Introduction

Combined simultaneous EEG-fMRI has a time and space resolution optimal to disentangle the complex processes of early visual perception. Previous studies demonstrated the feasibility of recording ERPs to centrally presented checkerboards inside the scanner (Becker et al., 2005; Bonmassar et al., 2003). Many cognitive applications with a need for combined EEG-fMRI recordings, e.g. spatial attention studies, use peripheral stimuli (Martinez et al., 1999). Spatial location is the most obvious manipulation of peripheral visual stimuli in ERP as well as fMRI studies (Di Russo et al., 2002). In order to combine EEG and fMRI data we evaluate a new integration-by-prediction technique technique that is a variant of existing models (Bénar et al.; 2007; Deeben et al., 2006; Eichele et al., 2009). This technique uses individual ERP peak amplitudes to retrospectively predict the location of the stimulus and introduces this stimulus-blind information into fMRI analysis.

Methods

The stimuli were segments of a circular checkerboard in each of 4 quadrants of the screen and a full central checkerboard. Stimulus-onset asynchrony (SOA) varied randomly from 1 to 2.5 sec in 100 ms steps (Fig.1). The participants were instructed to fixate at the cross in the center of the screen and to press a button upon detecting a checkerboard. Experiments were performed in a Philips 3T Intera whole-body scanner. 64-channel EEG was recorded at 5 kHz digitization rate with BrainProducts hardware and software (Munich, Germany). The amplifiers were positioned inside the scanner bore and the digitized data were transmitted outside the scanner via an optical cable. The gradient artifacts was removed from the EEG with a combination of average artifact subtraction method and low-pass filtering (Allen et al., 2003). Ballistocardiogram artifact was removed with the so-called optimal-basis set method (Niazy et al., 2005) and subsequent ICA. This combination has been shown to yield optimal results (Deeben et al., 2008, Vandersporen et al., 2010).

Two types of event-locked regressors were used in fMRI analysis: with a stick function at the onset of the stimulus as in traditional event-related fMRI and with an amplitude from individual ERP sweep at the onset of the stimulus, resulting in so-called integration-by-prediction analysis. The ERP regressors (predictors) were created as follows (Fig. 2):

1) Single-trial ERPs were averaged across 5 occipital channels in each hemisphere
2) the amplitude was measured in a pre-defined window for P1 and N1
3) the right-hemisphere amplitude was subtracted from the left-hemisphere amplitude to produce a single value for each trial for both ERP components
4) the positive values and the absolute values of negative values were separated in two vectors for each ERP component (P1 and N1); Gram–Schmidt orthogonalization was performed for the pairs negative P1 – positive N1 and positive P1 – negative N1
5) all 4 regressors were convolved with a canonical HRF
6) and included in one general linear model (GLM) design

Results

In the resulting ERPs we were mostly interested in the P1 with an average latency of 108 ms and the N1 that occurs around 189 ms after stimulus onset. The amplitude of the P1 differed between the right and left visual field and the amplitude of the P1 to the stimulus in the right visual field were larger in the contralateral than in the ipsilateral hemisphere (Fig. 3 A-B).

Stick-function-based event-related fMRI analysis produced strong activations in the occipital cortex. Contracting each quadrant stimulus against the sum of the rest of the peripheral stimuli produced activations in vicinity of calcarine sulcus opposite to the stimulus location along both vertical and horizontal axis (e.g., upper right stimulus – lower left activation). Right visual field stimuli results are shown at Fig 3 C.

Positive values of the amplitude difference between the left and right hemispheres at P1 latency correlated with left middle occipital gyrus (BA 37), left middle temporal gyrus (BA 19), left fusiform gyrus (BA 19 and 37), as well as with the left, inferior parietal lobule, left medial frontal gyrus, left postcentral gyrus, left precentral gyrus, thalamus, brainstem, and bilateral cerebellum. Negative values of the amplitude difference between the left and right hemispheres at P1 latency correlated with the right middle occipital gyrus (BA 37), left medial frontal gyrus (BA 6), and left precentral gyrus (BA 4).

Negative values of the amplitude difference between the left and right hemispheres at N1 latency correlated with the left middle temporal gyrus (BA 39), left medial frontal gyrus (BA 6), left precentral gyrus (BA 4), as well as with thalamus and brainstem. Positive values of the amplitude difference between the left and right hemispheres at N1 latency correlated with the right middle temporal gyrus (BA 39), left medial frontal gyrus (BA 6), and left precentral gyrus (BA 6 and 4) (Fig. 4).

Conclusions

We have recorded ERPs to peripheral visual stimuli inside the scanner, thus expanding earlier works on simultaneous EEG-fMRI of early visual processing (Becker et al., 2005; Bonmassar et al., 2001). Our results revealed that the traditional event-related fMRI analysis produced mostly activations in the vicinity of the primary visual cortex and in the ventral visual stream, while both P1 and N1 regressors activated areas in the dorsal stream.

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References