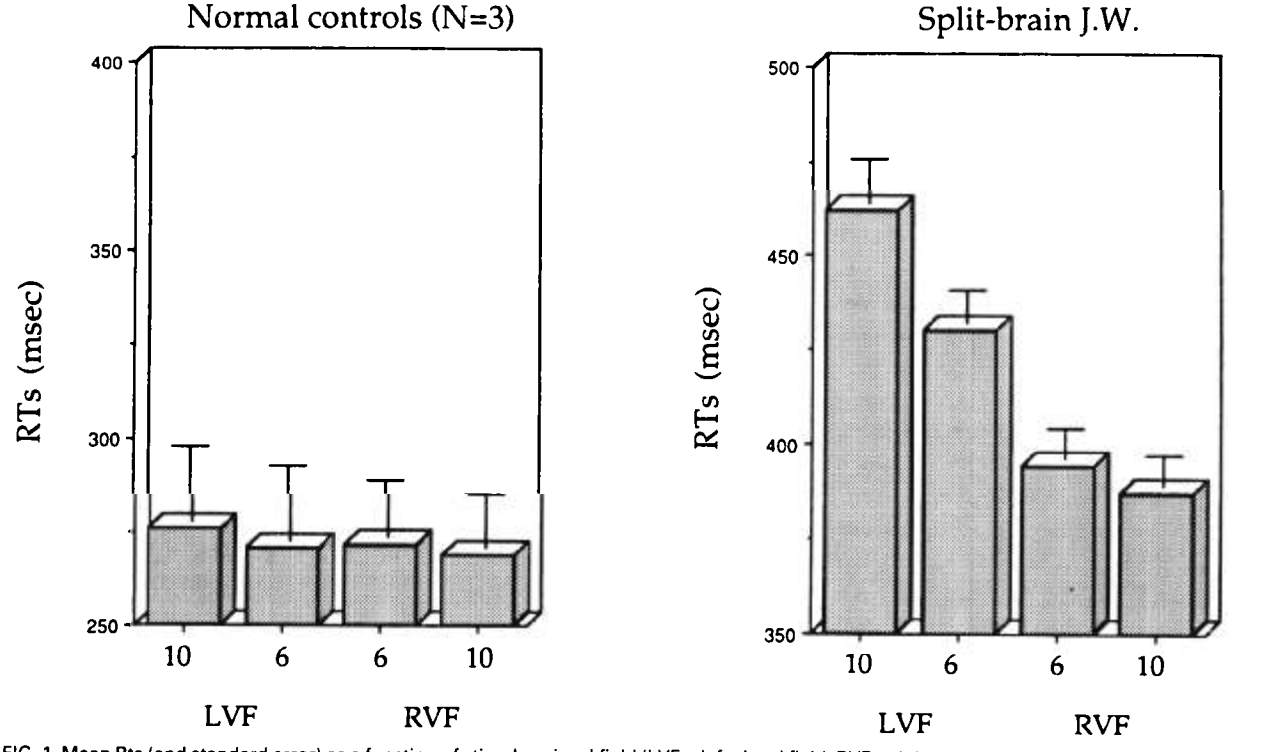

FIG. 1. Mean Rts (and standard error) as a function of stimulus visual field (LVF = left visual field; RVF = right visual field) and eccentricity (6° and 10°) for (a) normal controls and (b) patient J.W.

right = RVF) and stimulus location eccentricity (6° and 10°). As for RTs, ERP data also were analysed using ANOVA with blocks as the random factor. In this case, the independent variables of interest were visual field (left and right), stimulus location eccentricity (6° and 10°), hemisphere (LH and RH), and scalp site at occipital (O1, O2, OL, OR), temporal (T5, T6, CT7, CT8), parietal (P3, P4, P5, P6), central (C3, C4, C5, C6), and frontal areas (F3, F4, F5, F6). Control subjects' RT and ERP data were analysed by means of separate ANOVAs with the same independent factors as the ones performed for the split-brain patient. Reported p values and degrees of freedom for the F ratio were corrected on the base of the Greenhouse–Geisser epsilon adjustment for repeated measures designs.[8] Duncan tests were carried out for multiple comparisons.

Results

Behavioural results: No significant differences in RTs were found to stimuli in either visual field or eccentricity for normal controls (Fig. 1a). The mean RTs for patient J.W. are shown in Figure 1b. Overall the RTs to RVF stimuli (χ = 392 ms) were faster than RTs to LVF stimuli (χ = 444 ms). The ANOVA confirmed this main effect of visual field ($F(1,2) = 17.90$, $p < 0.05$; $\varepsilon = 1$). In addition, the interaction of visual field and eccentricity was statistically significant ($F(1,2) = 22.73$, $p < 0.04$; $\varepsilon = 1$). Post-hoc comparisons showed that this interaction resulted from there being a significant effect of stimulus eccentricity for LVF only ($p < 0.05$); RTs were slower for the farthest leftward location within this hemifield.

Electrophysiological results: Consistent with the RT results, no significant effects of hemisphere or visual fields were obtained in normal controls (Fig. 2a). P3b values recorded in the patient also showed a main effect of the visual field ($F(1,2) = 18.27$, $p < 0.05$; $\varepsilon = 1$): the P3b to RVF stimuli (χ = 7.06 μV) had greater amplitude than P3bs to LVF stimuli (χ = 4.51 μV). Importantly, the interaction of visual field × hemisphere proved to be highly significant ($F(1,2) = 114.55$, $p < 0.0086$; $\varepsilon = 1$). Post-hoc comparisons showed that responses over the RH were of about the same amplitude to both visual fields, whereas the responses over the LH were significantly reduced to stimuli of the ipsilateral visual field ($p < 0.01$; see Fig. 2b). Interestingly, LH responses to contralateral RVF stimuli were much larger than the RH responses to either visual fields ($p < 0.05$ for both comparisons). This general trend extended to the RH at frontal locations, in that the P3b was significantly larger to RVF than to contralateral stimuli at right frontal areas ($p < 0.01$), as indicated by the post-hoc analyses for the interaction of visual field × hemisphere × electrode ($F(2,4) = 39.39$, $p < 0.01$; $\varepsilon = 0.21$).

These same analyses also showed that the P3b had a

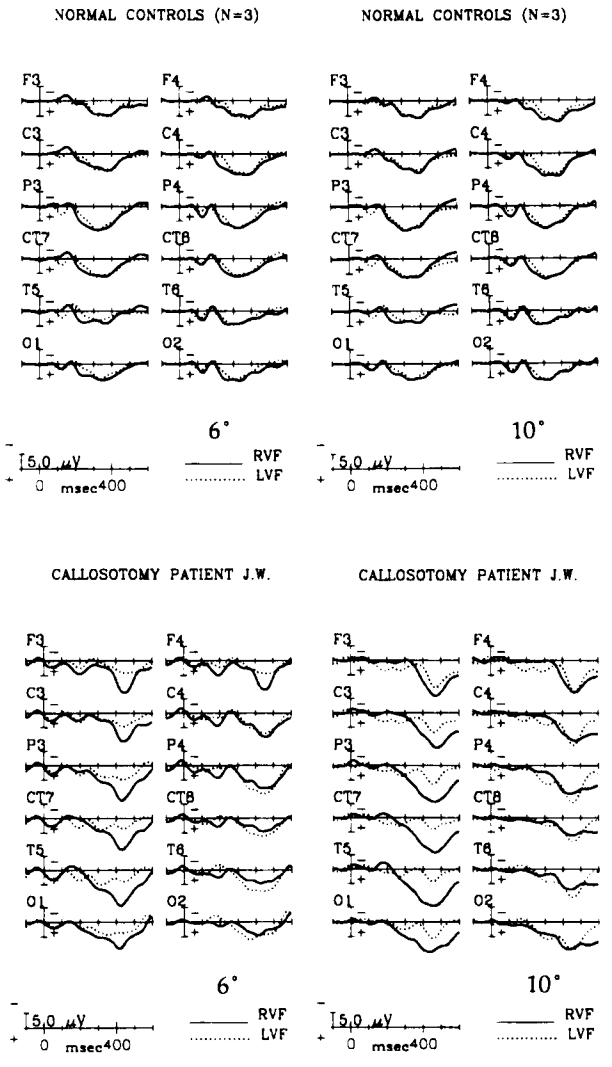

FIG. 2. (a) Grand average ERPs across all normal controls recorded at occipital, temporal, parietal, central and frontal areas to stimuli presented at 6° and 10° of eccentricity in both LVF and RVF; (b) Examples of ERPs recorded at occipital, temporal, parietal, central and frontal areas to stimuli presented at 6° and 10° of eccentricity in both LVF and RVF in patient J.W.

posterior–anterior topographical distribution with a maximum amplitude at parietal, posterior–temporal areas. Moreover, they also revealed that the P3b amplitude was larger over the RH at parietal ($p < 0.003$), lateral parietal ($p < 0.029$), and lateral frontal sites ($p < 0.03$), probably due to the undifferentiated response of this hemisphere to stimuli of both visual fields.

The ANOVA suggested that stimulus eccentricity might differently affect P3b mean amplitude at different scalp sites of the two hemispheres. However, ε-correction revealed that these effects were too much heterogeneous (E × H × L – ($F(1,3) = 2.66$, n. s.; $\varepsilon = 0.15$).

Isocontour voltage maps for brain activity between 350 and 500 msec postimulus latency in J.W. (see Fig. 3), confirmed that the positive source was localized over the parieto–temporal areas and reached its maximum strength for RVF stimuli.

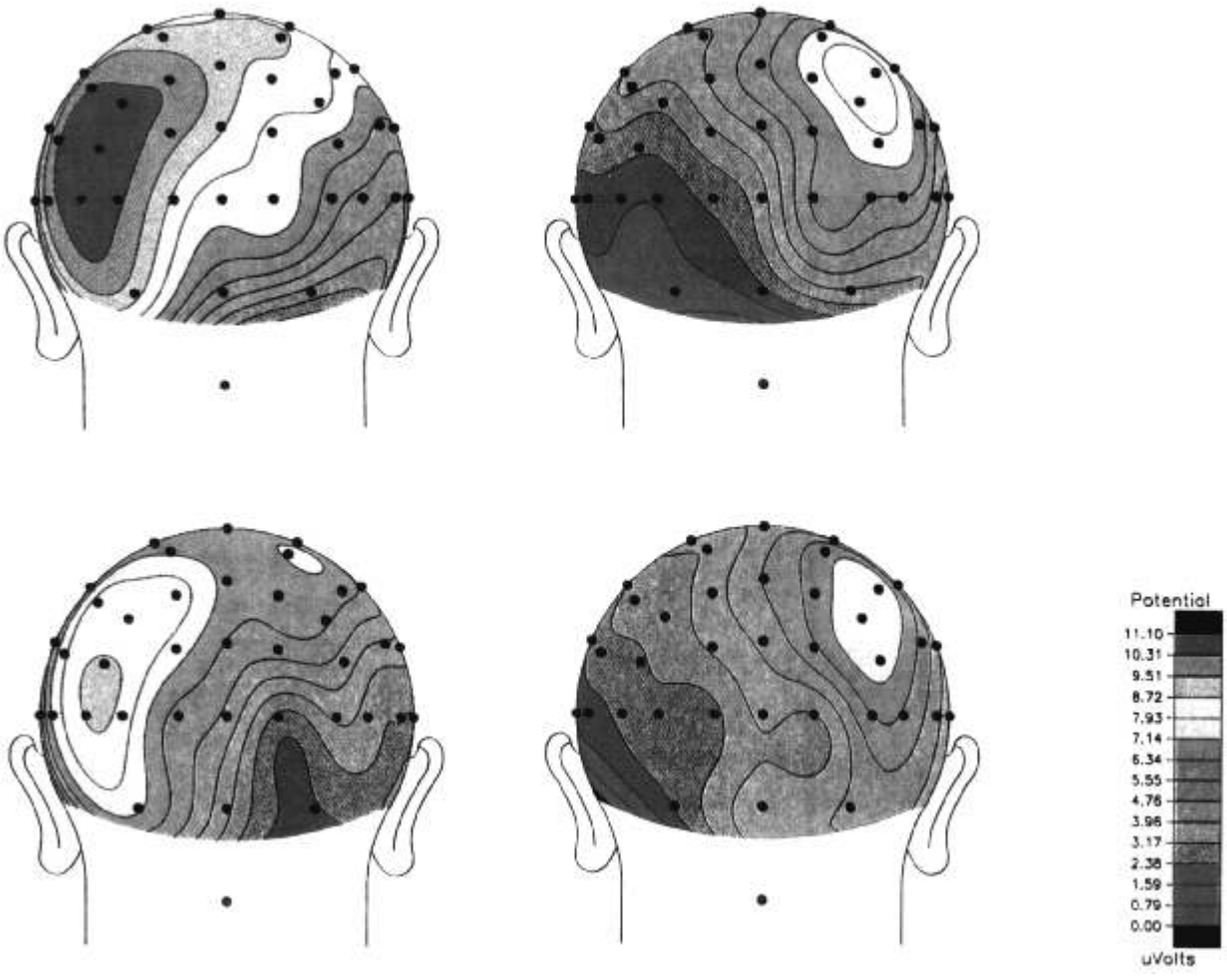

FIG. 3. Isocontour voltage maps of P300 mean amplitude (350–550 ms) as a function of eccentricity (bottom: 6°; top: 10°) and visual field (left: RVF; right: LVF) for patient J.W.

Discussion

The RT data obtained in the present study clearly indicate a strong rightward bias of attention to spatial location for LH in the split-brain patient. This bias manifested as a shortening of RTs and a lack of stimulus eccentricity effects for stimuli in the RVF. Conversely, LVF stimuli where shown to elicit longer RTs, especially at the leftmost location, thus suggesting that the RH is less biased toward contralateral space than is the LH. The above results are consistent with the findings of Aglioti *et al*[9] who investigated simple visuomotor responses to lateralized flashes in a callosotomized patient (M.E.) with a right prefrontal lesion. In their study, simple RTs to RVF stimuli were faster than the LVF RTs; again, the increase in RTs with eccentricity was greater in the left than the right hemifield. The fact that patient J.W. has no known cortical lesions other than the complete resection of the corpus callosum rules out the possibility that the present pattern results from lateralized focal brain damage, as in patient M.E. Rather, these effects reflect hemispheric attentional asymmetries that can be observed in split-brain patients following callosotomy to disconnect the two hemispheres. This view is also supported by similar results obtained by Mangun *et al*[10] who showed a lack of costs for RVF invalid targets in a spatial cuing paradigm in three callosotomy patients. Together then, these data imply that the corpus callosum has an essential role in mediating the control over attention to locations and objects in extrapersonal space by the two hemispheres. It follows that when the corpus callosum is surgically disconnected, a strong bias toward the rightmost space will occur, since the rightward orienting tendency of the LH is uninhibited.

Our electrophysiological data complement and extend RT results. They indicated that the response of the disconnected LH to RVF stimuli was much larger than the largest response of the RH to LVF stimuli. In our view, these RT and ERP asymmetries are manifestations of a rightward bias of attention by the LH for spatial orienting, as predicted by the Kinsbourne[5] model. Further, the ERP findings indicate that the RH, unlike the LH, gives P3b responses of about the same magnitude to stimuli falling in either visual hemifield. This pattern is consistent with the view that the RH has

a bilateral control over orienting in space.[4,5,11,12] Indeed, there is a close similarity between the present ERP results and those of the PET study by Corbetta *et al.*[13] They found that the right superior parietal lobule had anatomically separate spatial representations for directing attention within the contralateral and ipsilateral visual fields, whereas in the left parietal lobule there was only one representation for directing attention prevalently to the RVF. This may very well explain the reduced orienting response of the LH to stimuli in the ipsilateral visual field in a split-brain patient, as suggested by the P300 data in the present study.

Conclusions

The present data indicate that the disconnected cerebral hemispheres of a human split-brain patient differ in their control over attention to visual space. In particular, while the RH has a bilateral control of visual spatial orienting, the LH spatial orienting capability is more strongly biased to the contralateral hemispace. This LH rightward attentional bias resulted in shorter RTs and larger brain potentials to stimuli falling in the right hemispace.

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