Journal of Health Sciences (J of H Ss) 2013; 3 (7): 15-20
The journal has had 4 points in Ministry of Science and Higher Education of Poland parametric evaluation. Part B item 683.

Conflict of interest: None declared. Received: 12.04.2013. Revised: 14.05.2013. Accepted: 19.07.2013.

Magnetoencephalograpy in brain-computer interfaces - current and future solutions

Magnetoencefolografia w interfejsach mózg-komputer – rozwiązania obecne i przyszłe

Emilia Mikolajewska[1], Dariusz Mikolajewski[2]

[1]Rehabilitation Clinic, The 10th Clinical Military Hospital with Policlinic, Bydgoszcz, Poland
[2]Department of Informatics, Nicolas Copernicus University, Torun, Poland

Keywords: neurorehabilitation; physiotherapy; functional neuroimaging; magnetoencephalography; MEG; brain computer interface; BCI.

Abstract

Neurological disorders may cause severe disorders. Scientists and clinicians still look forward to novel technologies allowing for precise, relevant diagnosis and effective treatment. One of the most promising technologies seems be magnetoencephalography (MEG) and its possible application in diagnostics and treatment. MEG-based brain-computer interfaces (BCIs) are regarded as another breakthrough within relatively novel but rapid developing BCI technology. This article aims at investigating the extent to which the available opportunities are being exploited including novel concepts and observations.

Słowa kluczowe: rehabilitacja neurologiczna; fizjoterapia; inżynieria biomedyczna; udar; przezczaszkowa stymulacja magnetyczna; TMS.

Streszczenie

Schorzenia neurologiczne mogą powodować poważne deficyty. Naukowcy i klinicyści ciągle niecierpliwie oczekują na pojawienie się nowych technologii umożliwiających precyzyjną i wiarygodną diagnozę oraz efektywną terapię. Jedną z najbardziej obiecujących technologii wydaje się magnetoencefalografia (MEG) oraz jej potencjalne aplikacje w diagnostyce i terapii. Interfejsy mózg-komputer oparte na magnetoencefalografii są uważane za kolejny przełom w obszarze stosunkowo nowej ale szybko rozwijającej się technologii interfejsów mózg-komputer. Artykuł ma na celu próbę oceny, do jakiego stopnia są wykorzystywane możliwości w tym zakresie z uwzględnieniem nowych koncepcji i obserwacji.

Introduction

Neurological disorders may cause severe disorders. Scientists and clinicians look forward to novel technologies allowing for precise, relevant diagnosis and effective treatment. One of the most promising seems be magnetoencephalography (MEG) and its application in diagnostics and treatment. MEG-based brain-computer interfaces (BCIs) are regarded as another breakthrough within relatively novel but rapid developing BCI technology. Current influence of research on MEG-based BCIs on quality of life of patients with neurological disorders seems be underestimated. This article aims at investigating the extent to which the available opportunities are being exploited including novel concepts and observations.

Magnetoencephalography - theory and practice

Term "magnetoencephalography" was in 1989 introduced to MeSH (Medical Subject Headings) - NLM controlled vocabulary thesaurus. It is defined as "The measurement of magnetic fields over the head generated by electric currents in the brain. As in any electrical conductor, electric fields in the brain are accompanied by orthogonal magnetic fields. The measurement of these fields provides information about the localization of brain activity which is complementary to that provided by electroencephalography. Magnetoencephalography may be used alone or together with electroencephalography, for measurement of spontaneous or evoked activity, and for research or clinical purposes." [1].

Three major databases (PubMed - U.S. National Library of Medicine, PEDro – Physiotherapy Evidence Database, Health Source: Nursing/Academic Edition) was searched to identify relevant articles. Among 6123 articles with keyword "magnetoencephalography" only 13 (0.21%) of them concern MEG-based brain-computer interface (the oldest identified was published in 2006). Despite MEG is regarded as promising future technology in BCIs, number of research and even reviews is perceived insuficient.

Magnetoencephalography (MEG) - theory and practice

EEG and MEG allows for recording of the large-scale coherence of neural signals, reflecting both intracortical communication and functional integration [2, 3].

In MEG arrays of sensors (typically: 300 and more) are arranged in way surrounding patient's head. Electric current in synchronized neuronal fields (associated with EEG as well) causes magnetic field around the head (above the scalp). Small values of this magnetic field depending on cortical activity (usually > 10-100 fT [1]) compared with much highest (even more than million times) level of surrounding noise and distorsions need for magnetic shielding of the head and MEG sensors. Omitting external noises and distortions MEG signal is less distorted than non-invasively gathered EEG signal. We should be aware that we can not measure this way activity of single neuron. Both EEG and MEG reflects mean value of neural activity: under electrode (in case of EEG) or in the face of the sensor (in case of MEG). It is estimated there is need for synchronuous activation of a lot of thousands neurons for MEG purposes. Moreover advanced signal processing is need for effective and reliable MEG signal analysis and imaging, especially in real-time analysis.

High potential of MEG for classification of mental states and identification of the undelying neural mechanisms of the performed tasks makes important research on further practical applicaiona of MEG-based devices (including MEG-based EEG) [4]. Since first recording of MEG signal in 1968 [5, 6] development of this technology was rather weak due

[1] femtoTesla

to dynamical development of EEG regarded as cheaper and easier. It seems noninvasive EEG and MEG techniques bring similar information on brain activity, high time resolution (compared e.g. with Magnetic Resonance Imaging - MRI), moreover MEG is only partially dependent on EEG, and their spatial resolution is regarded as similar [7]. But, depending on the application, EEG and MEG may complement each other, e.g. recording of MEG signals using up to several hundred electrodes is much easier and quicker than similar EEG recording. From the other side EEG and MEG may differ in the area of selectivity and sensitivity of particular signal(s) features, useful e.g. in the assessment of epilepsy [8]. Thus combined EEG + MEG may be regarded as useful in research on human brain neuroanatomy and neurophysiology, e.g. due to improved localization accuracy [9]. MEG needs for different signal processing then EEG due to i.a. other propagation conditions and possible artifiacts.

SQUID-MEGs as a current solution

Whole-head MEG devices are very rare due to high price and associated technical problems (high dimensions, shielding, results interpretation and analysis, etc.) [8]. Currently the most popular silution is use of SQUIDs (superconducting quantum interference devices). But despite advantages there is a costs problem: MEG system is 10-100 times more expensive than similar (= the same number of electrodes) EEG system. Features of the current MEG systems may be described by features as follows:

- time precision/resolution: single miliseconds,
- MEG space precision/resolution: 3-5 milimeters, limited by location, dimensions and resolution of sensors, but usually better than EEG, moreover coregistration of MEG and fMRI may increase it.

Doublessly further research on MEG allow for significant improvement of aforementioned features thanks to both technical development (where available) and complementary use of various technologies (e.g. MEG + fMRI).

MEG-based BCIs

Primary research on BCIs technology were based on EEG signal (P300, etc. [10]) as well known and easy in use. But despite more than twenty years of development EEG-based BCIs are atill at the beginning of their clinical use. Wadsworth BCI system seems be the only commercially available medical BCI system worldwide. Other promising BCIs technologies are developed slower, but for this moment we know their limitations. Thus look forward to MEG-based BCIs as next step in BCIs.

MEG-based BCIs are developed since beginning of 21st century [11, 12]. Higher temporospatial features due to larger number of sensors and wider range of detected frequencies (even > 40 Hz, not always allowed in EEG-based BCI) may provide quicker transmission required by BCI-controlled devices. The MEG-based BCI also includes the information of the direction of movement, thus control of mechanical orthosis action may be much easier. It may require sophisticated computational techniques, as clustering linear discriminant analysis algorithm (CLDA) [13].

As threats in wider use of MEG-based BCIs are regarded artifacts from electromyography (EMG), problems of head movements control (to provide equal distance to sensors), artifacts from the other muscular activity (feet, hands, etc.) [12]. In selected applications reported accuracy approx. 60% may be regarded as low in commercial devices (although reported accuracy of CLDA is 87%), despite accuracy of EEG-based BCIs is reported approx. 45-50% [14]. Reported learning time 30-40 minutes (during first two sessions) seems be quite acceptable in clinical practice [12]. Not all potential users are able to use MEG-based BCIs: in research by Buch et al. [15] only 6 of 8 (75%) of post-stroke patients achieved this result.

Directions of further research

Main future areas of MEG application in medicine concern three basic areas:

- basic research in neuroanatomy and neurophysiology,
- new diagnostic tools,
- new BCIs for communication and control purposes.

It seems development in any of afforementioned areas my imply breakthrough within the others. Thus there is need for co-ordination of further research and efforts of both clinicians and engineers toward:

1. Another breakthrough thanks to combined MEG + fMRI to reflect brain dynamics[15];
2. Technical implications: influence of coil type(s), signal processing techniques, etc. On MEG results;
3. Development of cryogen-free solutions, e.g. spin exchange relaxation-free (SERF) magnetometers;
4. Solving the problem of cortex only as source of magnetic field - there are problems with signals from deeper brain tissues.
5. Reconstitution of models of EEG, MEG, fMRI signals generation based on computational neuroscience. These models may help in deeper understanding of complex brain processess associated with particular functions. Moreover further understanding of individually shaped features of brain processess and signals may be possible.
6. Clinical guidelines, indications and contraindications of clinical MEG application.

Conclusions

Further research with the aim of development MEG technology and its medical applications (including MEG-based BCIs) are necessary. Defining the the factors determining effective MEG signals gathering, processing, analysis and imaging toward clinical guidelines is essential.

Open Access

References

1. MeSH (Medical Subject Headings) – *http://www.ncbi.nlm.nih.gov/mesh* - access 15.07.2013.

2. Papanicolaou A. C., Castillo E. M., Billingsley-Marshall R., Pataraia E., Simos P. G. A review of clinical applications of magnetoencephalography. Int Rev Neurobiol. 2005;68:223-47.

3. Sacchet M. D., Mellinger J., Sitaram R., Braun C., Birbaumer N., Fetz E. Volitional control of neuromagnetic coherence. Front Neurosci. 2012;6:189.

4. Besserve M, Jerbi K, Laurent F, Baillet S, Martinerie J, Garnero L. Classification methods for ongoing EEG and MEG signals. Biol Res. 2007; 40(4): 415-437.

5. Cohen D. Magnetoencephalography: evidence of magnetic fields produced by alpha-rhythm currents. Science. 1968; 161(3843): 784-786.

6. Cohen D. Magnetoencephalography: detection of the brain's electrical activity with a superconducting magnetometer. Science. 1972; 175(4022): 664-666.

7. Malmivuo J. Comparison of the properties of EEG and MEG in detecting the electric activity of the brain. Brain Topogr. 2012; 25(1): 1-19.

8. Barkley G. L., Baumgartner C. MEG and EEG in epilepsy. J Clin Neurophysiol. 2003; 20(3): 163-178.

9. Sharon D., Hamalainen M. S., Tootell R. B. H., Halgren E., Belliveau J. W. The advantage of combining MEG and EEG: Comparison to fMRI in focally stimulated visual cortex. NeuroImage. 2007; 36(4): 1225-1235.

10. Mikołajewska E., Mikołajewski D. Neuroprostheses for increasing disabled patients' mobility and control. Adv Clin Exp Med. 2012; 21(2): 263-272.

11. Montazeri N., Shamsollahi M. B., Hajipour S. MEG based classification of wrist movement. Conf Proc IEEE Eng Med Biol Soc. 2009; 2009: 986-989.

12. Mellinger J., Schalk G., Braun C., et al. An MEG-based brain-computer interface (BCI). NeuroImage. 2007; 36(3): 581-593.

13. Zhang J., Sudre G., Li X., Wang W., Weber D. J., Bagic A. Clustering linear discriminant analysis for MEG-based brain computer interfaces. IEEE Trans Neural Syst Rehabil Eng. 2011; 19(3): 221-231.

14. Wang J., Zhou L. Research on magnetoencephalography-brain computer interface based on the PCA and LDA data reduction. Sheng Wu Yi Xue Gong Cheng Xue Za Zhi. 2011; 28(6): 1069-1074. In Chinese, abstract in English available.

15. Buch E., Weber C., Cohen L.G., et al. Think to move: a neuromagnetic brain-computer interface (BCI) system for chronic stroke. Stroke. 2008; 39(3): 910-917.

16. Hari R, Salmelin R. Magnetoencephalography: From SQUIDs to neuroscience. Neuroimage 20th anniversary special edition. Neuroimage. 2012; 61(2): 386-396.