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ScienceDirect
Procedia Manufacturing 3 (2015) 29 – 36
Procedia MANUFACTURING

6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015

Hybrid BCI coupling EEG and EMG for severe motor disabilities

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Abstract

In this paper, we are studying hybrid Brain-Computer Interfaces (BCI) coupling joystick data, electroencephalogram (EEG – electrical activity of the brain) and electromyogram (EMG – electrical activity of muscles) activities for severe motor disabilities. We are focusing our study on muscular activity as a control modality to interact with an application. We present our data processing and classification technique to detect right and left hand movements.EMG modality is well adapted for DMD patients, because less strength is needed to detect movements in contrast to conventional interfaces like joysticks. Across virtual reality tools, we believe that users will be more able to understand how to interact with such kind of interactive systems. This first part of our study report some very good results concerning the detection of hand movements, according to muscularchannel, on healthy subjects.

Keywords: Brain computer interfaces; Hybrid BCI;Handicap; Virtual reality

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1. Introduction

Although the concept of Brain-Computer Interface (BCI) had been introduced by Vidal [1] in 1973, it really emerged as a new field of research in the early nineties when systems allowing real-time processing of brain signals became available. Since then, BCI research has seen an impressive growth in the domains of neuroscience,

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doi:10.1016/j.promfg.2015.07.104

computer science, and clinical research. However, there are still a significant number of theoretical and technological issues that have to be dealt with, probably with a maximum efficiency if following an interdisciplinary approach. BCI is considered as an effective tool for rehabilitation and/or assistance of severely impaired patients. In our team, we are particularly working on BCI for Duchenne Muscular Dystrophy (DMD). DMD is a severe pathology of the skeletal musculature. It affects mostly males and is due to a progressive degeneration of the skeletal muscles but also of digestive, respiratory and heart muscles. Other disorders appear such as bone fragility, microcirculation disorders, nutritional disorders and anxiety syndromes. Recent advances in medicine may help delay the symptoms of DMD, and increase life expectancy of patients, but unfortunately fail to stop the natural evolution that leads to progressive loss of motor skills to extremely severe quadriplegia (see fig 1).

In the context of progressive, degenerative and very disabling disease such as DMD, the recommendation of assistive technology must adapt to the constant changes in the functional state of the user and each time the disease evolves. The purpose of our study is to observe various muscle and brain signals, when users push joysticks, typically to move a character in a 2D or 3D maze, or a car on a road, for instance.We want to check the level of correlation between movements performed by the patients (finger and foot) and changes in electrophysiological potentials (EEG and EMG). This correlation is well known for healthy people. For example, in the preparation of a motor action, a desynchronization of cortical rhythms in the beta and mu frequency band can be detected on the EEG signals recorded over motor areas. This desynchronization precedes the appearance of bursts of action potentials in EMG signals and the realization of movement. Our goal is to check whether similar correlations are present in DMD subjects, and if so at what level of repeatability and robustness they can be identified, at different stages of disease progression.

In this study, we mainly focus our attention on EMG signal. This electrophysiological potential is one component of our hybrid system. We want to know if, independently of the others (joystick and EEG), it carries relevant information for hand movements detection.The paper is organized as the following: part 2 presents our motivation in helping people suffering from muscular dystrophy or schizophrenia with BCI approaches; part 3 describes our approach around Hybrid BCI and virtual reality; part 4 and 5 presents the conducted experimentation and EMG data processing and classification techniques for hand movements detection; part 6 describes the obtained results; the last part gives a short conclusion and some perspectives for this work.

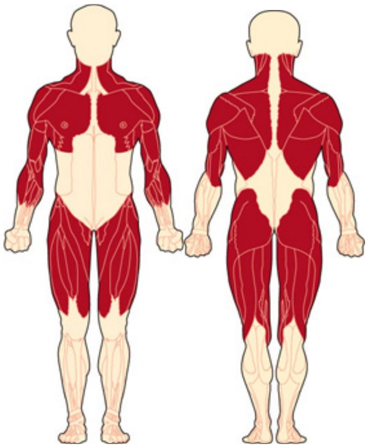

Fig. 1. In the early stages, DMD affects the shoulder and upper arm muscles and the muscles of the hips and thighs (in red). These weaknesses lead to difficulty in rising from the floor, climbing stairs, maintaining balance and raising the arms.[1]

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[1] Source: http://mda.org/disease/duchenne-muscular-dystrophy/overview

2. Helping disable people with BCI approaches

In the early stages of progressive disease such as DMD, the patient is still able to use his/her muscles. Thus, he/she can be trained to use a hybrid BCI with channels measuring his/her motion, his/her muscle activities through electromyography, as well as the activity of his/her motor and pre-motor cortical areas [2]. Later, with the disease evolution, motion-related channels will become less informative and the challenge will be to allow the control channels related to brain activity to take over. Clinicians of the physical medicine and rehabilitation service of Lille University Regional Hospitals will define user needs, recruit and manage DMD patients for long term experiments. Colleagues of the clinical neurophysiology service at Lille University Hospital help us define the most appropriate markers of cortical activity for each interaction task.

2.1. For people suffering from muscular dystrophy

As we said before, our first target population will be people suffering from Duchenne Muscular Dystrophy (DMD), but for the moment, we are improving our interactive system by testing it on healthy people. We are focusing on virtual reality in order to provide a better feedback to users. The goal of virtual reality is to enable a person to obtain a sensorimotor and cognitive activity in an artificial world, created digitally, which can be imaginary, symbolic or a simulation of certain aspects of the real world. For instance, Figure 2 presents hybrid BCIs developed in our laboratory, where the user can see in a virtual world (NeoAxis or Unity3D), realistic effects of his/her interaction in the world, when he/she pushes Arduino scanned buttons (left hand, right hand or both simultaneously) and/or when he/she thinks of pushing the buttons. We are also planning to use this approach (hybrid HCI and virtual reality) with other kinds of patients, such as schizophrenic people, where serious games will hopefully help to detect and manage their psychiatric disorders.

2.2. For people suffering from schizophrenia

As explained previously, DMD patient sometimes suffer from anxiety syndromes. Thus, we are also interested in the observation of brain signals detected on people suffering from schizophrenia. And so, our maze designed with Unity3D to study DMD pathologies could also be used with psychiatric disorders such as schizophrenia.

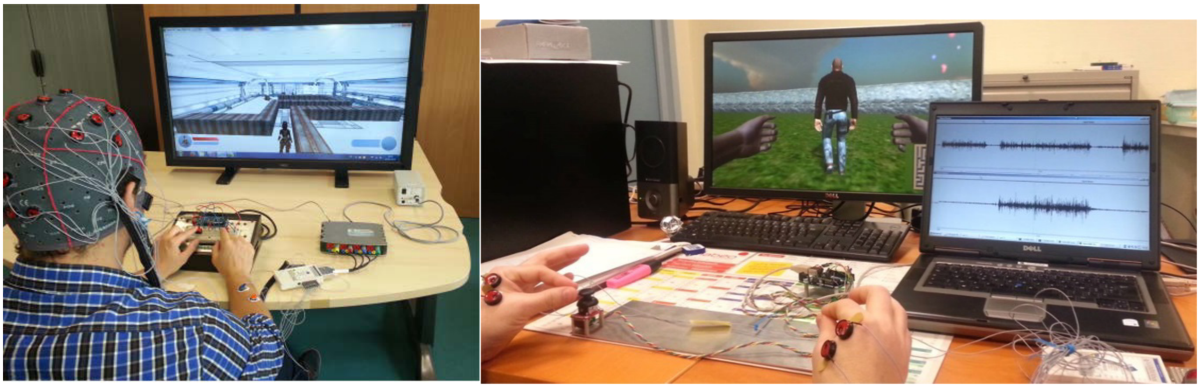

Fig. 2. (Left): Hybrid BCI developed in our team (EEG, EMG and Arduino). (Right): Hybrid BCI and virtual reality showing on the screen the hand(s) to move and the avatar responding to muscular commands

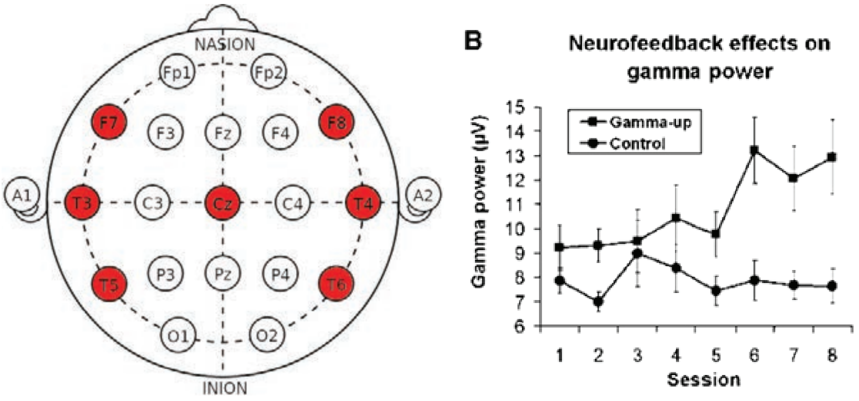

Fig. 3. Left: International 10-20 system and chosen electrodes. Right: Neurofeedback effect on gamma power (30-60 Hz) [4].

The maze would allow working on 2 items: occurrence of Auditive Verbal Hallucination (AVHs) and spatial memory. Many studies have characterized profiles of abnormal neuronal oscillations of schizophrenic (SCZ) patient. For example, reduction of the amplitude of theta waves and delayed phase are significant clues to detect such profiles [3]. We propose the use of a virtual maze because Theta waves are involved in the spatial orientation. The complexity of the maze would depend on the amplitude of SCZ's theta waves that will be measured in temporal area (see Fig 3, left).

A recent study [4] demonstrated that the repeated use of a playful serious game allows increasing the amplitude of gamma waves. The working assumption is that the same phenomenon could be observed with theta waves. In first time, increase of the theta wave would allow to resolve the problems of spatial orientation. In second time, as suppose McCarhy [5], this increase could reduce the severity of the AVHs or their occurring. The use of this serious game would also allow interacting with objects triggering the AVHs. Recent study [6] demonstrates that SCZ patient can identify these objects. We propose to place/hide/animate such objects in the maze. The aim would be to observe the effect these objects cause on profiles of neuronal oscillations of schizophrenic patient.In parallel we propose to work with the SCZ patient to develop strategies to be adopted during AVHs. McCarthy [4] proposes to use the humming, based on studies showing less AVHs occurred in periods when SCZ patients are humming [7].The aim would be to develop these strategies based on the song then to ask the SCZ patient to apply these strategies in front of the elements met in the maze. Among them the object activing would be hidden. The objective would be to re-educate the patient in its fear and to validate the use of the humming.

3. Hybrid BCI and virtual reality

To improve the speed and robustness of communication, Leeb et al. [8] have recently introduced the so-called "hybrid BCI" notion, in which brain activity and one or more other signals are analyzed jointly. We consider that each channel of our hybrid BCI carries some relevant information to understand the achievement of a particular task and we apply sensor fusion techniques to improve man-machine communication and interface robustness. Our goal is to provide various data (EEG, EMG and actual movements measured by the Arduino) to the kernel of our system (OpenVibe[2]) that performs a data fusion to derive the command sent to the avatar through a VRPN protocol [9].Analysis of EEG signals collected over the scalp provides guidance on the amplitude and phase of cortical rhythms, allowing to identify synchronizations or desynchronizations related to a real or an imagined event (movement of a limb, for example) [10, 11].The electromyography (EMG) detection allows the analysis of electrical phenomena that occur in the muscle during voluntary contraction. This examination detects an electrical signal

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[2] http://openvibe.inria.fr, retrieved on 08/04/2015

transmitted by peripheral motor neuron to the muscle fibers it innervates, called motor unit action potential (MUAP) [12]. Standard techniques use invasive electrodes, usually with concentric needles. The explored area is reduced and the exploration is very precise.But there are also non-invasive “global” EMGs, using a surface electrode, exploring a larger territory, applicable to many muscles. A compound muscle (or motor) action potential (CMAP) is then collected [13]. There are mainly used in the study of muscle strength and fatigue in patients with neuromuscular diseases [14].Patients with Duchenne muscular dystrophy have a myogenic EMG pattern during physical effort. Abnormally high compared to the effort, it is composed of potential polyphasic motor units, with low amplitude and short duration. Abnormal spontaneous activity can also be detected in the form of potential fibrillation waves of positive sharp waves and complex repetitive discharges. In very advanced forms, some areas may become electrically silent [15].The analysis of the EMG signal can be made on motor unit potential (MUP) [16], [17] or compound muscle action potential (CMAP) parameters [14], to check various elements such as duration, peak to peak amplitude, total area under the curve, number of phases, etc.

4. Experimentation

The experiment was realized by nine healthy subjects (6 men and 3 women) aged between 20 and 53 years old. Subjects' approval was verbally required. Two of them had previously used the system. Participants were asked to seat comfortably in an armchair and to keep their indexes on each joystick. They were asked to avoid blinking their eyes or contracting their jaws during the experiment in order to prevent recording ocular and muscular artifacts.

Subjects were wearing an electrode cap (GAMMAcap, g.tec), with Ag/AgCl electrodes located according to the international 10/20 system. Ten mono-polar channels were recorded from the central, parietal and frontal lobe: C1, C2, C3, C4, C5, C6, FC3, CP3, FC4 and CP4 with an electrode clipped on the right ear as a reference and another one on the forehead as mass. A gel was applied between skin and electrodes to increase conduction of electrical signal. Signals were amplified and sampled at the frequency Fe=512 Hz.Two bipolar channels were placed on left and right hands in order to record muscular activities when users manipulate the joysticks.Figure 3 shows our system which is composed of a physiological signals amplifier with 16 channels (g.USBamp, g.tec), two DELL computers using XP and windows 7 operating systems. Two joysticks are connected to the USB port of one computer via an Arduino UNO. On one computer runs OpenVibe software which collects data from EEG, EMG and Arduino sources. OpenVibe allows controlling online signal acquisition, signal processing and commands sending for application control. On the other computer runs the application developed under Unity 3D. The two computers are linked with an ethernet cable which enables commands sending from OpenVibe to Unity 3D application thanks to VRPN protocol.

The experiment was composed of a calibration phase followed by two online phases. During those second and third parts of the experiment, participants were asked to control a character in a maze. The experiment lasted about one hour. The calibration phase enables to record EMG and EEG data at specific moment. During this phase, the user has to push on the left, right or on both joysticks according to orange arrows displayed on the screen (see Fig. 4).During online phase users have to get the character out of the maze, following a yellow path. The character rotates to the right or left or goes straight by activating respectively right, left or both joysticks. In the first online phase the user controls the character thanks to joysticks. In the second online phase, joysticks are switched off and control is only based on muscular activity.

Fig. 4. Experiment setup.

The following section describes data processing and classification techniques which enable EMG-based control. Experiment ends with a questionnaire in order to get qualitative data.

5. Data processing and classification

Figure 5 shows signals used in our hybrid system: right joystick values, EMG from right hand and EEG from C3 electrode. They were recorded during a right hand movement which lasted 5 seconds. This movement is well detected thanks to joystick values and EMG signal. Indeed EMG amplitude is further during muscular contraction. Nevertheless EEG signal needs more processing in order to highlight relevant information and detect a hand movement.

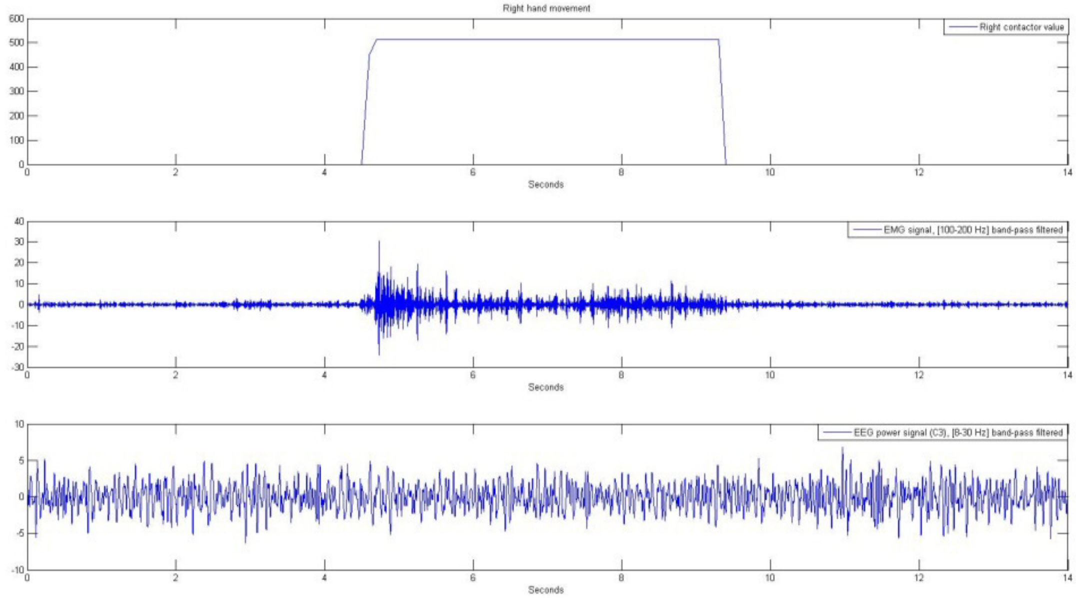

Fig. 5.From top to bottom: right joystick values, EMG and EEG signal.

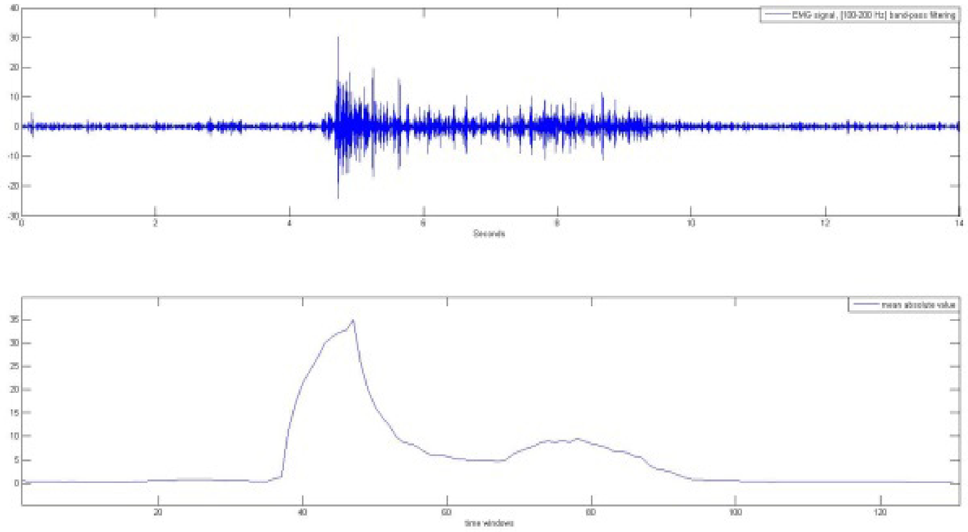

Fig. 6.From top to bottom: filtered EMG signal and mean absolute value of windowed signal.

As you can see on bottom of fig.5, EEG signals are not yet filtered and too noisy, so they will be ignored in this preliminary study. This part covers all signal processing and classification technique to detect right and left hand movements from EMG. Signal processing allows us to remove as many artifacts as possible from the signals in order to keep only relevant information. A LDA (Linear Discriminant Analysis) classifier uses this information to identify patterns specific to muscular contraction and to send orders to an online application. Two LDA classifiers are calculated, respectively for right and left hand movements. The first processing step consists in filtering raw signals from each bipolar channel between 100 and 200 Hertz with a 4th-order Butterworth band-pass filter. Then a window of 1 second is extracted from the filtered signals each tenth of second. To detect a hand movement, 3 distinctive features are calculated from each window: mean absolute value [18], signal length and root mean square [19].

Figure 6 shows filtered EMG signal and mean absolute value of windowed signal. Rest and hand movement periods are well differentiated after data processing. Finally, features values from right and left bipolar channels are sent respectively to right and left hand classifiers in order to detect right or/and left hand movements. Data recorded during calibration phase are used to calibrate those classifiers. A 5-fold cross validation test is used to assess classifier performances.

6. Results

The average time needed by users to get the character out of the maze based on muscular activity is slightly higher (173 seconds; standard deviation: 51seconds) than with joystick-based control (152 seconds; standard deviation: 42seconds). Nevertheless, a Wilcoxon non-parametric test doesn't show a significant difference (p-value = 0.2973) of time between muscular and joystick-based control, with an alpha risk of 5 %. Moreover, qualitative data indicate that users feel interact with muscular-based control as well as with joystick modality. This resultsshow that muscular activity can be correctly used as a reliable control modality for hybrid BCI. A 5-fold cross validation test is used to assess performances of left (0.99) and right (0.98) classifiers. According to these results, our data processing and classification techniquesclearly well detect hand movements. Moreover these good results are confirmedduring online phase:all users succeed in moving correctly the character without touching the joysticks.

7. Conclusion and perspectives

In this paper we have shown the reliability of our data processing and classification technique to detect hand movement, in the context of Hybrid BCI coupling EEG and EMG for severe motor disabilities. Indeed classification performances and time to get out of the maze using muscular modality are very satisfying. It is supported by qualitative data, indicating that participants feel well interact with this modality. Moreover, time comparison, thanks to a Wilcoxon test between joystick and muscular-based control doesn't indicate a significant difference. These results seem to show that muscular modality is a reliable control modality. Users can easily switch from joystick modality to muscular one without a significant loss of performance. This is particularly interesting for DMD patients who suffer from a loss of motor skills. User can initially use joysticks to interact with applications. Then, when he/she has some difficulties to handle joysticks, muscular modality can take over. Indeed, muscular-based control needs less ample movements and strength. Further experiments will be performed soon in order to assess our system with DMD patients. It will show if muscular activity is a reliable control modality in despite of their lower strength compared to healthy subjects.Obviously,the EEG signal processing is a necessary next step of this hybrid BCI approach. We will also use belief functions or/and others techniques available in the literature in order to realize appropriate online fusion of data generated from various modalities.

References

[1] Vidal, J.J.: Toward direct brain-computer communication. Annual review of Biophysics and Bioengineering 2(1), 157-180 (1973)

[2] Bermudez iBadia, S., Garcia Morgade, A., Samaha, H., Verschure, P.F.M.J.: Using a hybrid brain computer interface and virtual reality system to monitor and promote cortical reorganization through motor activity and motor imagery training. Neural Systems and Rehabilitation Engineering, IEEE Transactions on 21(2), 174-181 (2013)

[3] Uhlhaas, P.J., Singer, W.: Abnormal neural oscillations and synchrony in schizophrenia. Nature reviews neuroscience 11(2), 100-113 (2010)

[4] Keizer, A.W., Verschoor, M., Verment, R.S., Hommel, B.: The effect of gamma enhancing neurofeedback on the control of feature bindings and intelligence measures. International Journal of Psychophysiology 75(1), 25-32 (2010)

[5] McCarthy-Jones, S.: Taking back the brain: could neurofeedback training be effective for relieving distressing auditory verbal hallucinations in patients with schizophrenia?. Schizophrenia bulletin, sbs006 (2012)

[6] Escher, S., Romme, M., Buiks, A., Delespaul, P., Van Os, J.I.M.: Independent course of childhood auditory hallucinations: a sequential 3-year follow-up study. The British Journal of Psychiatry 181(43), s10-s18 (2002)

[7] Green, M.F., Kinsbourne, M.: Subvocal activity and auditory hallucinations: Clues for behavioral treatments?. Schizophrenia Bulletin 16(4), 617 (1990)

[8] Leeb, R., Sagha, H., Chavarriaga, R., del R Millan, J.: Multimodal fusion of muscle and brain signals for a hybrid-BCI. In Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE, pp. 4343-4346 (2010)

[9] Taylor II, R.M., Hudson, T.C., Seeger, A., Weber, H., Juliano, J., Helser, A.T.: VRPN: a device-independent, network-transparent VR peripheral system. In Proceedings of the ACM symposium on Virtual reality software and technology, pp. 55-61, ACM (2001)

[10] Pfurtscheller, G., Aranibar, A.: Event-related cortical desynchronization detected by power measurements of scalp EEG. Electroencephalography and clinical neurophysiology 42(6), pp. 817-826 (1977)

[11] Derambure, Ph., Defebvre, L., Bourriez, J.L., Cassim, F., Guieu, J.D. : Désynchronisation et synchronisationliées à l'évènement. Etude de la réactivité des rythmesélectrocorticauxen relation avec la planificationetl'évolution du mouvementvolontaire. Neurophysiol.Clin. 29, 53-70 (1999)

[12] Bouche P.: Electromyographieclinique. EMC – Neurol. 5(3), 1-32 (2008)

[13] Labarre-Vila, A.: Électromyographie de surface etfonctionmusculaireenpathologie. Revue Neurologique 162(4), 459-465 (2006)

[14] Lindeman, E., Spaans, F., Reulen, J.P., Leffers, P., Drukker, J.: Surface EMG of proximal leg muscles in neuromuscular patients and in healthy controls. Relations to force and fatigue. Journal of Electromyography and Kinesiology 9(5), 299-307 (1999)

[15] Yiu, E.M., Kornberg, A.J.: Duchenne muscular dystrophy. Neurology India. 56(3), 236–47 (2008)

[16] Zalewska, E., Hausmanowa-Petrusewicz, I.: Global and detailed features of motor unit potential in myogenic and neurogenic disorders. Medical engineering & physics 21(6), 421-429 (1999)

[17] Sonoo, M., Stålberg, E.: The ability of MUP parameters to discriminate between normal and neurogenic MUPs in concentric EMG: analysis of the MUP “thickness” and the proposal of “size index”. Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section 89(5), 291-303 (1993)

[18]Zecca, M., Micera, S., Carrozza, M. C., & Dario, P. (2002). Control of multifunctional prosthetic hands by processing the electromyographicsignal.Critical Reviews™ in Biomedical Engineering, 30(4-6).

[19] Kim, J., Mastnik, S., & André, E. (2008, January). EMG-based hand gesture recognition for realtimebiosignal interfacing. In Proceedings of the 13th international conference on Intelligent user interfaces (pp. 30-39). ACM.