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The quest for single trial correlations in multimodal EEG-fMRI data.

Maarten De Vos,Rob Zink,Bobala Hunyadi, Bogdan Mijovic, Sabine Van Huffel and Stefan Debener

Abstract— **In the past decade, technological advances have made it possible to reliably measure brain activity using simultaneous EEG-fMRI recordings inside an MR scanner. The main challenge then became to investigate the coupling between the EEG and fMRI signals in order to benefit from the simultaneously integrated temporal and spatial resolution. Although it is crucial to know when features in EEG and fMRI are expected to correlate with each other before the identification of common sources from multimodal data is possible, it is still a matter of debate. In this study, we address this question by analysing EEG and fMRI data separately from a face processing task. We show that we are able to reliably estimate single trial (ST) dynamics of face processing in EEG and fMRI data separately in four subjects. However, no correlation is found between the modalities. This implies that in this task modality-specific information is larger than the information that is shared by the modalities.**

I. Introduction

Simultaneous electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) promises to study brain activity with both precise temporal and spatial resolution. Assuming that a stronger electrical response to a single trial (ST) leads to a linearly larger increase in blood flow (and vice versa) a trial-by-trial coupling of parameters in EEG and fMRI should be present. If such fluctuations in ST responses can be reliably estimated in both modalities a subsequent correlation of ST fluctuations provides strong evidence that a certain time instance in the EEG is coupled to a certain region in the fMRI. Traditionally, such coupling is identified by the primary extraction of values from an event-related potential (ERP, e.g. peak amplitude) and a subsequent input into the statistical fMRI design (general linear model, GLM) as a parameterized EEG regressor such that significant correlations are displayed via color-coded statistical maps. Initiated by the pioneering works demonstrating meaningful event-related EEG-informed fMRI activations [4], [5] there is an ongoing quest to identify such correlations for a wide range of cognitive and emotional processes. While it should be clear that each modality reflects to some unknown degree brain activity the other modality is not sensitive for, the crucial assumption of the EEG-informed fMRI approach is that it assumes some degree of coupling between both modalities, as identified by temporal correlation [4].

Although some papers showed evidence for some degree of coupling, it is still a matter of debate how much the BOLD response is reflecting the actual neural activation. [9] illustrated that the BOLD response is correlated with local field potentials (LFP) in anaesthetized monkeys, providing support for the notion that fMRI can provide information about the actual neural activation. However, despite the constant increase in simultaneous EEG-fMRI research, the question of when and how much ST dynamics correlate remains unanswered. Several different reasons may lead to the absence of correlation between the EEG and fMRI modalities. One of these may be the fact that the event-related activity in both ST fMRI or EEG responses have a very low signal-to-noise ratio (SNR) compared to measurement noise and other ongoing processes.

The present study investigated the single trial correspondence of both modalities during face processing. Recently, [3] showed that Independent Component Analysis (ICA) is able to extract a face-sensitive component from the EEG, explaining most of the variance of the N170 component. By studying the dynamics of such a face-sensitive component, the SNR of ST fluctuations in EEG related to face processing can be assumed to be improved compared to dynamics observed on the sensor level. It is also known that the fusiform face area (FFA) is the main generator of this N170 and can be reliably identified in fMRI [7], [12]. From the separate modalities, we show that we reliably estimate ST fluctuations. The question that we address is how much variance of the ST estimates is common to both modalities, and how much variance is modality-specific.

II. Data & Methods

We recorded simultaneous EEG/fMRI from 20 subjects (age: 24.5 SD: 2.5, 14 female). All subjects gave informed consent regarding their participation in the study, which was approved by the ethical committee of the University of Oldenburg (Germany). fMRI data was recorded using a 1.5T MRI scanner, inversion recovery sequence (IRS) was used with TR = 2s, TE = 3.9ms, flip angle: 15 degrees, matrix 64x64. EEG data was measured from 64 equidistant MR compatible Easycap electrodes using a BrainAmp system (BrainProducts, Gilching, Germany), referenced to Cz and grounded to Iz. Sampling rate was 5000Hz. An ECG electrode was attached to the lower back.

In order to study face processing, a visual paradigm was presented to the participants. The stimuli consist of a visual representation of houses, faces, inverted faces and four-letter

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M. De Vos and S. Debener are withDept. of Psychology, University of Oldenburg, Oldenburg (Germany)

Email: maarten.de.vos@uni-oldenburg.de

R. Zink, B. Hunyadi, B. Mijovic and S. Van Huffel are with SCD/SISTA, Dept. of Electrical Engineering, KU Leuven, Leuven (Belgium) and iMinds Future Health Department, Belgium

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words. Face and house stimuli were matched for luminance and contrast differences. Participants were familiarized with a part of the stimuli before the scanning session. This was achieved by sending two pictures from each category to the participants one week prior to the scanning session. During presentation of the stimuli (120 per category), participants had to indicate with a two choice button press whether the displayed stimulus had been seen before or not. Interstimulus interval was (jittered) 3 seconds and additionally 1/3 of null trials was used. No feedback was given during the experiment.

Additionally, a block-design localiser run (with faces, objects, scenes and words) was presented to confirm identification of the regions involved in face and house processing.

A. fMRI

Pre-processing of the fMRI data was done using the statistical parametric mapping toolbox SMP8 (http://www.fil.ion.ucl.ac.uk/spm). The functional images were realigned to the first image, used as a reference to obtain the same orientation and position. Co-registration of the functional images with the T1 weighted anatomical image was performed. Finally, the functional images were smoothed by convolution with a 8mm Gaussian kernel.

FFA and parahippocampal place area (PPA) were identified in the task-related run by contrasting respectively faces and houses with other stimuli. The identified regions were always confirmed with activations found in the localiser run. After defining regions of interest (ROI) of FFA and PPA, the Blood Oxygen Level Dependent (BOLD) time courses in the ROIs from the most pronounced side (left or right) of the brain were averaged and ST estimates were obtained by regressing a canonical hemodynamic response function on the time instances of these BOLD courses when a face or house stimuli was presented. In order to check if the ST estimates are meaningful, the ST classification accuracy between faces and houses was computed wiht these ST estimates in a 10-fold cross validation. Under the assumption that the ST fluctuations within a condition are also well preserved when the ST fluctuations across condition are preserved, this classification accuracy gives an estimate of reliability.

B. EEG

Standard preprocessing steps were applied on the EEG. In brief, a template subtraction procedure was used to remove scanner gradient artefacts [1]. Template subtraction is based on the assumption that gradient artefacts are uncorrelated with the EEG signal and do not change rapidly. Additionally, Optimal Basis Set (OBS) was used to remove the heart pulse-related artifacts [13]. All data was band pass filtered between 1 and 40Hz. Infomax ICA [2] was then applied on 2.5 second epochs around the stimulus epochs to unmix the contributions of different brain processes and residual artifact and extract a face-sensitive component from the EEG data.

Calculation of the N170 ST responses are based on the average value over 24 ms around the most negative value in a 140 - 200ms interval after stimulus onset in this face-sensitive component. After extraction of ST values, this amplitude of the N170 is used as measure to correlate with the fMRI ST estimates. In order to estimate the reliability of the condition-specific modulation on the ST level, also a 10-fold classification between faces and houses was computed. The degree of correlation between the ERP and BOLD response can be used to evaluate the existence of a direct single-trial coupling between both methods in this task.

III. Results

As not all subjects allowed for a reliable estimation of both FFA and a reliable estimation of a face-sensitive IC, we present here the results on four subjects in which we found both face-related signatures reliably.

In figure 1, the identified FFA and face-sensitive ICs are shown for the four subjects. It can be seen that the subjects show clear activation in both fMRI and EEG. In particular, the topographies are very similar to the topographies shown in [3], indicating that reliable components involved in face-processing were extracted.

Figures 2 and 3 show the range of the ST estimations of the face and house trials in fMRI and EEG. The classification accuracies as given above each subfigure indicate that condition-specific modulations of ST strengths can be estimated and thus that ST strengths can be identified in both modalities.

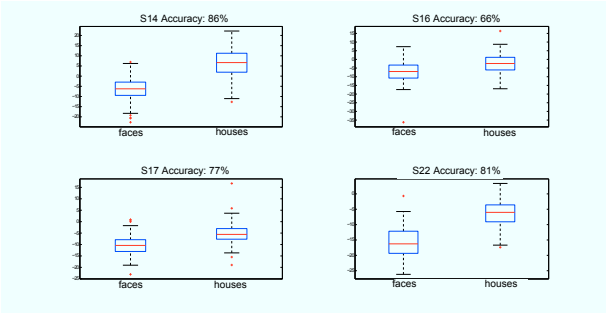


Fig. 3: The ST strengths as identified in the four subjects on the face IC for the face and house trials. It can be seen that ST can be reliably identified in the EEG.

Figure 4 illustrates then correlation between the ST dynamics in EEG and fMRI. A clear absence of coupling between the ST strengths of both modatlities can be seen. Although these four subjects have clear face-sensitive activation and reliable ST estimation in both modalities, this data supports the idea that the modality-specific variation is larger than the common variation.

IV. Discussion

Recording of simultaneous EEG-fMRI is mainly motivated by the improved spatio-temporal resolution that could potentially be obtained by integrating modalities. It is nowadays pretty common to record EEG inside the scanner, and many reliable tools are developed to remove the artifacts related to the fact that the EEG was recording inside a scanner

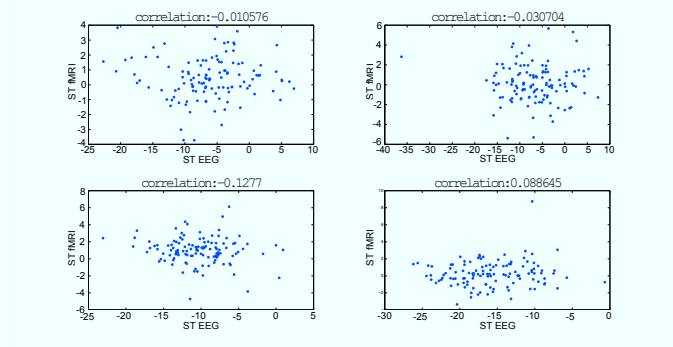


Fig. 4: The correlations between the fMRI (FFA) and the EEG (face-sensitive) ST for the four subjects. The absence of any correlation illustrates that the modality-specific activity is large compared to activity that is common to both.

environment. Although this technical possibility of recording simultaneous EEG-fMRI, the real challenge is to benefit from the simultaneity of the complementary modalities. The main challenge then is to investigate the coupling between the EEG and fMRI signals in order to benefit from the simultaneously integrated temporal and spatial resolution. Correlations across subjects, meaning that a stronger ERP response correlates with a stronger BOLD signal, have been multiple times been reported, e.g. [11], [12]. On the contrary, fewer papers show strong correlations within subjects, i.e. coupled ST fluctuations between the modalities, and some studies argue even for the explicit absence of it (e.g. [14]). One possible motivation for the absence of correlation is that the dynamics of the process of interest is not reliably estimated. ICA is a method that separates different sources based on its statistical properties, and was recently shown to reliably estimate a face-sensitive component [3]. This implies that by studying the ST dynamics on the ICA source level, we largely remove contributions of other ongoing processes that could obscure the ST dynamics of the face process of interest. We performed the EEG-fMRI study with the explicit goal to assess the degree of coupling of ST fluctuations. It is know that N170 component seen in EEG is (at least partly) generated in FFA, and if the ST fluctuations of the neural activity, as seen in the EEG, are reflected in the ST fluctuations of the fMRI, a coupling should be identified. Our results show that, although we carefully selected subjects based on the identification of strong face-sensitive activity in both modalities, no correlation was found. A further step to investigate is also to denoise fMRI data further, e.g. by applying ICA to the fMRI data and extract also from the fMRI a face-sensitive component.

Our data alone does not allow to argue for an explicit absence of any ST coupling between modalities, but certainly indicates that one should be careful with the concept of ST coupling between EEG and fMRI and the relevance of it. Speculating about the possible causes when ST coupling can be found and when not, we suggest that when events in the EEG are large, correlations with fMRI fluctuations can be found. Indeed, all demonstrated correlations are related to events in the EEG with a large SNR: epileptic spikes [8], alpha [10], ERN [4]. When SNR of the event of interest decreases, a less reliable estimation of the true fluctuation can be obtained, and also the likelyhood to identify correlations decreases. In this study, despite the fact that we perform EEG denoising with ICA, the SNR of the N170 might not be enough for a ST estimation of the modulation across trials.

Secondly, the fact that coupling is present or not can also be related to the paradigms used in the studies and even to particular brain functions. But more research is needed to provide evidence for this hypothesis.

REFERENCES

[1] Allen, P. J., Josephs, O., Turner, R. (2000). A method for removing imaging artifact from continuous EEG recorded during functional MRI. NeuroImage, 12(2), 230-239.

[2] Bell, A. J., Sejnowski, T. J. (1995). An information-maximization approach to blind separation and blind deconvolution. Neural Computation, 7(6), 1129-1159.

[3] De Vos, M., Thorne, J. D., Yovel, G., Debener, S. (2012). Let's face it, from trial to trial: Comparing procedures for N170 single-trial estimation. NeuroImage, 63(3), 1196-1202.

[4] Debener, S., Ullsperger, M., Siegel, M., Engel, A. K. (2006). Single-trial EEG-fMRI reveals the dynamics of cognitive function. Trends in Cognitive Sciences, 10(12), 558-563.

[5] Eichele, T., Specht, K., Moosmann, M., Jongsma, M. L. A., Quiroga, R. Q., Nordby, H., Hugdahl, K. (2005). Assessing the spatiotemporal evolution of neuronal activation with single-trial event-related potentials and functional MRI. Proceedings of the National Academy of Sciences of the United States of America, 102(49), 17798-17803.

[6] Gentile F., Jansma B.M. (2012) Temporal dynamics of face selection mechanism in the context of similar and dissimilar faces. Neuroimage 59: 682-694.

[7] Haxby, J. V., Gobbini, M. I., Furey, M. L., Ishai, A., Schouten, J. L., Pietrini, P. (2001). Distributed and Overlapping Representations of Faces and Objects in Ventral Temporal Cortex. Science, 293(5539), 2425-2430.

[8] LeVan P., Tyvaert L., Gotman J. (2010). Modulation by EEG features of BOL responses to interictal epileptiform discharges. Neuroimage 50: 15-26.

[9] Logothetis, N. K., Pauls, J., Augath, M., Trinath, T., Oeltermann, A. (2001). Neurophysiological investigation of the basis of the fMRI signal. Nature, 412(6843), 150-157.

[10] Martnez-Montes E, Valds-Sosa PA, Miwakeichi F, Goldman RI, Cohen MS. (2004) Concurrent EEG/fMRI analysis by multiway Partial Least Squares. Neuroimage. 22:1023-34.

[11] Mijovic B, Vanderperren K, Novitskiy N, Vanrumste B, Stiers P, Bergh BV, Lagae L, Sunaert S, Wagemans J, Huffel SV, Vos MD. (2012) The why and how of jointICA: results from a visual detection task. Neuroimage, 60, 1171-85.

[12] Sadeh, B., Podlipsky, I., Zhdanov, A., Yovel, G. (2010). Event-related potential and functional MRI measures of face-selectivity are highly correlated: A simultaneous ERP-fMRI investigation. Human Brain Mapping, 31(10), 1490-1501.

[13] Vanderperren K, De Vos M, Ramautar JR, Novitskiy N, Mennes M, Assecondi S, Vanrumste B, Stiers P, Van den Bergh BR, Wagemans J, Lagae L, Sunaert S, Van Huffel S. (2010) Removal of BCG artifacts from EEG recordings inside the MR scanner: a comparison of methodological and validation-related aspects. Neuroimage, 50,920-34.

[14] Vanderperren K, Mijovi B, Novitskiy N, Vanrumste B, Stiers P, Van den Bergh BR, Lagae L, Sunaert S, Wagemans J, Van Huffel S, De Vos M. (2013) Single trial ERP reading based on parallel factor analysis. Psychophysiology, 50, 97-110

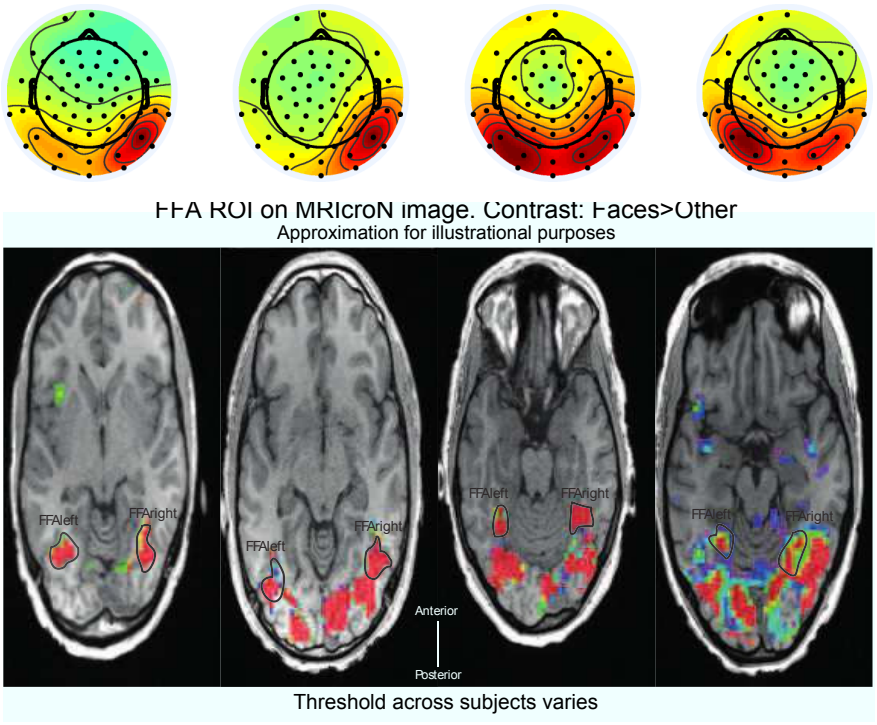


Fig. 1: The activated regions in fMRI for the four subjects by contrasting faces with all other stimuli. Both right and left FFA are marked and confirmed by activation identified in the localiser data. Above, the topographies of the IC components involved in face processing as identified in the same subjects. These topographies are look very similar to the topographies shown in [3].

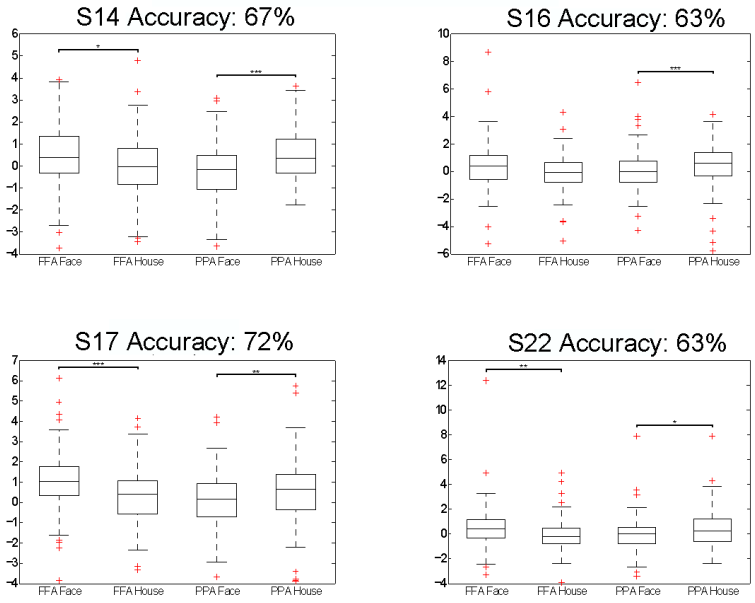


Fig. 2: The ST strengths as identified in the four subjects in FFA and PPA for the face and house trials. It can be seen that ST can be reliably identified from the BOLD signal.