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MRI with and without a high-density EEG cap—what makes the difference?

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ABSTRACT

Besides the benefit of combining electroencephalography (EEG) and magnetic resonance imaging (MRI), much effort has been spent to develop algorithms aimed at successfully cleaning the EEG data from MRI-related gradient and ballistocardiological artifacts. However, there are also studies showing a negative influence of the EEG on MRI data quality. Therefore, in the present study, we focused for the first time on the influence of the EEG on morphometric measurements of T1-weighted MRI data (voxel- and surfaced-based morphometry). Here, we demonstrate a strong influence of the EEG on cortical thickness, surface area, and volume as well as subcortical volumes due to local EEG-related inhomogeneities of the static magnetic (B_0) and the gradient field (B_1). In a second step, we analyzed the signal-to-noise ratios for both the anatomical and the functional data when recorded simultaneously with EEG and MRI and compared them to the ratios of the MRI data without simultaneous EEG measurements. These analyses revealed consistently lower signal-to-noise ratios for anatomical as well as functional MRI data during simultaneous EEG registration. In contrast, further analyses of T2*-weighted images provided reliable results independent of whether including the individuals' T1-weighted image with or without the EEG cap in the fMRI preprocessing stream. Based on our findings, we strongly recommend against using the structural images obtained during simultaneous EEG-MRI recordings for further anatomical data analysis.

Introduction

Magnetic resonance imaging (MRI) as well as electroencephalographic (EEG) techniques are well established and widely used in the field of clinical and cognitive neuroscience. In order to exploit the strengths of both measurements, which is the high spatial resolution of the MRI and the high temporal resolution of the EEG, more and more studies use simultaneous MRI-EEGEEG-MRI recordings. In this context, much work has been conducted so far to develop algorithms for cleaning EEG data from MRI-related ballistocardiological and gradient artifacts (Herrmann and Debener, 2008; Ritter and Villringer, 2006). However, previous studies have shown that the EEG electrodes and even the composition of EEG equipment such as the electrode paste exert negative influences on MRI data quality (Bonmassar et al., 2001). In particular, the interaction of the magnetic field and the EEG channels lead to susceptibility artifacts, which create magnetic field inhomogeneities and hence cause signal loss in the MRI data. In this context, Mullinger et al. (2008) showed that an increasing number of electrodes (32 and 64 channel net) as well as an increasing magnetic field strength (1.5, 3, and 7 Tesla) lead to both B_0 and B_1 field perturbations that result in decreasing signal intensity of the functional images in the affected regions. In addition, the strongest perturbations of the B_1, B_0, and the anatomical sequences were reported to be mainly driven by the electrocardiography (ECG) and the electrooculography (EOG) leads passing along the head (Mullinger et al., 2008).

Today, the usage of high-density EEG systems has become increasingly popular due to the benefit in source localization (Michel et al., 2004). Recently, Luo and Glover (Luo and Glover, 2012) tested the influence of a dense-array EEG system with 256 electrodes (the same system as used in the present study) on data quality of T2*-weighted functional and T2-weighted structural MRI sequences. Their findings reveal a significant reduction of the T2-weighted anatomical signal due to a shielding effect of the conducting wires, especially over

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occipital regions where all the wires of the net come together. However, the signal-to-noise ratio (SNR) of the functional data with and without the EEG cap was comparable.

To the best of our knowledge, here we provide first evidence for the influence of a high-density EEG net on T1- and T2*-weighted (echo-planar) images at 3 Tesla. In particular, the influence of EEG electrodes on structural data analysis such as surface- and voxel-based morphometry was tested. In addition, B_0 and B_1 maps were recorded to examine whether a putative destructive effect on data quality arises from magnetic inhomogeneities of the static magnetic field or of perturbations of the radio frequency (RF) pulse. Furthermore, we tested whether including the individual T1-weighted image with and without the EEG cap in the spatial normalization step of the fMRI preprocessing has any influence on the localization of functional activity.

Methods

The present study is divided into a structural and functional part. In the structural part, the influence of a high-density EEG net (256 channels) on the quality of the T1-weighted magnetic resonance imaging (MRI) scans was investigated. First, we evaluated the influence of the EEG net on common morphometric features of T1-weighted MRI data such as cortical thickness and cortical surface area (derived from surface-based morphometry), subcortical volumes (derived from subcortical segmentations), as well as on voxel-wise probabilistic gray matter density (derived from voxel-based morphometry). Subsequently, we investigated the influence of the EEG net on the spatial signal-to-noise ratio (SNR) of the T1-weighted images, as well as on the homogeneity of the static magnetic (B_0) and the gradient field (B_1).

In the functional part of our study, the influence of the EEG net on the blood oxygenation level dependent (BOLD) signal was investigated, of both resting-state data as well as during a simple auditory task. Here, we further assessed the influence of the EEG net on the temporal SNR. In addition, we also examined the bias onto spatial normalization of functional MRI scan time series when transformations are estimated based on the distorted T1-weighted images acquired during simultaneous EEG-fMRI recording.

Subjects

Thirteen young subjects (seven women and six men) with a mean age of 28.2 years (standard deviation, SD = 3.02 years) participated in the structural part of the study. To evaluate the influence of T1-weighted images with and without the EEG cap on functional data, we additionally recorded T2*-weighted images in six out the 13 subjects during 7 min resting state (without auditory stimulation, the control condition) with eyes open during a block of 6 min of auditory stimulation (here we used the first movement of "A little night music" by W.A. Mozart). This subgroup comprised one man and five women (mean age of 23.5 years, SD = 2.69 years). A functional T2*-weighted sequence (for a seed-based analysis of 5 min resting state data) and B_0 maps were recorded on five other subjects (one woman and four men with a mean age of 32.8 years, SD = 5.6 years). Five additional subjects (four women and one man with a mean age of 28 years, SD = 7.3 years) participated in the third part of data collection, with which the homogeneity of the B_1 field map was investigated. Except two men and one woman who participated in the T1 recordings, all other subjects were consistently right-handed as assessed by self-report. Table 1 provides an overview about the recorded sequences and how many subjects were measured. Participants did not report having any neurologic or psychiatric disease, showed no neuropsychological problems, and denied taking drugs or any illegal medication. The local ethics committee approved the study protocol and written informed consent was obtained from all participants.

Table 1
Overview of the recorded sequences/data processing and number of measured participants. Sequences that were applied to the same subjects are indicated with the same superscripts (either § or △). AC = auditory control condition; AS = auditory stimulation; DMN = default mode network; R = right handed; RS = resting state; RS-DMN = resting state data which were used for the seed based analysis of the DMN.

MR sequence	Number of subjects	Mean age ± SD	Number of women	Handedness
T1§	13	28.2 ± 3.02	7	10 R
T2* (AC, AS) §	6	23.5 ± 2.69	5	6 R
T2* (RS-DMN)△	5	32.8 ± 5.6	1	5 R
$B_0^{\triangle}$	5	32.8 ± 5.6	1	5 R
B_1	5	28 ± 7.3	4	5 R

Magnetic resonance imaging data acquisition

MRI scans were acquired on a 3.0 Tesla Philips Ingenia whole body scanner (Philips Medical Systems, Best, The Netherlands) equipped with a transmit-receive body coil and a commercial 15-element head coil array. Two volumetric 3D T1-weighted gradient echo sequence (TFE, turbo field echo) scans were acquired on 13 participants, one scan when participants wore the EEG cap and one scan without wearing the cap. The spatial resolution of these T1-weighted images was $1.0 \times 1.0 \times 1.0$ mm^3 (acquisition matrix 240×240 pixels, 160 slices) and reconstructed to a resolution of $0.94 \times 0.94 \times 1.0$ mm^3 (reconstruction matrix 256×256 pixels, 160 slices). Further imaging parameters were: Field of view (FOV) = 240×240 mm^2, echo-time TE = 3.8 ms, repetition-time TR = 8.27 ms, flip-angle $\alpha = 8°$; sensitivity encoding (SENSE) factor R = 1.5. Total acquisition time was 8 min 23 s per scan.

A fast gradient echo echo-planar imaging sequence was applied in the functional part of the study in order to obtain BOLD scans at rest as well as during auditory stimulation. 300 functional volumes were acquired with a measured spatial resolution of $3.0 \times 3.0 \times 3.7$ mm^3 (acquisition matrix 80×78 pixels, 35 slices) and a reconstructed spatial resolution of $3.0 \times 3.0 \times 3.7$ mm^3 (reconstruction matrix 80×80 pixels, 35 slices). Further imaging parameters were: FOV = 240×240 mm^2; TE = 30.0 ms; TR = 1.96 ms; flip-angle $\alpha = 83°$; SENSE factor R = 2.2. Total acquisition time was about 13 min (7 min auditory control condition without auditory stimulation, 6 min auditory stimulation) and 5 min (resting state), respectively.

A T1-weighted fast field echo (FFE) sequence was used to map the B_0 field. The B_0 map (3D echo sequence) is composed of a magnitude and a phase image and was measured with a spatial resolution of $2.0 \times 4.0 \times 4.0$ mm^3 (acquisition matrix 112×56 pixels, 75 slices). Further imaging parameters were: FOV = $224 \times 224 \times 120$ mm, dual echo-time TE = 3.6/5.63 ms, repetition-time TR = 30.0 ms, flip-angle α = 60°; total acquisition time was 4 min 11 s.

The B_1 field was also mapped using a T1-weighted FFE sequence. The B_1 map was calculated by the MRI scanner software using a dual repetition method, the actual flip angle method (AFI) (Yarnykh, 2007), with TR = 30.0/150 ms and flip-angle $\alpha = 60°$. Further imaging parameters were: FOV = $400 \times 400 \times 120$ mm^3, echo-time TE = 2.2 ms, spatial resolution of $5.9 \times 6.0 \times 12.0$ mm^3 (acquisition matrix 68×67 pixels, 20 slices); total acquisition time was 3 min 40 s.

Electroencephalographic system

MR images were recorded with and without the presence of an MR-compatible (field isolation containment) high-density EEG Geodesic Net Amp system with 256 channels (Electrical Geodesics, Eugene, Oregon). Electrode cables were placed along the subjects back, leaving the scanner parallel to the subjects' legs. Before EEG cap application, the sponge-equipped electrodes were soaked with salted water (potassium chloride) and shampoo, as done during usual EEG