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Prosopagnosia and structural encoding of faces: Evidence from event-related potentials

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EVENT-RELATED brain potentials (ERPs) were recorded in response to unfamiliar faces and to houses from a severely prosopagnosic patient (PHD) and 24 control subjects. For all control subjects, faces elicited an enhanced negativity at lateral temporal electrodes (N170). This component was absent for PHD. Comparable results were obtained in response to inverted faces and houses. A selective deficit in face recognition is therefore reflected by abnormalities in ERP components specific to faces. As PHD was shown to have substantial deficits on tasks requiring the structural analysis of faces, these findings are consistent with the view that the N170 reflects processes involved in the structural encoding of faces, and may be a measure of selective impairments in the analysis of face components. *NeuroReport* **10:255–259**

Key words: Event-related potential (ERP); Faces; Fusiform gyrus; Prosopagnosia; Temporal lobe; Visual

Introduction

In prosopagnosia, face recognition is disproportionally affected, compared with the recognition of other stimulus classes. In the most extreme cases, object recognition capabilities seem entirely spared [1]. Prosopagnosic patients can be highly efficient in identifying specific cars [2] or individual animals [3,4]. More often, they are impaired in recognizing other object classes, such as animals, clothing, foodstuffs [5], plants [6] or buildings [3]. Other agnosic patients are more impaired in object recognition than in recognizing faces [7]. Double dissociations between face and object recognition suggest that they are based on distinct capacities and brain mechanisms [8]. Impaired face recognition in prosopagnosia may be caused by damage to processes involved in the structural encoding of face stimuli and/or by a selective impairment of facial recognition despite intact structural encoding mechanisms. The study of event-related brain potentials (ERP) specific to faces may help to distinguish component processes specific to face perception and their impairment in prosopagnosia. Previous studies have found that faces elicit a negativity at lateral temporal sites (N170) [9–11]. It has been argued [10] that the N170 is related to the encoding of face components, most notably the eyes. While it is unlikely that the N170 primarily reflects eye detection [12], the finding that this component is not affected by face familiarity [13] suggests that the N170 is associated with structural encoding processes prior to face identification. The attenuation or absence of the N170 component in prosopagnosia would be consistent with an impairment of the cerebral systems required for the structural processing of faces. In the present experiment, ERPs elicited by unfamiliar faces and non-face stimuli in a prosopagnosic patient (PHD) were compared to ERPs elicited by the same stimuli in 24 control subjects.

Subjects and Methods

PHD: PHD is a 39-year-old left-handed man who sustained a closed head injury in a road traffic accident in 1977 and has significant cognitive deficits including some visual agnosia and prosopagnosia. He is not amnesic, but complains of persistent difficulties in recognizing people, problems in reading and writing and he also makes errors in recognising common animals, fruits and vegetables. PHD shows substantial prosopagnosic deficits in everyday life, often failing to recognize highly familiar faces including those of his mother and partner. He appears to find context helpful in recognizing people and he also makes use of cues such as the sound of a voice or the style of clothes. On examination no sensory or motor deficits were noted; his visual fields were full. MRI scanning showed moderate diffuse damage with an area of more focal injury in the left temporo-parietal region. He has good spatial perception and spatial thinking: on the visual object and space perception battery (VOSP) [14] he scored 20/20 on position discrimination, 10/10 on cube

analysis and 20/20 on dot location. His identification of fragmented letters was also normal (20/20), he had no difficulty in identifying objects photographed from unusual views (17/20), and was within the normal range on the VOSP object decision test (17/20). He scored 16/20 on the Whitely and Warrington matching tests of same/different buildings and same/different countrysides [15], which is at the lower end of the control subjects' range. His prosopagnosia was formally documented. He was very impaired on the Benton and Van Allen test of face matching [16] scoring no better than at chance (3/25). On the McNeil and Warrington face perception battery [17] he scored 60% and 80% in judging the age of faces (just below the score of the worst control); 22/30 in discriminating male from female faces (also below the level of controls). On tests of face memory PHD was at chance on tests requiring him to learn and recognise pictures of unfamiliar faces (Warrington recognition memory test [18] for faces: 27/50). He was also very poor in recognizing familiar famous faces. His knowledge of people accessed from their faces or from their names was directly compared using 56 items [19]. PHD was significantly worse than controls in recognising people from their portraits (16.98% $z = -4.15$; $p < 0.001$). It was notable that he failed on a number of easy items such as Marilyn Monroe and John F. Kennedy. In contrast, he was within the normal range in providing information about people from their names (73.58% $z = -1.51$) indicating that his deficit is particular to faces. PHD appears to have a prosopagnosia affecting both levels of the face recognition system. He is impaired in the structural and perceptual analysis of faces and is also impaired in recognizing and identifying familiar faces.

Stimuli and procedure: All subjects were seated in a dimly lit cabin, with response buttons under their left and right hands. Stimuli were photographs of unfamiliar faces and houses that were presented centrally on a computer monitor in front of a white background. Sixteen images of houses and 16 face images (eight male, eight female) were used. Stimuli were presented for 100 ms, separated by intertrial intervals of 1300 ms, and occupied a visual angle of about $3 \times 4.5°$. The experiment consisted of eight successive blocks. Faces and houses were shown in random sequence, and subjects had to respond with a left-hand or right-hand response whenever a stimulus of a given category (faces or houses) was immediately repeated on successive trials. The relevant category and response were varied between blocks. Within each block, 20 immediate stimulus repetitions occurred, with an average of 10 repetitions for the relevant category. Non-repeated faces and houses each appeared on 40 trials, resulting in a total of 100 trials per block. Practice blocks of 40 trials were delivered prior to the experiment.

ERP recording and data analysis: Recordings were made from Ag-AgCl electrodes at Fz, Cz, Pz, T5, O1, T6 and O2, referenced to an electrode positioned on the tip of the nose. Horizontal EOG was recorded from electrodes at the outer canthi of both eyes; vertical EOG was recorded from electrodes above and below the right eye. Impedance was kept below 5 kΩ. Amplifier bandpass was 0.10–40 Hz. EEG and EOG were sampled with a digitization rate of 200 Hz. ERP analyses were restricted to non-repetition trials. Trials with eyeblinks, lateral eye movements or overt responses were excluded. Repeated measures analyses of variance (ANOVAs) were performed on ERP mean amplitudes obtained from the control subjects at lateral posterior electrodes measured relative to a 100 ms pre-stimulus baseline between 140 ms and 180 ms post-stimulus intervals for the within-subject variables of stimulus type (face *vs* house) and recording hemisphere (left *vs* right).

Results

Behavioural performance: For the control subjects, mean response times (RTs) were 489 ms and 490 ms to face targets and house targets, respectively. They missed 2.8% of the targets, and responded in $< 0.4\%$ of all non-repetition trials. Their performance did not differ significantly for faces and houses. For patient PHD, mean RTs to face and house targets were 655 ms and 604 ms, respectively. In blocks where repeated faces had to be detected, he missed 30% of all targets and responded incorrectly in 42.6% of non-repetition face trials. In blocks where repeated houses had to be detected, he missed 35% of all targets and responded incorrectly in 31.2% of non-repetition house trials. However, he never responded to faces or houses in blocks where the other stimulus category was relevant.

ERPs: For the control subjects, a face-specific N170 effect was elicited at lateral temporal electrodes T5 and T6 (Fig. 1, middle). The N170 component is visible in the faces–houses difference waveforms (Fig. 1, bottom), and was reflected in an effect of stimulus type on ERP mean amplitudes in the 140–180 ms post-stimulus time interval ($F(1,23) = 139.1$, $p < 0.001$) that was accompanied by a stimulus type × recording hemisphere interaction ($F(1,23) = 5.28$; $p < 0.031$), indicating that this effect was larger at T6 than at T5. Without exception, all 24 controls showed an enhanced N170 to

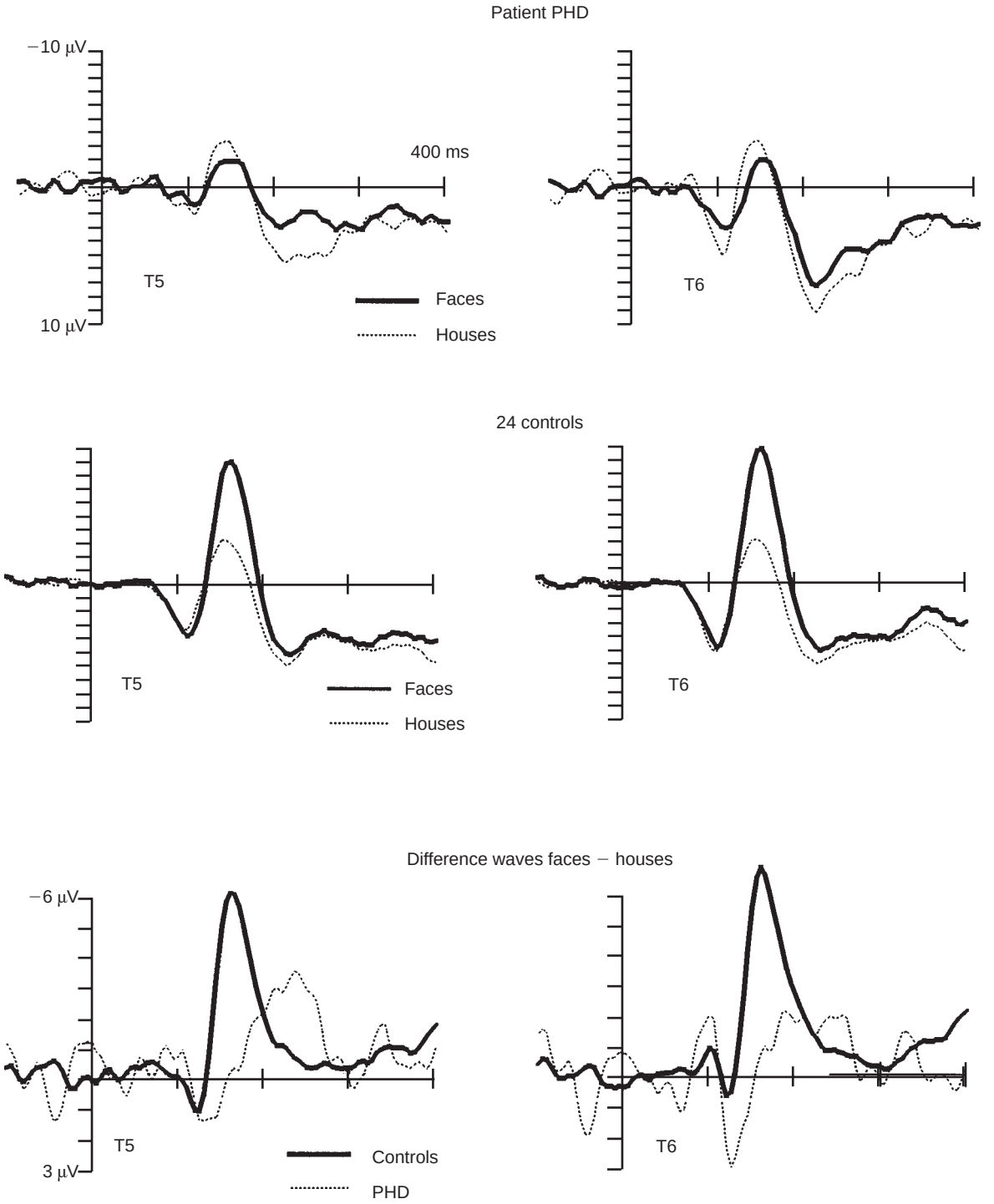

FIG. 1. ERP waveforms at lateral temporal electrodes in response to faces (thick solid lines) and houses (dashed lines) for patient PHD (top) and grand-averaged ERPs from 24 control subjects (middle) plus the resulting faces–houses difference waveforms (bottom).

faces as compared to houses at T5 and T6. The distribution across subjects of the size of this effect (quantified as mean faces–houses difference amplitudes in the 140–180 ms post-stimulus interval, collapsed over T5 and T6) is shown in Fig. 2 (top). Effect size ranged from −1.7 μV to −12.2 μV (average −5.5 μV).

In marked contrast to the highly consistent face-specific N170 effect seen in control subjects, no such effect was observed for patient PHD in the N170 time range (Fig. 1, top and bottom). The mean faces–houses difference amplitude was +0.2 μV at T5 and −0.3 μV at T6. To study whether visual-evoked ERP components were generally attenuated

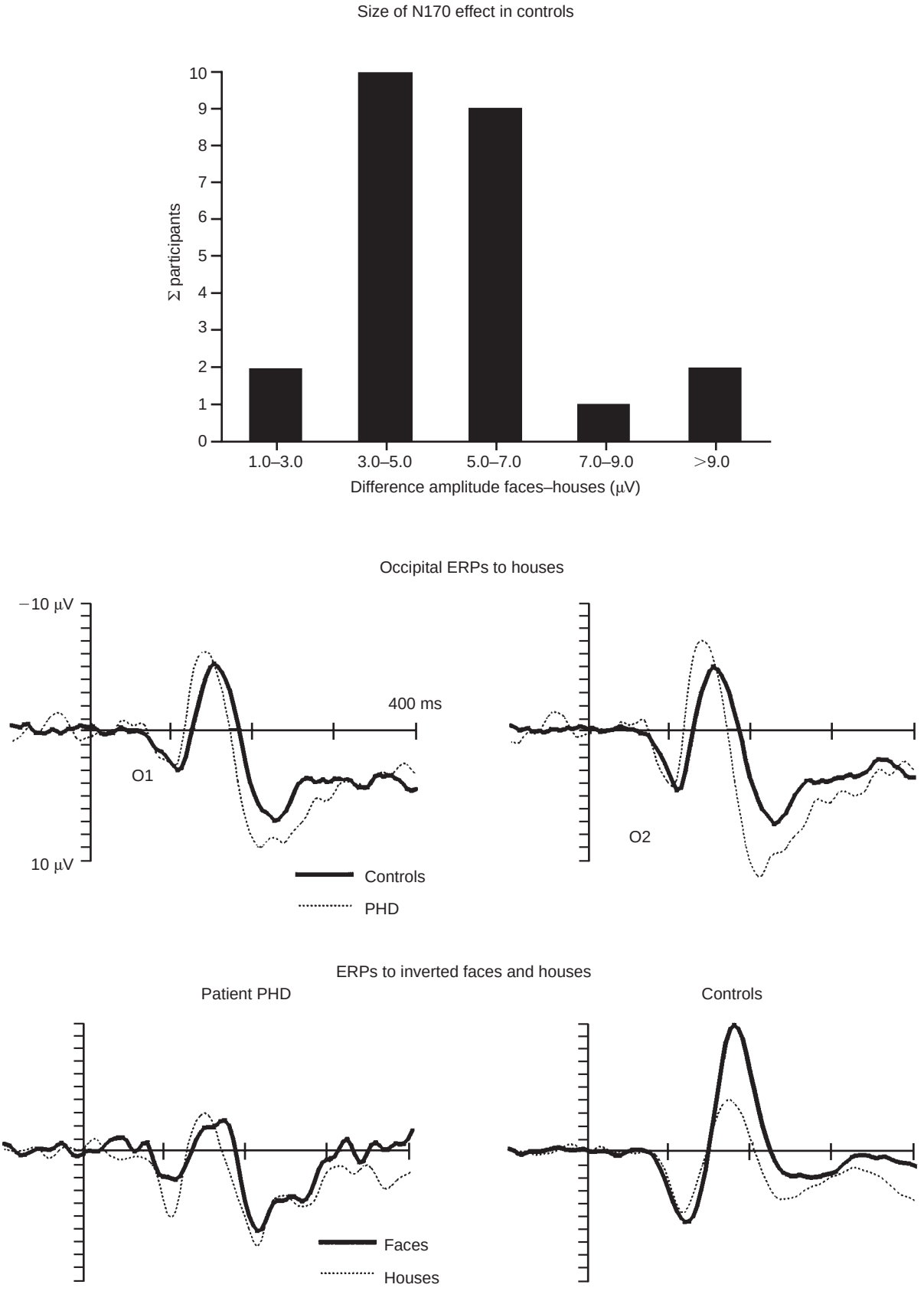

FIG. 2. Top: Distribution of the absolute size of the N170 effect across control subjects. Middle: ERPs at lateral occipital electrodes in response to houses for the control subjects (thick solid lines) and patient PHD (dashed lines). Bottom: ERPs obtained at right lateral temporal electrode T6 in response to inverted faces (thick solid lines) and inverted houses (dashed lines) for patient PHD (left) and grand-averaged ERPs obtained from 12 control subjects (right).

in PHD, ERPs recorded in response to houses at lateral occipital electrodes O1 and O2 were compared to grand-averaged ERPs from the control subjects. Amplitudes and latencies of occipital P1, N1, and P2 components were very similar for PHD and the controls (Fig. 2, bottom).

In a separate session, PHD was presented with a random series of inverted faces and houses and had to detect immediate stimulus repetitions. In Fig. 2 (bottom), the resulting ERPs at right lateral temporal electrode T6 are compared with ERPs recorded at T6 from twelve control subjects under the same conditions. While an enhanced N170 was elicited by inverted faces for controls, confirming previous results [10], no such effect was found for PHD.

Discussion

Face-specific ERP effects were measured by comparing ERPs elicited by faces and houses in 24 control subjects and in a prosopagnosic patient (PHD). PHD showed substantial deficits in target detection performance. RTs were slower and False Alarm rates higher for faces than for houses, although performance deficits were clearly present for both stimulus categories. The high error rates in response to faces as well as houses may in part reflect the temporal demands on identification and response selection caused by fast presentation rates and short stimulus durations. The fact that PHD never responded to items of one category in blocks where the other category was relevant indicates that between-category discrimination was intact. The face-specific ERP modulations observed for the control subjects confirmed previous findings [9–13]. Faces elicited an enhanced lateral temporal N170 that was larger over the right hemisphere. The presence of a face-specific N170 is a remarkably reliable effect that was found in all 24 control subjects. However, no such effect was observed for PHD. With inverted faces and houses, the N170 effect was again clearly present for control subjects, and absent for PHD. The lack of a face-specific N170 component in PHD is unlikely to be due to a general attenuation of visual ERPs related to his brain damage. The latencies and amplitudes of visual-evoked ERPs at occipital electrodes in response to houses were similar for PHD and control subjects. Consistent with this, PHD's documented ability to recognise buildings in a matching test also suggests a relative sparing of the perceptual analysis of houses.

If the N170 component is an electrophysiological index of structural encoding of faces, its absence in PHD suggests that his impairment in face recognition is at least in part caused by deficits prior to face identification. Further ERP evidence needs to be collected from patients with deficits specific to the recognition of familiar faces (prosopamnesics). Intact structural encoding in these patients should be reflected by the presence of face-specific N170 effects. ERPs may thus be used as markers for the selective impairment of component processes involved in face perception and identification.

Conclusion

Face-specific N170 components were consistently elicited in 24 control subjects, but were absent in prosopagnosic patient PHD. As the N170 is assumed to be related to the structural encoding of faces, its absence may help to locate a primary source of face-specific performance deficits in PHD prior to face recognition.

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