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Sound level dependence of auditory evoked potentials: Simultaneous EEG recording and low-noise fMRI

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Abstract

The simultaneous recording of EEG and fMRI offers the advantage of combining precise spatial information about neuronal processing obtained by fMRI data with the high temporal resolution of EEG data. One problem for the analysis of auditory processing, however, is the noisy environment during fMRI measurements, especially when EPI sequences are employed.

While EEG studies outside an MRI scanner repeatedly demonstrated a clear sound level-dependent increase of N1 amplitude, this finding was less obvious in simultaneous recordings inside a scanner. Based on the assumption that this inconsistency might be due to the confounding effect of the rather loud EPI noise, we employed a low-noise fMRI protocol. This method was previously used to reveal level-dependent fMRI activation in auditory cortex areas. We combined this method with simultaneous EEG recordings to investigate the effect of different sound intensities on the auditory evoked potentials.

Eight participants without hearing deficits took part in our experiment. Frequency modulated tones (FM) were presented monaurally with two sound intensities (60 and 80 dB HL). The task of the participants was to categorize the FM-direction (rising vs. falling).

Our results inside the scanner replicate the sound level dependence of AEPs from previous EEG studies outside the scanner. The data analysis revealed a significant shortening of N1 latency and an increase in the N1–P2 peak-to-peak amplitude for the higher sound intensity. On a descriptive level, the 80 dB HL stimulation yielded more activated voxels in fMRI and stronger activations. This effect was pronounced over the right hemisphere.

Our results suggest that low-noise sequences might be advantageous for the examination of auditory processing in simultaneous EEG and fMRI recordings.

Keywords: EEG; Low-noise fMRI; Simultaneous; AEPs; Loudness; Sound intensity

1. Introduction

Changes in the blood oxygenation level-dependent (BOLD) signal measured with functional magnetic resonance imaging (fMRI) allow excellent spatial localization of metabolic responses induced by neuronal activation, but the temporal resolution is rather low. Conversely, the electroencephalogram (EEG) offers a fine temporal resolution, since it is a direct consequence of the neuronal activity, but provides limited spatial information. The combination of both techniques allows an improved localization of neuronal generators of different event-related components, as well as enhanced temporal resolution of BOLD activation foci or even the trial-by-trial correlation of EEG and BOLD (Debener et al., 2006).

Regarding the advantages of each method, most research groups try to combine EEG and fMRI data from separate studies. A disadvantage of this approach is the potentially different vigilance and attentional state of the participants across the two experiments which would need to be controlled for by counter-balancing the order of measurements (Liebenthal et al., 2003). Another variable which possibly affects neuronal processing is the familiarity with the task, which can differ between two separate sessions (Mulert et al., 2004). This is especially true if

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learning effects are the focus of interest. Probably the major drawback of separate recordings is the lacking possibility to correlate EEG and BOLD responses in a trial-by-trial fashion (Debener et al., 2006).

Although simultaneous recording avoids the abovementioned disadvantages, a couple of technical problems appear, such as EEG artifacts induced by gradient switching and motion artifacts linked to the heartbeat. Many research groups have dealt with these problems and have attempted to find appropriate correction algorithms (Allen et al., 1998, 2000; Bonmassar et al., 2002; Debener et al., 2007; Ellingson et al., 2004; Garreffa et al., 2003; Niazy et al., 2005; Sijbers et al., 2000; Srivastava et al., 2005). Although most algorithms are not able to completely eliminate all artifacts, it is possible to obtain reasonable EEG quality from simultaneous measurements. This has been shown for signals with high amplitudes which are visible in raw EEG, like alpha activity (Goldman et al., 2002; Laufs et al., 2003; Moosmann et al., 2003) and epileptic spikes (Krakow et al., 1999; Lazeyras et al., 2000; Seeck et al., 1998; Symms et al., 1999; Warach et al., 1996).

Since the feasibility of obtaining event-related potentials (ERPs) during fMRI had been demonstrated in principle (Bonmassar et al., 1999; Kruggel et al., 2000), a number of studies employed simultaneous recordings to investigate visual processing (Comi et al., 2005; Kruggel et al., 2001; Müller et al., 2005; Sammer et al., 2005). However, only few studies focused on activity resulting from auditory processing (Ellingson et al., 2001; Scarff et al., 2004b), since one problem for the analysis of auditory processing is the noisy environment during fMRI measurements, especially when echo planar imaging (EPI) sequences are employed. Many fMRI studies have shown that the noise induced by the gradients activates the auditory cortex (Bandettini et al., 1998; Edmister et al., 1999; Scarff et al., 2004a) and could mask the representation of the auditory stimulus. Furthermore, the fMRI gradient noise modulates auditory event-related fields (Herrmann et al., 2000) and potentials (Novitski et al., 2001, 2003). These findings can be described as an interference of neuronal activity on stimulus processing induced by fMRI noise.

In order to avoid these influences, EEG–fMRI recordings can be performed interleaved, such that no gradient noise is present during stimulus presentation and EEG recording. However, it appears disadvantageous that interleaved fMRI recording leads to a reduction in detection power and hence lower sensitivity towards the BOLD effect (shape of BOLD signal) (Garreffa et al., 2004). Furthermore, interleaved acquisitions may not completely avoid the noise effect. As reported by Budd et al. (1998), preceding auditory stimulation influences the processing of succeeding stimuli. They reported a relatively stable inverse relationship between the N1 component decrement of the auditory evoked potential (AEP) and the inter-stimulus interval (ISI) in such a way that the amplitude reduction is higher for shorter ISIs. This effect was more pronounced at higher intensities (Picton et al., 1970). Since the gradient noise represents an auditory stimulus and thus reduces the ISI, interleaved measurements of EEG and fMRI with EPI sequences do not completely avoid the interference of gradient noise on processing of the desired auditory stimuli.

This negative influence of fMRI noise on AEPs may be one potential explanation of the results reported by Mulert et al. (2005). They investigated the sound level dependence using a simultaneous measurement of EEG and fMRI with EPI sequences and found no increase in the N1 amplitude with rising sound intensity. This is in contrast to numerous EEG studies outside the scanner (Beagley and Knight, 1967; Beauducel et al., 2000; Carrillo-de-la-Peña, 1999; Hegerl et al., 1994; Kaskey et al., 1980; Picton et al., 1976; Rapin et al., 1966; Näätänen and Picton, 1987, for a review). In the study by Mulert et al. (2005), the effect only reached significance when the current source density of the auditory cortex was analyzed.

Therefore, we designed a similar experiment investigating the effect of different sound intensities on the AEPs with a low-noise fMRI sequence. This method was previously used to reveal level-dependent fMRI activation in auditory cortex areas (Brechmann et al., 2002). Consequently, we hypothesized that the sound level dependency of the N1 should occur when this low-noise sequence is employed.

2. Materials and methods

2.1. Participants

Eight paid subjects (mean age 28.5 ± 7 years, six female) participated in this study. They reported no history of hearing impairment and showed no signs of psychiatric or neurological disorders. All subjects gave written informed consent to the study, which was approved by the ethics committee of the University of Magdeburg. Two subjects were excluded from the entire data analysis because of technical problems.

2.2. Stimuli and procedure

Thirty-two different linearly frequency modulated (FM) tones (16 upward and 16 downward), each covering one octave (500–1000 Hz, 600–1200 Hz and so on in increments of 100 Hz up to 2000–4000 Hz and reverse) were presented monaurally to the left or right ear at two different sound intensities: 60 and 80 dB hearing level (HL). The duration of each stimulus was 500 ms (10 ms rise and fall time) with randomized ISIs ranging between 1100–1900 ms. For each participant, the individual hearing threshold for the left and the right ear was determined using one rising FM tone (1500–3000 Hz) in intensity steps of 1 dB. The experiment contained 16 blocks of 64 s duration, each block including all 32 FM tones and being separated by silence-blocks (32 s). Within each stimulation block, the sound intensity as well as the stimulated ear remained constant. The participants had to detect the direction of frequency modulation of the FM tones and to press a button with their left index finger for one direction and another button with their right index finger for the opposite direction.

2.3. Data acquisition

EEG was recorded with a BrainAmp MR amplifier (Brain Products, Munich) using 29 sintered and nonmagnetic Ag/AgCl