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Mapping (and modeling) physiological movements during EEG–fMRI recordings: The added value of the video acquired simultaneously

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HIGHLIGHTS

- Video acquisition during fMRI allows a reliable way to detect facial movements.
- Modeling facial movements lead to more informative fMRI maps.
- Inclusion of facial movements in the SPM is particularly important in surgical candidates.
- We provided a reliable method for brain mapping spontaneous swallowing and blinking.

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ABSTRACT

Background: During resting-state EEG–fMRI studies in epilepsy, patients' spontaneous head–face movements occur frequently. We tested the usefulness of synchronous video recording to identify and model the fMRI changes associated with non-epileptic movements to improve sensitivity and specificity of fMRI maps related to interictal epileptiform discharges (IED).
New methods: Categorization of different facial/cranial movements during EEG–fMRI was obtained for 38 patients [with benign epilepsy with centro-temporal spikes (BECTS, $n=16$); with idiopathic generalized epilepsy (IGE, $n=17$); focal symptomatic/cryptogenic epilepsy ($n=5$)]. We compared at single subject- and at group-level the IED-related fMRI maps obtained with and without additional regressors related to spontaneous movements. As secondary aim, we considered facial movements as events of interest to test the usefulness of video information to obtain fMRI maps of the following face movements: swallowing, mouth–tongue movements, and blinking.
Results: Video information substantially improved the identification and classification of the artifacts with respect to the EEG observation alone (mean gain of 28 events per exam).
Comparison with existing method: Inclusion of physiological activities as additional regressors in the GLM model demonstrated an increased *Z*-score and number of voxels of the global maxima and/or new BOLD clusters in around three quarters of the patients. Video-related fMRI maps for swallowing, mouth–tongue movements, and blinking were comparable to the ones obtained in previous task-based fMRI studies.
Conclusions: Video acquisition during EEG–fMRI is a useful source of information. Modeling physiological movements in EEG–fMRI studies for epilepsy will lead to more informative IED-related fMRI maps in different epileptic conditions.

Abbreviations: BECTS, benign epilepsy with centro-temporal spikes; BOLD, blood oxygen level dependent; DMN, default mode network; EZ, epileptogenic zone; fMRI, functional magnetic resonance imaging; FWE, family wise error; GLM, general linear model; GM, global maxima; GSWD, generalized spike and wave discharges; HRF, hemodynamic response function; ICA, independent component analysis; IED, interictal epileptic discharges; IGE, idiopathic generalized epilepsies; ILAE, international league against epilepsy; IZ, irritative zone; SPM, statistical parametric mapping.

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1. Introduction

EEG-correlated fMRI (EEG–fMRI) can be used to investigate not-invasively the blood oxygenation level dependent (BOLD) signal variations linked to spontaneous epileptic activity (Laufs, 2012). This technique has been largely applied in numerous studies to characterize the hemodynamic correlates of interictal epileptiform activity (IED) (Pittau et al., 2012; Thornton et al., 2011) as well as ictal discharges (Chaudhary et al., 2013, 2012b) and it is employed in the pre-surgical evaluation of refractory focal epilepsy for the localization of the epileptogenic zone (EZ) (Pittau et al., 2013; Zhang et al., 2012). Despite this great success, the sensitivity of EEG–fMRI studies in epilepsy is still limited. One of the major issues is related to intrinsic nature of epileptic activity itself with its unpredictability and variability, which in some case reduces the sensitivity of the effects of interest. It has been reported that in about 40% of cases, there is a lack of epileptiform abnormalities on EEG recorded during fMRI sessions (Salek-Haddadi et al., 2006). This might be a significant problem, as the absence of IED/seizures during EEG–fMRI could make the functional data not analyzable. Recent alternative approaches has been developed allowing to a significantly increase of the sensitivity of EEG–fMRI study in epilepsy (Grouiller et al., 2011). Even with the presence of epileptic activity during the fMRI sessions, around 30% of datasets might not reveal significant hemodynamic changes (Aghakhani et al., 2006; Salek-Haddadi et al., 2006). A possible explanation for this result is the use of a standard hemodynamic response function (HRF) model instead of a specific HRF (Storti et al., 2013) and inaccurate or inconsistent labeling of IED (Flanagan et al., 2009). Furthermore the occurrence of numerous confounding effects during the fMRI acquisitions, such as motion and heartbeat might affect the sensitivity of fMRI data analyses (Allen et al., 2000, 1998; Bénar et al., 2003; Siniatchkin et al., 2007). In particular, EEG–fMRI recordings remain very sensitive to patients' small movements. These additional artifacts might affect the identification of epileptic activity by the expert neurophysiologists as well as produce low quality image data. Motion remains an important concern in the analysis of fMRI data, even with the best immobilization measures (Lund et al., 2005) and particularly in patients' populations. Furthermore, in cases where the head motion is stimulus correlated (i.e., coincident with events of interest), the results can be artifactual areas of false activation or a decrease in specificity. Realignment parameters derived from the fMRI data pre-processing are commonly included in the design matrix to explain some of the residual variance in the data, although with different degrees of sophistication (Friston et al., 1995; Moeller et al., 2008; Salek-Haddadi et al., 2006; Tyvaert et al., 2008). Similarly, modeling hearth beating (Liston et al., 2006) and respiratory related artifacts (van Houdt et al., 2010) as confounds can improve the sensitivity. Very recently, EEG–fMRI studies have been implemented with the simultaneously recordings of synchronized video documentation by one or two camera monitoring patients' face and body movements (Chaudhary et al., 2010). This additional equipment has been shown to increase recorded information without fMRI data quality reduction (Chaudhary et al., 2010). Chaudhary and colleagues (2012a) have demonstrated the usefulness of synchronous video to identify and model the fMRI changes associated with non-epileptic physiological activities, leading to increases in the fMRI data analyses sensitivity to the effect of interest (IED). In a small sample of patients with IED during fMRI (six patients with focal epilepsy and four with generalized epilepsy), these authors compared the fMRI maps obtained with and without additional regressors related to spontaneous movements. The results provided suggest that, at single subject level, the inclusion of additional regressors derived from video information explains a greater amount of variance and can reveal additional IED-related BOLD clusters, which might be part of the epileptic network. Despite this interesting finding, systematic studies about the potential added value of modeling physiological activities within the design matrix in a large number of patients, both at single-subject and at population level, have not been performed to date.

We have routinely conducted EEG–fMRI studies with the simultaneous recording of synchronized video at 3 T for almost 3 years with more than 80 epileptic patients recruited. In the presented work, we explore the additional information provided by the synchronous video documentation during EEG–fMRI recordings in the available data sets.

The main aims of this study are the following: (1) to assess if the synchronized video provides more information in terms of EEG artifacts' identification and classification with respect to the visual-based EEG observation; (2) to provide a simple anatomic, although limited atlas, of the BOLD changes related to the more common face/cranial movements observed during resting state EEG–fMRI recordings; (3) to expand the previous observations by Chaudhary et al. (2012a), by documenting the added value of modeling the physiological artifacts shown by the video in order to obtain more informative fMRI maps. To this end we compared the *Z*-score and the statistical significance of IED-related BOLD maps obtained without and with physiological artifacts regressors respectively in a large cohort of epileptic patients both at single and population level analyses.

2. Materials and methods

We retrospectively reviewed the population of patients with epilepsy who underwent to an EEG–fMRI study for different purposes between April 2012 and February 2014. A total number of 84 patients were scanned. Among these, 12 subjects were excluded from further analyses as EEG and fMRI data were collected without video recorded simultaneously. 27 out of the remaining 72 patients did not shown physiological movements during the fMRI data acquisitions or had a poor quality video documentation and were discarded. The remaining 45 video-EEG–fMRI data sets (and a corresponding number of patients) were reviewed and further analyzed. This pool of patients presented different epileptic syndromes (Commission on Classification and Terminology of the International League Against Epilepsy, 2001). We further excluded from the present study seven patients affected by genetic epilepsies or epileptic encephalopathies since no a priori predictions of BOLD signal changes could be made for these conditions. We therefore focused on a pool of 38 subjects affected by: (a) Idiopathic Generalized Epilepsies (IGE; $N = 17$) (for whom an established network of BOLD signal changes is well known (Laufs et al., 2006; Moeller et al., 2010); (b) benign epilepsy with centro-temporal spikes (BECTS, $N = 16$), for whom the sensory-motor cortex has been demonstrated the generator of IED (Boor et al., 2003; Masterton et al., 2010); (c) drug-resistant focal symptomatic epilepsy ($N = 5$), for whom non-invasive electro-clinical data (according to clinical information, electrophysiology, and structural MRI) allowed us to identify the irritative zone (IZ, the brain region generating interictal discharges) at single-subject level.

Fig. 1 summarizes the design of the study. The human ethic committee of the University of Modena and Reggio Emilia approved this study and written informed consent was obtained from all the patients recruited or from their parents if underage.

2.1. Video-EEG recordings

Scalp EEG has been recorded by means of a 32-channel MRI-compatible EEG recording system (Micromed, Mogliano Veneto, Italy). Electrodes were placed according to conventional 10–20 locations. ECG activity was recorded from electrodes positioned