COMPARISON BETWEEN ERP (sLORETA) AND fMRI OF SOMATOSENSORY CORTEX FOR HEALTHY GROUP*

I. Karpiel[a,b], Z. Drzazga[b]

[a]Łukasiewicz Research Network —
Institute of Medical Technology and Equipment
118 Roosevelt St., 41-800 Zabrze, Poland
[b]Department of Medical Physics, Institute of Physics
Silesian Center for Education and Interdisciplinary Research
University of Silesia, Pułku Piechoty 1, 41-500 Chorzów, Poland

(Received June 12, 2020)

The purpose of this paper is to present event-related potential (ERP) measurements during visual language processing experiment and comparison with functional magnetic resonance imaging as well as compare brain activity and estimate the diagnostic value. sLORETA (standardized Low Resolution Electromagnetic Tomography) was chosen to compute current source densities because it can lead to the same type of mapping activity as fMRI, which was used as a reference method for imaging of somatosensory areas. Research focused on selected paradigms which was finger movement for healthy group. Exogenous potentials and associated endogenous potentials were analyzed, taking into account the phenomenon of lateralization and showing the impact of parameters in SPM in the area of somatosensory cortex of fMRI study.

DOI:10.5506/APhysPolBSupp.13.923

1. Introduction

Both Electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) are basic, non-invasive studies that allow the analysis of brain function. fMRI is the method sensitive to magnetic properties of blood and indicates which areas of the brain are reached by the oxygenated blood — it is called BOLD-sequence [1]. This sequence is a starting point in the mapping of the brain structure activation evoked by cognitive activity [2] using the advanced MATLAB and SPM8 and/or SPM12 software. Since its invention, fMRI has been applied in every aspect of brain research but it does

* Presented at the 45th Congress of Polish Physicists, Kraków, September 13–18, 2019.

not measure activity of neurons directly. Unfortunately, it is not possible to determine the number of active neurons in a particular moment. In addition, the signal, *i.e.* the increase of blood flow due to a stimulus, may be difficult to extract from the noise of normal changes of blood flow occurring in the brain. Despite this, fMRI is still widely used because there is no better method to observe what occurs in the brain. Current publications suggest that the increase in the oxygen level may occur in preparation for neuron activity or even that it may fluctuate due to reasons different from such an activity. In recent times, there appeared publications showing the simultaneous use of different methods of neuroimaging *i.e.* EEG and fMRI based on activation combining high spatial and temporal resolution. Modern techniques of hybrid, however, are expensive and thus less available [3–7]. Therefore, it seems interesting to take the test as the power of the art EEG and fMRI as separate methods [8–10]. There are different methods to find approximate activations of the brain sources giving rise to a scalp electric potential recording method [11–13] solving the inverse problem in EEG. The method requires previous recording of encephalographic signal and, by the means of created paradigm, evoking particular potential, assumed by the researcher. The method requires software to analyze data, to remove artifacts from the signal (*i.a.*, filtering, artifact detection, baseline correction), and to average the signal. As a result, these procedures permit to map three-dimensional distribution of current density deriving from source generators on the basis of electrical activity distribution on the surface area of the head. The advantage of this method is the lack of assumptions about a limited number of sources in the form of dipole points and distribution on a given surface. LORETA, on the other hand, maps the present distribution in the whole brain volume. The assumption of this method is that the adjoining neurons are simultaneously and synchronically activated in three-dimensional space. The distribution of activation in the brain volume, which is discretized as a dense three-dimensional network, where electric sources are located in every point of the network, is calculated [14–16]. There are several methods for the analysis of the inverse problem for the location of the sources of EEG *i.e.*: parametric LORETA, sLORETA, VARETA, S-MAP, Blackus–Gilbert, LAURA and nonparametric *i.e.*: MUSIC or FINES [13]. sLORETA is a method that, due to the modification, permits to eliminate excessive errors connected with localization of the activated areas which had been considered insuperable until its invention [17]. sLORETA is a development of original LORETA algorithm. It was discussed also by Pascual-Marqui in 2002 [11]. The method precisely determines source generators localization even if they are located very deep. The distance between the actual source generator and the determined maximum activation area in an imaging method is called a localization error. In contrast to other methods,

sLORETA has zero localization error. Activation localizations in the images are created by standardization of estimated current density. During reconstruction of a single source, it means that the maximum current density coincides with the exact location of a dipole [11]. Comparing with similar technique (*i.e.* LORETA), sLORETA gives the best performance both in terms of localization error and ghost sources [13]. sLORETA and LORETA have the benefit of superior time resolution of EEG measurements of milliseconds, which is 3-fold better than that of fMRI, with spatial resolution of approximately 7 mm, which is similar to that of fMRI [13, 18]. The purpose of this paper is to present event-related potential measurements during visual processing experiment. sLORETA (standardized Low Resolution Electromagnetic Tomography) was chosen to present MCI and MCII (somatosensory area) and it can lead to the same type of mapping activity as fMRI, which was used as a method for imaging of somatosensory. In our studies, we focused on activations of motor cortex — primary (M1), premotor (PMA) and supplementary (SMA) which are important in terms of life quality — ability of movement which is a continuation of earlier research [19].

2. Material and methods

Ten native Polish-speaking students of the University of Silesia (four females and six males at the age of 21–31) participated in this experiment. They all were healthy, physically active, non-smokers, with no neural disorders diagnosed. The methodology was fully explained to the participants who gave their consent to perform the experiment. Each of the subjects had two tests, one for the right hand and the other for the left hand. Information about their health condition and lifestyle was gathered in a questionnaire. The paradigm to stimulate motor areas was created by means of evoke scenario generator (ANT). The experiment lasted 15 minutes for the right hand and 10 minutes for the left hand, respectively. Between the first and second examination, the patient had a short break to rest and prepare for further action. Right-hand paradigm: on the screen a black number 2 or 3 or 4 appeared on a white background for 1200 ms, each of the numbers was displayed in a loop 150 times, at this point the patient was tasked with telling the number he was seeing. The numbers corresponded to each finger as follows: 2 index, 3 middle, 4 ring. After each of the digits, a white cross appeared in the center of the screen on a black background for 800 ms, at this point the patient moved his finger. The movement consisted of pressing a button on the joystick. The finger used to make the move depended on what number preceded the displayed cross. The displayed numbers were shown in random order. Left-hand paradigm: a black number 2 or 3 or 4 appeared on the screen against a white background for 1200 ms, each of the numbers was displayed in a loop 100 times, at this point the patient was

tasked with telling the number he was seeing. The numbers corresponded to each finger as follows: 2 index, 3 middle, 4 ring. After each of the digits, a white cross appeared in the center of the screen on a black background for 800 ms, at this point the patient moved his finger. The movement consisted of pressing a button on the joystick. The finger used to make the move depended on what number preceded the displayed cross. The displayed numbers were shown in random order.

2.1. Experimental paradigm (fMRI)

Paradigms with classic blocked design were prepared in PsychoPy software. Paradigm created to stimulate the motor cortex composed of 4 active and 5 rest blocks — collected 90 volumes. For activation motor cortex, we used paradigms finger tapping and ankle flexion (dorsiflexion and plantar flexion) using a computer coupled projector.

2.2. Data analysis

Analysis of brain activations based on EPI SE sequence was performed in SPM12 package in MATLAB (MathWorks, Inc.) environment. The steps of data analysis process consisted of spatial pre-processing: realignment, coregistration, and spatial smoothing. Coregistration was performed to maximizing the mutual information between anatomical and functional MRI scans. Finally, the data had to be smoothed. The goal of fMRI statistical analysis was to define those brain regions that show significant activation. The most popular statistical approach assumes that dependence of the signal and stimulus is linear. In these analyses, we used model based on the T-statistic, where selected significance level (p) defined probability, that exist a difference between active and rest phases. The smaller value of p, the threshold level (T-threshold) increase. In order to obtain the optimal highlighted active area analysis of fMRI, measurements was performed for different parameters such as: fixed Gaussian kernels with various widths (FWHM of 6 and 8 mm), significance level ($p < 0.001$ and $p < 0.01$). Localization of active areas were made using functional atlases [20, 21] and Talairach Client.

3. Results

fMRI is a very helpful tool for the diagnosis and vizualization of our brain. The problem of adopted statistical techniques is not a new subject, but still actual in the neuroscientists environment. This method gives a possibility to locate the relevant functional areas of the brain responsible for the movement and sensation. Along with developing the method, more and more questions on how to properly analyse and whether the choice of the analysis is appropriate appear. The ultimate success of any experimental

fMRI depends not only on the quality of the collected image data but also appropriate selection of the parameters (kernel, p, voxel) to maximize the statistical power. In addition, it aims to shorten the analysis time and to better define the motor centers (planning and execution of body movements) and hence help to make a diagnosis. Figure 1 presents activation in primary and secondary motor cortex (MCI MCII and SMA) for fMRI. Analysis with and without FWE was performed and shown using parameters kernel and p (Fig. 1). In the case of the motor cortex, there is a difference in the application of the analysis method. Our results showed that during the use of kernel 8 almost 17 000 active voxels were obtained, while for kernel 6, which is the most commonly used parameter, it is about 14 000. The volume voxel for both kernels is 22 000, while the number of erroneous activations for kernel 8 is 0.00027 and for the most commonly used kernel 6 is 0.00039. The ratio of incorrect activations to true for kernel 6 is 0.0000029% is and for kernel 8 is 0.0000016%. In Fig. 1 we presented only visual results. Our pre-processing and data analysis in MATLAB and SPM showed that kernel 8 and $p < 0.001$ are better for the analysis.

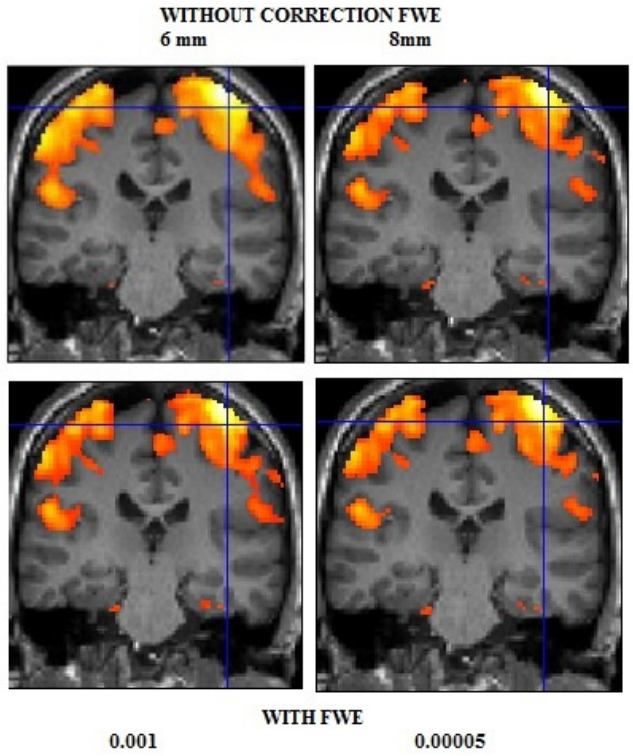


Fig. 1. Imaging of activation of somatosensory with the indicated MCI and MCII for healthy person (parameters: kernel 6 mm and 8 mm; with FWE correction: 0.001 and 0.00005).

It should be mentioned that FWE statistics will work better in other centers, *e.g.* in the analyzed areas of speech, hearing or vision due to the volume of these areas. More activation was found using kernel 8, but the image is inferior in resolution. There was a smaller ratio of incorrect activations to the true one when determining kernel 8 than kernel 6. In addition, a greater number of active voxels was shown, a greater total number of voxels was generated and a greater degree of activation was determined.

Evoked potentials associated with the movement of the finger were investigated, which were evoked by a visual paradigm. Signals were obtained for all tested electrodes with relatively large amplitudes, reaching even 6 μV. All leads selected for the experiment show well-shaped waveforms with high amplitude values. Analyzing the curves, we consider three processing phases. The early vision phase, which is in the 75–120 ms latency range, the pre-executive phase 175–260 ms and the executive phase 310–420 ms. Tables I and II show the values of amplitudes and latencies from all selected electrodes for the right and left hand. The phenomenon of lateralization during the movement of the finger of the right and left hand was examined for the subjects.

TABLE I

Potentials generated for F and C — right hand.

Electrode	Pre-MP		MP		Post-MP	
	Amplitude [μV]	Latency [ms]	Amplitude [μV]	Latency [ms]	Amplitude [μV]	Latency [ms]
F3	−0.23	16	0.52	86	−0.91	145
Fz	−0.53	35	0.43	86	−1.11	145
F4	−0.29	16	0.36	86	−1.47	145
C3	—	—	0.37	82	−1.08	148
Cz	−0.47	39	0.35	90	−0.93	141
C4	—	—	0.35	94	−1.81	145

TABLE II

Potentials generated for F and C — left hand.

Electrode	Pre-MP		MP		Post-MP	
	Amplitude [μV]	Latency [ms]	Amplitude [μV]	Latency [ms]	Amplitude [μV]	Latency [ms]
F3	0.83	27	−0.08	86	−3.34	141
Fz	0.59	27	−0.16	86	−3.6	141
F4	—	—	−0.28	86	−3.59	141
C3	0.92	23	−0.04	86	−2.56	152
Cz	0.64	31	−0.30	86	−3.27	152
C4	0.14	31	−0.41	90	−3.3	148

For motor-evoked potentials, it was noted that the amplitude values are differet, in the case of pre-motor potential, the amplitude values are greater for the left hand, for the motor potential, the amplitude values are a little larger for the right hand, but a large difference can be observed in the case of post-motor potential where the amplitude is three times greater in favor of the left hand. Tables I and II show the amplitude and latency values of all selected electrodes for the right and left hand of the patient who volunteered for the study as a right-handed person, and the results show that the patient is most likely two-handed. For the left hand, more authoritative potentials were depicted than for the right hand. The amplitude values for each potential and lead are greater for the left hand than for the right hand.

Figure 2 shows the average curves of all three fingers from leads C3, Cz, C4 for four right-handed female examinations. In the early visual phase, the largest average amplitude value is observed for the Cz electrode, in the pre-executive phase, the largest amplitude value is observed for the C3 electrode. In the executive phase, it is very difficult to notice the value of the amplitude. It may be due to the fact that the examined women reached lower amplitude values. Marker at the height of the maximum peak with the highest amplitude value, which reaches -1.89 μV. In this case, men achieve a higher amplitude value.

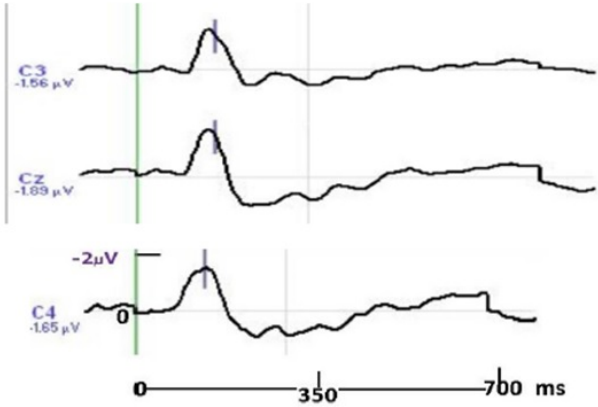


Fig. 2. Curve for electrodes C3, Cz, C4 for examined women.

4. Conclusion

Somatosensory area were detected using ERP tomography and compared with functional magnetic resonance imaging. Both methods revealed the similar networks. sLORETA turned out to be appropriate for the test source localization and analysis may help to differentiate brain areas with haemodynamic response.

REFERENCES

[1] S. Ogawa *et al.*, *Magn. Reson. Med.* **14**, 68 (1990).

[2] K.D. Davis, «New Techniques for Examining the Brain», *Chelsea House Publications*, New York 2007, pp. 37–38; J.W. Peirce, *J. Neurosci. Methods* **162**, 8 (2007).

[3] P.J. Allen *et al.*, *Neuroimage* **8**, 229 (1998).

[4] A.P. Bagshaw *et al.*, *Neuroimage* **24**, 1099 (2005).

[5] T. Ball *et al.*, *Neuroimage* **10**, 682 (1999).

[6] G. Bonmassar *et al.*, *Neuroimage* **13**, 1035 (2001).

[7] C. Christmann, M. Ruf, D.F. Braus, H. Flor, *Neurosci. Lett.* **333**, 69 (2002).

[8] R.J. Huster, S. Debener, Eichele, C.S. Herrmann, *J. Neurosci.* **32**, 6053 (2012).

[9] S. Debener, M. Ullsperger, M. Siegel, A.K. Engel, *Trends Cogn. Sci.* **10**, 558 (2006).

[10] F. Kruggel, C.J. Wiggins, C.S. Hermann, D.Y. von Cramon, *Magn. Reson. Med.* **44**, 277 (2000).

[11] R.D. Pascual-Marqui, *Methods Fin. Exp. Clin. Pharmacol. Suppl. D* **24**, 5 (2002).

[12] R.D. Pascual-Marqui, M. Essen, K. Kochi, D. Lehmann, *Methods Fin. Exp. Clin. Pharmacol. Suppl. C* **24**, 91 (2002).

[13] R. Grech *et al.*, *J. NeuroEngineering Rehabil.* **5**, 25 (2008).

[14] D. Lehmann *et al.*, *Psychiatry Res.* **90**, 169 (1999).

[15] A. Lavric, D. Pizzagalli, S. Forstmeier, G. Rippon, *Trends Cogn. Sci.* **5**, 301 (2001).

[16] A. Lavric, D. Pizzagalli, S. Forstmeier, G. Rippon, *Clin. Neurophysiol.* **112**, 1833 (2001).

[17] M. Dumpelmann, T. Ball, A. Schulze-Bonhage, *Human Brain Mapping* **33**, 1172 (2012).

[18] Y. Stern *et al.*, *J. Clin. Neurophysiol.* **26**, 109 (2009).

[19] I. Karpiel *et al.*, «Optimization Analyses of Functional MR Imaging of Motor Areas in Preoperative Patients», in: M. Gzik, E. Tkacz, Z. Paszenda, E. Piętka (Eds.) «Innovations in Biomedical Engineering, Advances in Intelligent Systems and Computing, vol. 526», *Springer International Publishing*, 2016, pp. 219–227.

[20] J. Tamraz, Y. Comair, «Atlas of Regional Anatomy of the Brain Using MRI: With Functional Correlations», *Springer*, Berlin 2005.

[21] W. Orrison, «Atlas funkcjonalny mózgu», *PZWL*, Warszawa 2010 (in Polish).

[22] M. Sommer, J. Meinhardt, H.-P. Volz, *Acta Neurobiol. Exp.* **63**, 49 (2003).