EEG-fMRI at 7T using simultaneous multislice 2D-EPI: safety and functional sensitivity at the single-subject level

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Synopsis

The enhanced BOLD sensitivity available at 7T can bring significant advantages for EEG-fMRI studies, and the use of accelerated fMRI sequences such as SMS-EPI could further boost sensitivity. This work investigated whether SMS-EPI can be safely acquired with EEG at 7T, and whether the resulting sensitivity is favorable for combined EEG-fMRI approaches. The adopted SMS-EPI sequence (1.8mm isotropic resolution, whole-brain, TR_{vol}=1.57s) produced no temperature increases when combined with EEG. In a human, eyes-open/closed and resting-state activity patterns could be robustly detected in both modalites, and EEG-derived timecourses produced consistent BOLD predictions, even at a single-subject level with minimal spatial smoothing.

Purpose

The increased magnetization and BOLD sensitivity available at 7T can bring important benefits for simultaneous EEG-fMRI approaches, such as when studying the role of finer brain structures or subject-specific features[1]. The increased SNR facilitates the use of accelerated fMRI sequences, one prime example being simultaneous multi-slice (SMS) EPI, in which multiple 2D slices are acquired together in each excitation. Recent developments have brought SMS-EPI to an excellent trade-off between temporal resolution and image quality[2], and its application to EEG-fMRI could prove highly valuable. Nevertheless, a number of technical issues must be addressed. First, the RF pulses used to excite multiple slices may compromise subject safety due to interactions with EEG wires[3]. Second, accelerated sequences carry compromises in image SNR, which may aggravate the degradation effects already caused by EEG components[4], and overall potentially reduce functional sensitivity to levels unsuitable for EEG-fMRI applications. This work investigates both issues with EEG-fMRI at 7T using SMS-EPI: first, temperature measurements were conducted on a phantom during simultaneous acquisitions, for safety assessment; subsequently, simultaneous acquisitions were performed on a human volunteer, during resting-state and an eyes-open/closed paradigm. The functional sensitivity of each modality, and their integration, was investigated at the single-subject level.

Methods

Acquisition setup: acquisitions were performed on a 7T head scanner (Siemens), equipped with an 8ch Tx/Rx head RF array (Rapid Biomedical); the 8 elements of the array were arranged in a single cylindrical row surrounding the head (Fig.1a). EEG data were recorded using a 64ch cap (EasyCap) connected to two BrainAmp MR amplifiers (Brain Products) in an optimized setup[5].

SMS-EPI protocol: to best exploit the head array sensitivity profiles, SMS-EPI was acquired in sagittal slices, with 2× acceleration (with CAIPI factor=2), and AP phase encoding (with 2× GRAPPA). Other acquisition parameters: whole-brain FOV=140mm(LR)×187mm(AP)×216mm(HF), res=1.8mm isotropic, 78 slices, partial Fourier=7/8, TR_{vol}/TE=1572/25ms.

Temperature measurements: temperature was monitored with 4 fiber optic sensors (Neoptix) placed on a phantom during EEG-fMRI acquisition, for 2 successive runs: 10min of SMS-EPI, followed by 10min of standard EPI (comparable parameters, with 30 slices, 160% inter-slice gaps).

Human study: for the resting-state paradigm (10min), the subject lied awake fixating a red cross; the eyes-open/closed paradigm comprised eight blocks of 15s eyes-open and 15s eyes-closed, mediated by auditory cues. Post-acquisition, EEG data were preprocessed to reduce gradient and pulse artifacts via average artifact subtraction, and ICA-decomposed to identify components with relevant power fluctuations in the alpha-band. FMRI data were motion-corrected and lightly smoothed (FWHM=2mm). The eyes-open/closed run was analyzed with a GLM approach using the task paradigm as regressor of interest. The resting-state data were either ICA-decomposed to search for typical resting-state networks (RSNs), or underwent GLM analysis using an EEG-derived alpha-power timecourse as regressor of interest.

Results

Based on pilot acquisitions, an SMS acceleration factor of 2 introduced no discernible artifacts compared to non-accelerated data; subtle artifacts could be found using a factor of 3, and considerable degradation ensued with higher factors (Fig.1b). A factor of 2 was selected for this study to assure minimal slice cross-talk effects. Temperature measurements during the 20min session showed no safety concerns, with overall increases below 0.6°C in the measured electrodes, and of 5.2°C on the EEG amplifiers (Fig.2). Strong responses to the eyes-open/closed paradigm could be found in both EEG and fMRI data; ICA-decomposed EEG revealed several components with anterior-posterior dipolar topology and strong alpha power increases during eyes-closed periods (Fig.3a); GLM analysis of the fMRI data revealed significant signal changes ($|Z|>2.5$) for eyes-closed vs. open periods in visual cortical regions (Fig.3b). For the resting-state experiment, ICA decomposition of the fMRI data yielded several well-known RSNs including visual areas, auditory and somatosensory areas, and the default mode network (Fig.4a). From the EEG data, three independent components displayed a pronounced peak in the alpha band (close to 11Hz for this subject) (Fig.4b). Two of these components yielded alpha power timecourses that proved to be meaningful predictors of BOLD fluctuations in visual cortical areas (Fig.4c); moreover, these two visual regions closely matched two of the fMRI RSNs previously identified with ICA (IC15 and IC16 in Fig.4a).

Conclusion

We present the first report on EEG-fMRI at 7T using SMS-EPI. The adopted sequence raised no safety concerns when combined with EEG recordings. From human data, eyes-open/closed and resting-state activity patterns could be robustly detected in both EEG and fMRI, and EEG-derived timecourses produced consistent predictions in the BOLD data, even at a single-subject level with minimal spatial smoothing (2mm). These results indicate that SMS-EPI may be a highly advantageous choice for fMRI acquisition with concurrent EEG at ultra-high fields.

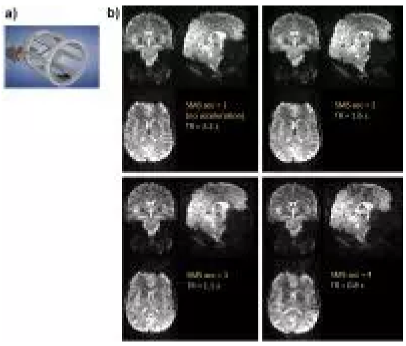
Acknowledgements

This work was supported by Centre d'Imagerie BioMédicale (CIBM) of the UNIL, UNIGE, HUG, CHUV, EPFL and the Leenaards and Jeantet Foundations, and by the Portuguese Science Foundation (FCT) through grants PTDC/EEI-ELC/3246/2012 and PEst-OE/EEI/LA0009/2013.

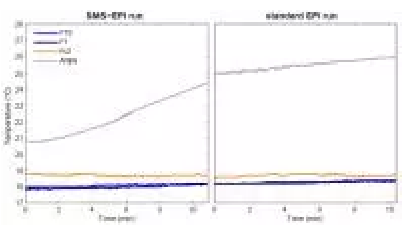
References

(1) Grouiller et al., Proc. ISMRM 2015. **(2)** Setsompop et al., MRM 2012. **(3)** Lemieux et al., MRM 1997. **(4)** Mullinger et al., I.J.Psycho 2008. **(5)** Jorge et al., NeuroImage 2015.

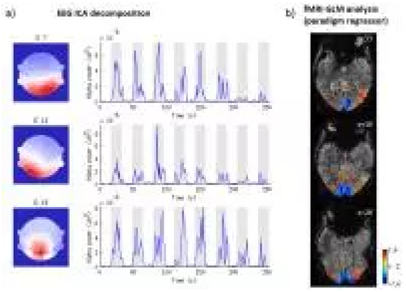
Figures



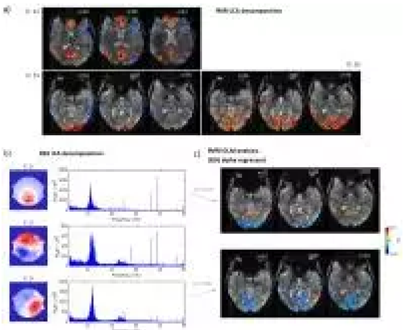
a) The single-channel transmit, 8ch-receive head RF array used in this study. **b)** The effects of increasing the SMS acceleration factor (sagittal slices) on EPI image quality. A factor of 2 was selected for this study.



Temperature fluctuations on a phantom during a 10min SMS-EPI followed by a 10min standard EPI acquisition. Probes were placed in electrodes FT9, F1 and FC2 (within the gel), and in-between the two EEG amplifiers.



Responses to the eyes-open/eyes-closed paradigm. **a)** EEG independent components with strong alpha modulation during eyes-closed periods (grey-shaded) vs. eyes-open periods. **b)** Regions with significant signal changes (|Z|>2.5) for eyes-closed, vs. eyes-open periods, given by GLM analysis of the fMRI data.



Resting-state activity captured by EEG and fMRI, separately and combined. **a)** fMRI independent components matching well-known RSNs: default mode network (top) and two visual networks. **b)** EEG independent components displaying an alpha-band peak. **c)** Brain regions for which EEG-derived alpha power timecourses predict BOLD fluctuations (|Z|>0.9) – note the close resemblance to IC15 and IC16 in a).