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Visual stimuli modulate frontal oscillatory rhythms in a cortically blind patient: Evidence for top-down visual processing

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HIGHLIGHTS

- Faces and scrambled faces led to different brain oscillation patterns in a blindsight patient.
- Incorrect responses led to a frontal midline theta rhythm in this patient.
- The results support the presence of an alternative pathway for visual processing in blindsight.

ABSTRACT

Objective: We investigated neuronal correlates of faces versus non-faces processing in a cortically blind patient (TN) and a group of healthy age-matched controls in order to test electrophysiological correlates of the processing of pertinent stimuli in this patient.
Methods: An EEG paradigm was used, in which intact and scrambled faces were displayed on a screen. First, time-frequency transforms were conducted on the patients' data alone. These oscillations were then compared to the frontal activity of six control participants.
Results: Post stimulus oscillatory modulations (synchronisation in theta and alpha frequency bands) of both intact and scrambled faces at frontal scalp sites were observed in TN. These modulations were different for correct and incorrect responses. A more important increase in the theta band for incorrect responses was observed. The oscillatory rhythms highlighted in blindsight and in frontal regions differ from the ones observed in control participants.
Conclusion: Despite the destruction of the visual cortex, oscillatory rhythms are not cancelled out but are shifted to anterior regions, revealing the activity of an alternate pathway for residual visual function.
Significance: The results provide evidence for a top-down cognitive control process in blindsight.

1. Introduction

Faces are among the most relevant stimuli for humans (Itier and Taylor, 2004). The processing of this type of stimuli has been linked to the occipito-temporal network in an fMRI study (Rossion et al., 2003) and to frontal activations in terms of face-selective responses in the macaque (Scalaidhe et al., 1997). A spreading effect of emotional face perception from occipital and temporal to frontal regions has been reported in epileptic patients implanted with depth electrodes (Krolak-Salmon et al., 2004). Localisation studies using fMRI have shown that a region in the extrastriate cortex is more active for faces than other objects (Kanwisher et al., 1997; Rhodes et al., 2004). This region has consequently been labelled the *fusiform face area* (FFA) in order to emphasise its face specificity (Kanwisher et al., 1997). Studies addressing the dynamics of face processing with electrophysiological techniques have shown that faces elicit a specific early component, the N170, which appears at around 170 ms and is characterised as a negativity over the posterior temporal region (e.g. Bentin et al., 1996).

More recently, the extent of processing carried out by the non-striate visual pathway has received much attention. This pathway, involving the superior colliculus, the pulvinar and the amygdala, is

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hypothesised to be responsible for the processing of visual information when the visual cortex is damaged, such as for example in the case of blindsight (Weiskrantz, 1986). Blindsight, a condition in which the striate cortex (V1) is damaged resulting in cortical blindness, has been described in certain patients. Patients presenting this condition have shown to be able to discriminate visual features, such as motion direction or orientation (Weiskrantz et al., 1995). These observations were first made on more elementary features, such as light spots that were presented in the blind field, subsequently raising the question of whether higher level representations could use this alternate route as well. Interestingly, stimuli conveying emotional information, including faces and bodies, seem to represent a specific category that is processed in blindsight patients (Van den Stock et al., 2014), which has led to the term "affective blindsight". In an initial study, de Gelder et al. (1999) showed that a patient was able to guess above chance level the expression of emotional faces, even though he was unaware of the presence of the stimulus. Another study on a patient (TN) with bilateral V1 destruction (Pegna et al., 2005) showed that emotionally expressive faces elicited brain responses, notably in the right amygdala. This finding is not altogether surprising, as the amygdala is known to be associated with the processing of relevant stimuli in the healthy human brain (Sander et al., 2003), highlighting the evolutionary advantage in processing relevant stimuli. In support of this evolutionary trace, responses to faces and emotional faces have been observed as early as 50–90 ms and 100–130 ms respectively and lasting until 200 ms in surface (e.g. Linkenkaer-Hansena et al., 1998) as well as in intracranial ERP recordings in healthy subjects (e.g. Seeck et al., 1997; Krolak-Salmon et al., 2004). There is also recent interesting evidence of face cells in the pulvinar (Maior et al., 2010) and the superior colliculus (Nguyen et al., 2014), suggesting specific activations for faces beyond the classical striate pathway.

Over the past years, the study of cognitive processes has been widely linked to oscillations modulated by different types of stimuli in the human brain. The frequency content of electro- or magneto-encephalography measures provides key information about oscillations and has been divided in low (delta range, <3 Hz; theta range, 4–7 Hz), mid (alpha range, 8–12 Hz; beta range, 15–25 Hz) and high (gamma range, 30–120 Hz) frequencies (Tallon-Baudry, 2009). In patient TN, mentioned above and who suffered from bilateral cortical blindness, alpha and beta oscillations in frontal regions were observed for fearful and happy face processing between 100 and 400 ms post-stimulus (Del Zotto et al., 2013). Another hemianopic patient (GY) showed induced-gamma band oscillations linked to stimulus awareness (Schurger et al., 2006). However, overall, there is little evidence on the modulation of oscillatory activity by visual or cognitive tasks in blindsight.

Consequently, the general aim of this study was to explore the electrophysiological correlates of processing of relevant stimuli in the human brain, using time-frequency decompositions. Particularly, we aimed to identify the manifestation of unconscious processing in a blindsight patient, and compare it to healthy controls. Since it has been shown that blindsight patients may process visual stimuli in the absence of a functional visual cortex, we questioned the electrophysiological correlates of these residual visual capacities. Our aim was to extend the results observed by Del Zotto et al. (2013) in frontal regions to the processing of faces, independently of (facial) emotional expressions.

Three research questions guided our analyses. Firstly, we wanted to determine the presence of a potential oscillatory response to visual stimuli in general, i.e., independently of the stimulus in TN. We expect a modulation of the post-stimulus oscillatory pattern following visual stimuli in this patient. The presence of a specific activation in one of the explored frequency bands would reflect the activity of an alternate pathway for visual processing when the visual cortex is not accessible. In this study, post-stimulus activations were explored over frontal regions in three frequency bands (theta, alpha, and beta). As gamma frequencies have been linked to visual awareness, this frequency was not investigated in patient TN, whose vision lacks the subjective qualia associated with conscious seeing. Moreover, this frequency has been shown to appear following involuntary micro eye movements (Yuval-Greenberg et al., 2008) which have not been controlled in TN during the experiment. Finally, the computation of the wavelet coefficients for lower (delta) frequency uses such a large interval of values that the values obtained are probably too much influenced by pre-stimulus values and by the border conditions of the wavelet transform (Misiti et al., 2016). We thus did not treat the delta band.

The second aim was to investigate whether these modulations were distinct as a function of stimulus category (faces/scrambled faces) and accuracy (correct/incorrect responses) in TN. This analysis would reflect behavioural performance in this patient. The pattern of oscillations for the three different frequencies (theta, alpha, beta) associated with (1) faces (vs scrambled faces) and (2) correct (vs incorrect) responses were analysed.

Finally, in order to obtain more information about the time course of brain activations, we then decided to compare the post-stimulus period between TN and the control participants. In an fMRI study, Van den Stock et al. (2014) showed that the amygdala and the superior temporal sulcus were activated during the passive viewing of faces in the same patient (TN). Therefore, this approach would allow us to test whether TN was different from the control participants.

2. Materials and method

2.1. Participants

TN was a 52 year-old male patient when he suffered from two consecutive strokes in his left and right visual cortices within 36 days of each other. The MRI scans performed at that time are shown in Fig. S1 of the Supplementary Material 1. The left hemisphere stroke affected the parietotemporo-occipital cerebral area including the inferior parietal region, the left inferior/medial/superior occipital areas, the calcarine sulcus and the fusiform gyrus whilst the subsequent stroke damaged the inferior and medial occipital areas, the calcarine sulcus and the fusiform gyrus. After the first stroke, TN presented with right hemiplegia and transcortical sensory aphasia, which receded rapidly but left him with a persistent right hemianopia. The second stroke caused a loss of the remaining left visual half field.

A neuropsychological assessment performed 2 months after the second stroke showed no cognitive impairment except for slight word-finding difficulties. He was clinically blind and unable to detect movement, colours, or geometrical shapes. He complained of a sensation of complete darkness and was subjectively never aware of any visual stimulation.

At the time of testing, he was 60 years of age and remained unable to detect any visual stimulus. He claimed that he could occasionally detect that "something had happened" when visually stimulated, but this was not confirmed when he was asked to detect the presence or absence of a strong light source or its motion. The presentation of the stimuli on the computer screen was not associated with any systematic awareness of stimulation and TN stated that he could not see when a stimulus appeared. His case history has been reported extensively elsewhere (Pegna et al., 2005; de Gelder et al., 2008; Buetti et al., 2013; Burra et al., 2013). In addition, 8 age-matched men (mean age = 64 years, SD = 2.5) participated as controls in this study. Controls were right-