Inter- and Intra-hemispheric Processing of Visual Event-related Potentials in the Absence of the Corpus Callosum

Sophie Bayard¹, Nadia Gosselin¹, Manon Robert¹, and Maryse Lassonde¹,²

Abstract

Interhemispheric differences of the N100 latency in visual evoked potentials have been used to estimate interhemispheric transfer time (e.g., Saron & Davidson, 1989). Recent work has also suggested that the P300 component could reflect the efficacy of interhemispheric transmission (Polich & Hoffman, 1998). The purpose of the present study was to study the differential role of the corpus callosum (CC) and anterior commissure (AC) in the interhemispheric propagation of these two electrophysiological components. Thus, the amplitude and latency distribution of the N100 and P300 components were analyzed using high-density electrical mapping in a subject with agenesis of CC but preservation of AC, a subject with agenesis of both CC and AC, and 10 neurologically intact control subjects. The task consisted of a modified visual oddball paradigm comprising one frequent and two rare stimuli, one presented on the same and the other on the opposite side of the frequent stimulus. Interhemispheric differences in latency were found for the N100 component in controls. However, in the acallosal subjects, this component was not identifiable in the indirectly stimulated hemisphere. In controls, no interhemispheric differences were observed in the distribution of the P300 latency and amplitude to rare and frequent stimuli. The distribution of the P300 amplitude in the acallosal subject with an AC was identical to that of the controls, whereas in the acallosal subject lacking the AC, the amplitude was greater in the hemisphere receiving the frequent stimuli, regardless of the visual hemifield in which the rare stimuli were presented. In both acallosal subjects, hemispheric differences in the P300 latency were observed, the latencies being shorter in the hemisphere directly stimulated for all categories of stimuli. These results suggest that the interhemispheric transfer of both the N100 and P300 components relies on the integrity of cortical commissures. Possible P300 generator sources are discussed.

INTRODUCTION

Interhemispheric communication is possible through commissural fibers of cortical and subcortical origin that connect the two hemispheres. The corpus callosum (CC) is the largest commissure at the cortical level, comprising a topographical representation of most cortical areas (for a review, see Clarke & Zaidel, 1994; Aboitiz, Scheibel, Fisher, & Zaidel, 1992; Pandya & Seltzer, 1986). In addition, three other forebrain commissures provide interhemispheric communication. These are the anterior commissure (AC) and the dorsal and ventral hippocampal commissures. Subcortical interhemispheric communication is assumed by projections through the hippocampal, habenular, intercollicular, and posterior commissures. Among the forebrain commissures, the CC, because of its size and distribution, is considered to be the most efficient interhemispheric pathway in terms of speed of transfer and the complexity of information that is transferred.

In the visual modality, Poffenberger (1912) was the first to estimate an interhemispheric transfer time (IHTT), referring to the speed with which information is transferred from one hemisphere to the other, by comparing manual reaction times (RTs) to visual stimuli presented to the hemifield ipsilateral or contralateral to the responding hand. He observed that RTs of the hand ipsilateral to the visual stimulation (uncrossed responses) were shorter than those to the contralateral visual input (crossed responses). Based on the neuroanatomical principle that the hand and a laterized visual input are controlled by the contralateral cortex, an uncrossed response should be directly produced by the hemisphere receiving the visual stimulation, whereas a crossed response would require an interhemispheric transfer of the visual stimulation to the hemisphere controlling the responding hand. The RT difference between the crossed and uncrossed responses has been considered a measure of interhemispheric transmission time, or IHTT. In the normal population, replications of this classical paradigm estimate the IHTTs to be 3 msec (e.g., Marzi, Bisiacchi, & Nicoletti, 1991; Bashore, 1981).
By exploring the behavior of patients who underwent complete or partial section of the CC for intractable epilepsy (i.e., split-brain patients), as well as individuals who present a total or partial absence of the forebrain commissures (i.e., acallosal patients), it has been shown that the CC is crucial for efficient interhemispheric transfer. In patients lacking the CC, IHTTs are abnormally long. For instance, in acallosal subjects, visual IHTTs may vary between 12.8 and 52 msec with a mean value in the 20-msec range. Even larger IHTTs, ranging from 20 to 96 msec are observed in split-brain patients (e.g., Lassonde, Sau-erwein, & Lepore, 2003; Iacoboni & Zaidel, 2000).

More recently, electrophysiological methods, especially event-related potentials (ERPs), have been used to estimate IHTTs. Compared to behavioral studies, ERPs have several advantages. First, ERPs constitute a functional, noninvasive imaging technique that offer an excellent temporal resolution (in the order of milliseconds). Second, ERPs allow the simultaneous recording of activity from both hemispheres even in the case of unilateral stimulation. However, it appears that the classical 3-msec IHTT derived from behavioral studies of unilateral stimulation. Even larger IHTTs, ranging from 20 to 96 msec are observed in split-brain patients (e.g., Lassonde, Sau-erwein, & Lepore, 2003; Iacoboni & Zaidel, 2000).

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Lateralized visual ERPs have long been considered an excellent index to estimate IHTT (Saron & Davidson, 1989). In this context, two major ERP components have been explored: the P100 and the N100, also called N160 (e.g., Nalcaci, Basar-Eroglu, & Stadler, 1999; Larson & Brown, 1997; Brown & Jeeves, 1993; Lines, Rugg, & Milner, 1984). Under unilateral visual presentations, these two ERP components have a maximal distribution in the occipital region (Bonmassar et al., 2001; Arroyo, Lesser, Poon, Webber, & Gordon, 1997). They generally show a brief latency delay and an attenuation of amplitude at the recording sites over the indirectly stimulated hemisphere, that is, the hemisphere ipsilateral to the visual stimulus.

More recently, Hoffman and Polich (1998, 1999) have suggested that the P300 component could also reflect interhemispheric transmission efficacy. Using standard visual oddball tasks, these authors observed a larger P300 amplitude and a shorter P300 latency for left- than right-handed subjects. Based on anatomical observations of a larger corpus callosal in left-handers, they proposed that the P300 could be influenced by morphological differences in CC.

Very few studies have investigated lateralized visual ERPs in patients with abnormalities of the CC. Satomi, Horai, Kinshita, and Wakazono (1995) studied a patient with a posterior callosal lesion and found a delay in the P300 latency and an attenuation of the amplitude of the N1–P2 and N2–P3 components over the hemisphere ipsilateral to the visual presentations. Brown, Bjerke, and Galbraith (1998), on their part, observed an absence of the P100 and N100 components at the recording sites ipsilateral to the visual input in callosal agenesis and commissurotomy patients. Similarly, Rugg, Milner, and Lines (1985) failed to identify an ipsilateral N160 component in two acallosal subjects. Finally, using bilateral stimulus presentations, Kutas, Hillyard, Volpe, and Gaz- zaniga (1990), studying a commissurotomized patient, observed a larger P300 amplitude over the right hemisphere for left visual field presentations but an equal P300 amplitude over both hemispheres during right visual field presentations.

It appears from this brief literature overview that studies in patients with CC abnormalities have predominantly focused on the early ERP components. To our knowledge, only one study has explored the later P300 component in such patients (Kutas et al., 1990), but none has analyzed this component in cases of developmental callosal pathology.

The P300 component is generally obtained in “oddball” paradigms in which two types of stimuli are presented that occur at different frequencies. Independently of the sensory modality of stimulation, the infrequent stimulus elicits a larger positive brain potential with a maximal deflection over parietal sites, the so-called P3b subcomponent. A modification of the classical oddball paradigm, the “three-stimulus paradigm” where infrequent “novel” stimuli are introduced in the sequence, can produce a “novel” P300 subcomponent, the P3a, which is larger over the fronto-central areas. The P3a has been proposed to be a marker of the initial signal evaluation (Comerchero & Polich, 1998; Katayama & Polich, 1998; Courchesne, Hillyard, & Galambos, 1975; Squires, Squires, & Hillyard, 1975), whereas the P3b is considered to be associated with working memory operations (see reviews by Donchin, Karis, Bashore, Coles, & Gratton, 1986). The P300 amplitude is thought to represent the amount of attentional resources allocated to a stimulus (Kramer & Strayer, 1988; Wickens, Kramer, Vanasse, & Donchin, 1983), while the P300 latency is viewed as reflecting the time required to classify a stimulus (Polich, 1986; McCarthy & Donchin, 1981; Kutas, McCarthy, & Donchin, 1977).

In the present study, we analyzed the amplitude and latency of the N100 and P300 components, using high-density electrical mapping, in two acallosal subjects, one of whom also lacks the AC and 10 controls subjects. A three-stimulus modified visual oddball task was used. The task comprised a frequent and two rare categories of stimuli, one being presented ipsilaterally (rare intra-stimuli) and the other contralaterally (rare inter-hemispheric stimuli, referred here as rare intra stimuli) and the other contralaterally (rare inter-hemispheric stimuli, referred here as rare inter stimuli) to the frequent stimuli (see Figure 1). With this modified oddball methodology, we hoped to be able to, first,
replicate in controls the classical findings of a larger amplitude and a shorter latency of the N100 component in the directly stimulated hemisphere and, second, to corroborate previous findings in acallosal subjects that have shown the absence of the N100 component in the indirectly stimulated hemisphere. The key question we wanted to explore was, however, whether the P300 could be fully observed in the indirectly stimulated hemisphere in subjects with total congenital absence of the CC. Finally, we wanted to investigate the possible contribution of the AC in interhemispheric propagation of this component by comparing the P300 features obtained from the acallosal subject lacking the AC to those of the acallosal subject with an intact AC.

RESULTS

Oddball Effects

Behavioral Results

A Shapiro–Wilk test performed on the behavioral data of the controls indicated normal distribution. The performances on the behavioral tests are summarized in Figure 2. Analyses of the RTs of the controls yielded a main stimulus effect among frequent, rare intra, and rare inter stimuli, $F(1,9,17.4) = 5.8, p = .012$. Contrast analyses revealed shorter RTs for the frequent stimuli (441 msec, $\sigma = 81$) than for the rare intra (465 msec, $\sigma = 112$), $F(1,9) = 6.459, p = .032$, and rare inter stimuli (476 msec, $\sigma = 83$), $F(1,9) = 9.687, p = .012$. No differences in RTs were obtained between the rare intra and rare inter stimuli. Furthermore, no significant differences were found with regard to the number of correct responses (frequent = 96%; rare intra = 96%; and rare inter = 92%).

Descriptive statistics showed that the acallosal subject S.G. with an intact AC had shorter RTs to frequent stimuli (561 msec, $\sigma = 133$) than to rare intra (581 msec, $\sigma = 132$) and rare inter stimuli (698 msec, $\sigma = 91$). The same results were obtained from the acallosal subject S.Pe. without an AC who showed shorter RTs to frequent stimuli (658 msec, $\sigma = 124$) than to rare intra (773 msec, $\sigma = 156$) and rare inter stimuli (773 msec, $\sigma = 107$).

Figure 2. Mean response times (msec) and percent correct responses for the control subjects, the acallosal subject S.G. with AC, and the acallosal subject S.Pe. without AC across the three stimulus categories: frequent, rare intra, and rare inter stimuli. *$z > 1.96, p < .05$; **$z > 2.54, p < .01$. 

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The comparisons of z scores indicated that S.G. with preserved AC was slower than the controls in the rare inter condition (z = +2.7) only, whereas S.Pe. without AC was slower than the controls for all stimulus categories (frequent, z = +2.7; rare intra, z = +2.7; rare inter, z = 3.6). In addition, the z score comparison showed that the acallosal subject lacking the AC was significantly slower than the acallosal subject with an AC for all stimulus categories.

With regard to response accuracy, no significant differences were observed between the two subjects and the controls.

In sum, despite the relative slowness observed in both acallosal subjects, the RTs of all subjects confirmed the validity of the modified oddball paradigm, with RTs being shorter for frequent stimuli than rare stimuli.

P300 Latency and Amplitude

P300 latency. In control subjects, a significant main stimulus effect among frequent, rare intra, and rare inter stimuli, F(1.33, 12) = 4.79, p = .041, was found over all averaged electrodes (Figure 3). Latency differences were observed among the frequent (364 msec, σ = 18.1), rare intra (355 msec, σ = 21.1), and rare inter stimuli (347 msec, σ = 15). Contrast analyses revealed a shorter P300 latency for the rare inter, F(1,9) = 10.73, p = .01, than the frequent intra stimuli. No significant difference was observed between the rare intra and frequent stimulus latencies or between the rare intra and rare inter P300 latencies.

The acallosal subject with an AC (S.G.) did not show these P300 latency effects: the frequent (401 msec), rare intra (399 msec), and rare inter (405 msec) P300 latencies in this subject did not differ. In contrast, for the acallosal subject without AC (S.Pe.), shorter P300 latencies were observed for the rare intra (400 msec) and rare inter stimuli (398 msec) than for the frequent ones (441 msec). A z score comparison among these P300 latencies revealed, however, significantly longer latencies for each stimulus category in both acallosal subjects (see Figure 3).

P300 amplitude. In control subjects, a significant main effect of stimulus type was found, F(1.71,15.42) = 11.84, p = .001. Amplitude differences were observed among the frequent (8.3 μV, σ = 2.4), rare intra (10.4 μV, σ = 3.1), and rare inter stimuli (11.6 μV, σ = 1.7). Contrast analyses revealed larger P300 amplitudes for the rare inter, F(1,9) = 37.45, p < .001, and rare intra, F(1,9) = 2.01, p = .014, than for the frequent stimuli. No significant P300 amplitude differences were obtained between the rare intra and rare inter stimuli.

As illustrated in Figure 4, the acallosal subject S.G. and the acallosal subject S.Pe. without AC both demonstrated this stimulus effect. In the acallosal subject S.G., larger P300 amplitudes were observed following presentations of the rare intra (10.4 μV) and rare inter stimuli (9.9 μV) than after the appearance of the frequent (5 μV) stimuli. Similar results were obtained for the acallosal subject S.Pe. without AC who showed a larger P300 amplitude for the rare intra (10.1 μV) and rare inter stimuli (14.9 μV) than for frequent ones (5.3 μV). A z score comparison of these P300 amplitudes revealed, however, that the rare inter stimuli elicited a larger P300 amplitude in the acallosal subject S.Pe. without AC (z score = +2.1) than in the controls. The acallosal subject S.G. who has an AC did not differ from controls.

The latter results confirm once more the validity of the modified oddball paradigm. The controls as well as the acallosal subjects with and without AC demonstrated a larger P300 amplitude following presentations of both rare types of stimuli (rare intra and inter) than after the occurrence of frequent stimuli.

Interhemispheric Differences

N100 Amplitude and Latency

Table 1 summarizes the statistical results of the hemispheric comparisons carried out on the N100 amplitude and latency data of the control subjects. The analyses...
were carried out only on the posterior sites since the N100 component was not visualized in anterior locations.

As can be seen in Figure 5A, the N100 was systematically larger in the hemisphere that directly received the visual input. Thus, in the controls, the stimuli presented in the left visual hemifield (rare inter stimuli) elicited a higher N100 amplitude in the right hemisphere, and the stimuli presented in the right visual hemifield (frequent and rare intra stimuli) elicited a larger N100 amplitude in the left hemisphere. Moreover, the hemispheric

Table 1. Summary of the Two-factor (3 Stimulus Types × 2 Electrode Sites) MANOVA Performed on the N100 Amplitude and Latency for the More Lateral Electrodes in the Control Subjects

<table>
<thead>
<tr>
<th>Source (df)</th>
<th>Amplitude (µV)</th>
<th>Latency (msec)</th>
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<tbody>
<tr>
<td></td>
<td>F</td>
<td>p</td>
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<tr>
<td>T7/T8</td>
<td></td>
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<tr>
<td>S (1.6,14.4)</td>
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<td>–</td>
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<tr>
<td>E (1,9)</td>
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<td>.005</td>
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<tr>
<td>Tp7/Tp8</td>
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<tr>
<td>S (1.9,17.3)</td>
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<td>–</td>
</tr>
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<td>P7/P8</td>
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<tr>
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</tr>
<tr>
<td>E (1,9)</td>
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<td>.036</td>
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<tr>
<td>S × E (1.7,15.9)</td>
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<td>.0001</td>
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<tr>
<td>Po7/Po8</td>
<td></td>
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<tr>
<td>S (1.8,16.3)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>E (1,9)</td>
<td>5.08</td>
<td>.05</td>
</tr>
<tr>
<td>S × E (1.2,10.8)</td>
<td>29.50</td>
<td>.0001</td>
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S = stimulus types (frequent, rare, rare intra, rare inter); E = electrode sites; T = temporo-parietal; P = parietal; Po = parieto-occipital.
difference in amplitude was larger for the frequent stimuli, thus yielding a significant Stimulus Type × Electrode Sites interaction (see Table 1).

Figure 5A also shows that, in controls subjects, hemispheric differences in the N100 latency were observed (see also Table 1) and that these differences were more marked in the posterior region with significant Stimulus Types × Electrode Sites interactions being observed for the Po7/Po8 and P7/P8.

For the acallosal subject with preserved AC (S.G.), the N100 amplitude was also larger in the directly stimulated hemisphere (Figure 5B). The rare intra and the frequent stimuli presented in the right visual hemifield elicited a larger N100 amplitude in the left hemisphere and, inversely, the rare inter stimuli, presented in the left visual hemifield yielded a larger N100 amplitude in the right hemisphere. However, the N100 component was not identifiable in the indirectly stim-
ulated hemisphere: the rare intra and the frequent stimuli, presented in the right visual hemifield, did not produce an identifiable N100 component in the indirectly stimulated right hemisphere, and the rare inter stimuli, presented in the left visual hemifield, did not induce an N100 component in the indirectly stimulated left hemisphere.

For the acallosal subject without AC (S.Pe.), a large P100/N100 complex was observed in the directly stimulated left hemisphere for the frequent and rare intra stimuli (Figure 5C). This P100/N100 complex could not be identified in the right hemisphere, although for the rare intra stimuli a low peak (not exceeding 1.5 μV) was observed in the N100 latency window. In this subject, differences were observed between the P100/N100 complex obtained following presentation of the frequent intra, rare intra, and rare inter stimuli. This complex was larger when elicited by the frequent and rare intra stimuli that directly stimulated the left hemisphere than in response to the rare inter stimuli over the directly stimulated right hemisphere. Thus, the P100/N100 complex was larger in the hemisphere that

**Figure 5.** (continued)

<table>
<thead>
<tr>
<th></th>
<th>Frequent</th>
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<th>Rare inter</th>
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</table>

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both produced the motor response and received the frequent stimuli.

In sum, in control subjects, the N100 component amplitudes were larger and their peak latencies earlier in the contralateral (directly stimulated) than in the ipsilateral (indirectly stimulated) hemisphere. In the acallosal subject S.G. with an AC, the N100 component was present in the directly stimulated hemisphere but could not be identified over the ipsilateral, indirectly stimulated hemisphere. In the acallosal subject S.Pe. without AC, a larger P100/N100 complex was observed in response to the frequent and rare intra stimulus categories presented to the directly stimulated left hemisphere than following direct visual stimulation of the right hemisphere (rare inter stimuli).

P300 Amplitude and Latency

P300 amplitude. In controls, no interhemispheric differences were observed regarding the P300 amplitude.
This component was homogeneously distributed over both hemispheres for all stimulus categories. Table 2 shows the \( z \) scores for the interhemispheric differences determined for the P300 amplitude and latency in the two acallosal subjects. The acallosal subject S.G. did not differ from the controls when interhemispheric P300 amplitude differences were considered, regardless of the stimulus categories. The acallosal subject S.Pe., however, who lacks the AC, obtained a larger P300 amplitude in the left than in the right hemisphere, regardless of the site of stimulus presentation. These results are illustrated in Figure 4B and C. Just as in the controls (Figure 4A), the P300 amplitude was homogeneously distributed on both sides of the scalp in the acallosal subject S.G. (Figure 4B). In the acallosal subject S.Pe. without AC, on the other hand, larger P300 amplitudes were observed in the left than in the right hemisphere (Figure 4C). It is noteworthy that these larger P300 amplitude differences were most marked in the posterior part of the scalp.

### DISCUSSION

To begin with, the behavioral results confirmed the validity of our modified visual oddball task. Both the controls and the acallosal subjects obtained slower response times for rare than for frequent stimuli, whereas no differences were observed between experimental subjects and controls with regard to accuracy levels. However, it is noteworthy that the performance of the two acallosal subjects was significantly slower than that of the controls, and this effect was especially marked in the acallosal subject S.Pe. who lacks the AC, regardless of the stimulus categories (frequent or rare). These results corroborate previous studies that have shown that, independently of their intellectual functioning, subjects with callosal agenesis are slower on a variety of psychomotor tasks (Sauerwein, Nolin, & Lassonde, 1994; Lassonde, Sauerwein, McCabe, Laurencelle, & Geoffroy, 1988).

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ens the notion that congenital absence of the CC may result in a slowing of cognitive processing, at least as far as psychomotor functions are concerned.

The N100 component was identified with a maximal peak amplitude over posterior recording sites in the controls and the acallosal subjects. These data are concordant with the findings obtained from scalp dipole localization studies (Gonzalez, Clark, Fan, Luck, & Hilliard, 1994; Towle et al., 1993), work carried out in brain lesioned patients (Knight, 1997) and from intracranial recordings (Arroyo et al., 1997) that all suggest an extrastriate cortical source of the N100 component. In the control subjects, a decreased amplitude and an increased latency were observed in the indirectly stimulated hemisphere. These results are in close agreement with previous electrophysiological studies. The ipsilateral–contralateral N100 amplitude and latency differences in control subjects have been interpreted as reflecting callosal transfer (see Saron & Davidson, 1989, for a review).

The acallosal subject S.G. did not show an N100 component when the ipsilateral hemisphere was being indirectly stimulated. In the acallosal subject S.Pe. who lacks the AC, a large P100–N100 complex was observed in the directly stimulated hemisphere but the P100–N100 complex was not identifiable in the indirectly stimulated hemisphere, and this was true for all stimulus categories. Moreover, the P100–N100 complex was larger in the left responding hemisphere than in the right. The latter result could indicate a possible top–down effect that would reflect the preparation set of the responding left hemisphere when it was directly stimulated. Our results also support the previous finding that the transfer of the N100 component is dependent upon the integrity of the CC (Brown et al., 1998; Satomi et al., 1995; Kutas et al., 1990, Rugg et al., 1985). It is plausible that in the intact brain this transfer would be assumed by the posterior part of the CC, the splenium, which connects extrastriate visual areas.

In the control subjects, no interhemispheric P300 amplitude and latency differences were observed. These results are in accord with the general notion that this late positivity is an endogenous component, which remains independent of the physical characteristics of the stimulation (e.g., the spatial position in the different visual hemifields). In the acallosal subject S.G., no interhemispheric differences were found in P300 amplitude. This suggests that the AC, which is present in this subject, is sufficient to ensure a bilateral distribution of this component. This finding contrasted with the asymmetrical pattern that was observed in the acallosal subject S.Pe, who lacks the AC. In the latter, interhemispheric differences in the P300 amplitude were observed, with a larger P300 being elicited in the left hemisphere when this hemisphere processed the frequent stimuli and controlled the responding hand. Interestingly, when the motor response was eliminated in a complementary study, these interhemispheric differences, which were more pronounced in the posterior region, remained unchanged. Finally, in both acallosal subjects, interhemispheric latency differences were observed. The P300 latencies were earlier in the directly stimulated hemisphere for all stimulus categories, and they were more pronounced in the anterior two thirds of the scalp.

There was thus a dissociation between the P300 amplitude and latency components in the two acallosal subjects with regard to location: Interhemispheric latency differences were observed over anterior sites while interhemispheric differences in amplitude were limited to more posterior regions. In this context, a number of studies have suggested that the P300 could be divided into two subcomponents, the P3a and P3b, which are distributed over the centro-frontal and centro-parietal regions, respectively. It is possible that the differential amplitude and latency results observed in the present study reflect the relative contribution of the two subcomponents, which are presumed to subserve different psychological processes (Comerchero & Polich, 1998; Katayama & Polich, 1998; Courchesne et al., 1975; Squires et al., 1975).

The latency of the P3a subcomponent has been interpreted as reflecting the time taken to classify a stimulus (Polich, 1986; McCarthy & Donchin, 1981; Kutas et al., 1977). The more pronounced interhemispheric differences in the centro-frontal P300 latency observed in the two acallosal subjects may indicate that the P3a subcomponent is produced more anteriorly, an interpretation that is supported by intracranial recordings (Clarke, Halgren, & Chauvel, 1999) and studies in brain-lesioned patients (Knight, 1996), which have underlined the contribution of the frontal areas to the generation of the P3a component. The earlier P300 latencies observed in the directly stimulated hemisphere in the two acallosal subjects could therefore reflect the initial signal evaluation, a process associated with the P3a subcomponent, on which a later cognitive decision is made in posterior cerebral regions.

Donchin et al. (1986) was the first to propose that the more parietaIly distributed P300 subcomponent P3b is cognitively associated with working memory processes, more specifically, memory updating. This interpretation gains support from brain lesion studies (Knight, 1996; Verleger, Heide, Butt, & Kämpf, 1994) and intracranial recordings (Halgren et al., 1997), which have shown that the corticobulbar circuits involving temporo-parietal and hippocampal regions are crucial for the generation of the P3b subcomponent (for a more comprehensive review, see Knight, 1997). Our results indicate that, in the absence of the AC, the larger P300 amplitude observed in the centro-parietal part of the hemisphere (P3b component?) that processes the frequent stimuli may reflect the matching taking place between frequent and rare stimuli (i.e., memory updating). The fact that such differences were not seen in the acallosal subject...
with an intact AC points to the possible role of the AC in the interhemispheric propagation of the P3b subcomponent or, at least, the P300 component. This interpretation is in keeping with the report that a unilateral temporo-parietal lesion is sufficient to abolish the P3b bilaterally, suggesting some kind of interhemispheric synergy in its generation (Knight, Scabini, Woods, & Clayworth, 1989).

In the acallosal subject S.G., the homogeneous distribution of the P300 amplitude over both hemispheres illustrates the potential plasticity of the AC in this subject. By contrast, the interhemispheric P300 amplitude differences seen in the acallosal subject S.Pe. without AC suggest that the subcortical commissures are not sufficient to produce a homogenous distribution of the P300 component. Moreover, our results rule out the “brainstem arousal” theory (Desmedt, 1981) that postulates that the P300 component deflection results in a diffuse bilateral electrical activation from subcortical sources. If this were the case, no interhemispheric differences would be noted in the absence of the CC in terms of either amplitude or latency.

Our data illustrate that the P300 is not a unique phenomenon and that the generators of its subcomponents need to be further explored. Indeed, several cerebral sources seem to be implicated in the generation of the P300 (for a review, see Soltani & Knight, 2000). PET and fMRI studies that have investigated the regional changes evoked by infrequent targets in classical oddball paradigms (McCarthy, Luby, Gore, & Goldman-Rakic, 1997; Stern et al., 1996; Tulving, Markowitsch, Kapur, Habib, & Houle, 1994) report activation in the midfrontal gyri, the hippocampal areas, and the inferior parietal lobule regions. Our own results point to the crucial involvement of other structures in its distribution, such as the CC and the AC.

METHODS

Subjects

Acallosal Subjects

S.G. is a 31-year-old right-handed woman with complete callosal agenesis as revealed by both CT and MRI scans. She was regarded as being asymptomatic except for a slow acquisition of walking, a symptom frequently associated with callosal agenesis. Her callosal agenesis was detected when she agreed to take part into a neuroradiological investigation of her family because of the presence of callosal agenesis in two of her siblings. S.G. has a global IQ of 84 and is presently working as an auxiliary nurse.

S.Pe. is a 33-year-old right-handed man. His MRI shows complete agenesis of the CC and the anterior commissure. At the age of 18 months, a neonatal basal transpalatal encephalocele was surgically removed through a small bifrontal craniotomy, which caused a discrete bilateral prefrontal atrophy. He has a global IQ of 107 and is currently employed as an assistant manager in a drugstore.

Control Subjects

Seventeen neurologically intact young adults (9 women, 8 men, all right-handed, mean age 31 ± 5 years) with no history of pharmacological treatment or neurological disease participated in this study. Seven subjects were eliminated from the analysis due to excessive EEG artifacts, leaving 10 subjects (6 women, 4 men) in the final study.

Electrophysiological Recordings

The EEG was recorded from 62 tin electrodes mounted in a cap (Electro-cap International). The electrodes were placed according to the guidelines for standard electrode positions at Fp1, Fp2, Af7, Af3, Afz, Af4, Af8, F7, F5, F3, F1, Fz, F2, F4, F6, F8, F7, Fc5, Fc3, Fc1, Fcz, Fc2, Fc4, Fc6, F8, T7, C5, G3, C1, Cz, C2, C4, C6, T8, Tp7, Ctp, O1, Oz, and O2 sites, referred to linked earlobes, with a forehead ground and impedance kept below 5 kΩ. The electrooculogram (EOG) was recorded using four tin electrodes with a diameter of 6 mm placed at the outer canthus of each eye for horizontal EOG and infra- and supraorbitally to the right eye for vertical EOG, in line with the pupil when looking straight ahead. The EEG was averaged time-locked to the stimulus and corrected for EOG artifacts by a dynamic regression analysis in the frequency domain (InstEP-TALO; Woestenburg, Verbaten, & Slangen, 1983). A bioelectric analog amplifier model ISS-32BA (SAI-InstEP), amplified the EEG signals (gain = 3500 for the EOG and 10,000 for the EEG) with a bandpass between 0.02 and 100 Hz and was digitized continuously at a sampling rate of 250 Hz, 4 msec/point for 2048 msec. Remaining trials with artifacts exceeding ±100 μV were excluded from the analysis in all channels. Waveforms were averaged offline, using the INSTEP software system for 850 msec including a 100-msec prestimulus baseline period and were low-filtered below 30 Hz (3 dB octave/slope).

Experimental sessions were held in a sound-attenuated, dimly lit, electrically shielded room. The stimuli were presented on a monitor located 85 cm from the subject’s eyes; a chin rest assured that this distance remained constant. A closed-circuit video system allowed monitoring of the subject’s position and eye fixation.

Stimuli and Tasks

ERPs were elicited using a modified oddball task comprising a total of 160 stimuli presented on a computer monitor for a duration of 400 msec, with an interstimulus
interval varying randomly between 2200 and 2800 msec. The stimuli, presented on a black background, consisted of three different locations of the same stimulus (a gray circle of a diameter of 6.7° at the fixation point), with unequal probabilities of appearance. The stimuli were defined as “frequent,” “rare inter,” or “rare intra” and presented with probabilities of .70, .15, and .15, respectively. As illustrated in Figure 1, the frequent stimulus was positioned in the inferior right corner of the monitor, the rare intra in the superior right corner, and the rare inter in the superior left corner. The subjects were instructed to press a left key with the right index at the presentation of the frequent stimuli and a right key with the right middle finger upon presentation of the rare stimuli, independently of the visual hemifield. Thus, only the rare inter stimuli, presented in the left visual hemifield (right hemisphere) required an interhemispheric transfer since the motor response was effected by the right hand (controlled by the left hemisphere). Stimulus presentation and data collection were controlled by an InstEP system.

**Data Analysis**

**ERP Component Identification**

Averaged ERPs were derived from each recording site for each subject. The amplitude was measured relative to the mean of the prestimulus baseline. Latency was defined as the time point of maximum positive or negative amplitude within the latency window. Hence, the N100 component was defined as the negative-going peak within the latency window of 80–230 msec poststimulus. However, the N100 component was not always identifiable in some controls at the anterior electrode sites (Af, F, and Fc lines). Thus, only the central and posterior recording sites were retained for the analyses of the N100 component. The P300 component was defined as the positive-going peak within a latency window of 300–500 msec. Because of ocular artifacts at Af7, Af8, Af3, Af4, and Af recording sites, these five anterofrontal electrodes were not included in the P300 analyses.

In the 10 control subjects retained for the analysis, the percentage of trials rejected was 5% for all stimulus categories (frequent = 5/110, range = 0–18/110; rare intra = 24/25, range = 0–3/25; rare inter = 24/25, range = 0–6/25). In the acallosal subject S.Pe. lacking the AC, this percentage was also 5% (frequent = 8/110; rare intra = 0/25; rare inter = 2/25); in the acallosal subject S.G., this percentage was 4% (frequent = 1/110; rare intra = 2/25; rare inter = 1/25).

**Statistical Procedure**

All results pertaining to the behavioral and electrophysiological data of the 10 control subjects were submitted to an analysis of variance (SPSS Windows) and employed Greenhouse–Geisser corrections to the degrees of freedom. Contrast methods were used for post hoc comparisons, with a significance level of .05.

For the controls, the behavioral data (response times, accuracy level, and electrophysiological data) linked to the oddball effect were assessed in a one-way (three stimulus categories) analysis of variance as a function of all averaged recording sites.

Although the oddball effects (frequent vs. rare presentations) were derived from all recording sites, interhemispheric latency and amplitude analyses were only performed on the more lateral recording sites because the lateral scalp positions allowed for clear interhemispheric comparisons. For each pair of lateral recording sites, values from the right hemisphere were subtracted from values obtained in the left hemisphere. Consequently, amplitude and latency values were computed for the following comparisons: Po7–Po8, P7–P8, Tp7–Tp8, T7–T8, F7–F8, F7–F8. Hemispheric latency and amplitude analyses were examined using repeated two-factor (3 stimulus categories [S: frequent, rare intra, or rare inter] × 2 electrode sites [E: right and left]) analyses of variance.

Behavioral and electrophysiological data of the two acallosal subjects were compared to those of the controls by calculating z scores on their performance. A z score deviation higher than 2 (more than two standard deviations above the mean) was considered to be significant. Because of this last statistic, a Shapiro–Wilk test was applied to explore the hypothesis of the normal distribution for the controls behavioral and electrophysiological data.

**Electrophysiological Data Illustration**

Electrophysiological data are illustrated in two ways: First, considering the high-density electrical mapping of this study and a concern for clarity, averaged ERP waveforms that illustrate the principal phenomena are reported. The waveforms were fitted by eye with a commercial curve fit software (Jandel Scientific: Table Curve 2D). The optimal chosen curve fit had a strong correlation ($r > .9$) with the data points. Second, the P300 component mean voltage (µV) distribution for all electrodes is illustrated by means of two-dimensional topographical maps obtained with the StatMap program (DigiMed Systems) compatible with the InstEP recording system.

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