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Analysis of Electrodermal Activity during Performance of Two-Leveled Mental Arithmetic Task and Its Possible Implications in Man-Machine Interface

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Abstract

There are limited practical methods available for communicating with the people who are in a locked-in state. This experiment is designed to examine the changes in Electrodermal activity (EDA) in young individuals in the performance of two levels of arithmetic mental calculation tasks. Seven Male and five Female participants had performed the two levels of mental arithmetic (MA) calculations, *i.e.*, 15 easy and 15 calculative. Each task was for 10 seconds, for both easy and calculative and presented in a random manner, and digital data of EDA was acquired. EDA from the easy MA task showed higher values in when compares to that obtained during the calculative MA task. With increased complexity in MA assignments, EDA decreases that are influenced by the autonomic nervous system under increased complexity of the mental arithmetic task and a pattern of separation at just before the 6th second from the onset of MA task has been identified. This study demonstrates the potential of using mental arithmetic based mental exercises to examine their influence on EDA of the performers.

Keywords: Autonomic Nervous System; Electrodermal Activity; Mental-Arithmetic task; Man-Machine interface.

Introduction

Physical disability is characterized by the inability to make use of body parts at will either partially or wholly. In many instances, mental blockade or a locked-in condition turns out to be the cause of such disability [1, 2]. In such circumstances the individual loses his/her ability to speak and reaches a complete paralytic condition, thus being deprived of any means of communication with the people around him. There is intactness of conscious mind, and the individual is able to feel and understand everything but lacks ways of interacting with the environment [3]. There may be an exhibition of certain voluntary functions such as yawning tearing or drooling, but these activities do not serve the purpose of communication effectively.

Development that have been made the area of brain-computer interface has provided efficient alternative for communicating with the disabled, making use of the technologies such as electroencephalography via either surface or brain-implanted electrodes [4, 5, 6]. Although much research has been done to improvise their usability, these modes are still in their development stage [6, 7, 8]. It is the lesser readiness to use, expense and real-time analytical integration of brain-computer interface that has lead to encouragement of research for alternate modes of communication.

Studies of autonomic physiological changes for the differentiation of mental states can serve as an alternative approach to communicating with such subjects. There are a number of physiological signals which can be correlated with an individual's mental states, namely electrodermal activity, heart rate, blood pressure and respiration rate [9, 10]. Electrodermal activity (EDA) comprises of the changes in electrical properties of the skin caused by sympathetic stimulation of the sweat glands. Skin conductance is a widely studies property and can be quantified by the application of an electric potential between two points of skin contact and measuring the resulting current flow between them. EDA has also been recorded from patients where sweating is entirely absent [11].

The purpose of this study is to determine the possible distinction in the EDA of individuals during the performance of two levels of Mental Arithmetic (MA) tasks, namely Easy and Calculative. Effects of such mental activity have been addressed prominently in previous studies showing variation in autonomic activity with MA tasks. As the EDA has a link with the autonomic variations of an individual, such identified patterns of changes may be unique and affirmative. These may be proposed to have direct application in Human-Machine Interaction.

Materials and Methods

For signal acquisition, 12 subjects (7 Male and 5 Female) had participated strictly on a voluntary basis; all lying within the age group of 18-25 years. All the subjects were explained and demonstrated a sample paradigm and the care was taken that every query of the volunteers regarding the experimental procedure was answered to their satisfaction. They were required to fill up and sign a consent form including a small health questionnaire before the experiment. All the subjects were having a normal vision or corrected-to-normal vision and hearing.

Task Design:

The task assigned in this study was MA calculation. An instruction paradigm for the task was designed using Superlab 4.5 (Cedrus, USA). It is a cue-based paradigm, worked in real time with the signal acquisition system MP35 (Biopac Inc, Goleta, California, USA). There were two sets of mental calculation instructions designed for the experiment, *i.e.*, easy and calculative; each set consisting of 15 questions. The easy mental calculation tasks consisted of easy level questions (e.g. 2+2.9; uses simple summation or subtraction); the higher calculative level questions (e.g. 4.65×7.82)/41.9; uses multiple arithmetic operators) as shown in figure 1. Two computers were used for the work that was connected in real-time for the paradigm part. One of the monitors displayed the MA instructions and on the other, the signals, which were being recorded with the cue applied, were displayed.

Recording Procedure:

The easy and the calculative tasks appeared in a random manner on the computer screen. The subjects were provided with a response sheet, where they were required to calculate and write down the answers to the MA calculations. The paradigm started with a blank screen (black in color) and remains for 2 seconds; followed by a fixation cross for 1 second. This fixation cross served as an indicative signal for the subject that the task (easy or calculative) was about to begin. The time allotted for each MA calculation for every individual task was 10 seconds after that a response time of 3 seconds was allotted during which the subjects were supposed to write their responses. The paradigm is illustrated in figure 1. Before the beginning of the recording session, the subjects were instructed well and were made to perform a similar task of short duration for making them well acquainted with the task to be performed.

The EDA was recorded from the middle and the ring fingers of the left hand of the subjects. Single session continuous recording of the subjects was done throughout all the 15 easy and 15 calculative tasks appearing randomly on the screen as shown in figure 2. It was a single subject single session recording. Acqknowledge 4.0 (Biopac Inc, Goleta, California, USA) was used for all the preprocessing and processing of the signals. For both easy and calculative arithmetic assignments, the EDA responses were evaluated and averaged. Both averaged tachogram and EDA were further normalized to maintain the baseline.

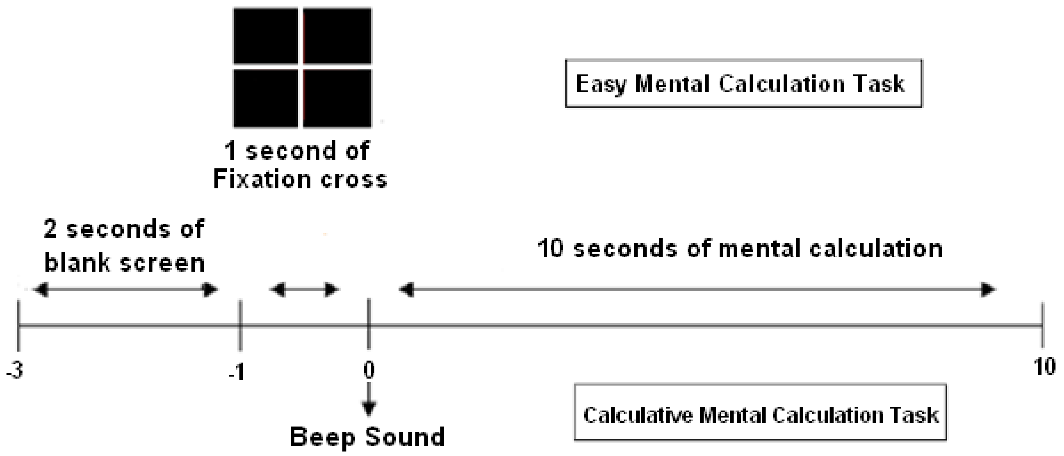

Figure 1: Schematic representation for the paradigm design.

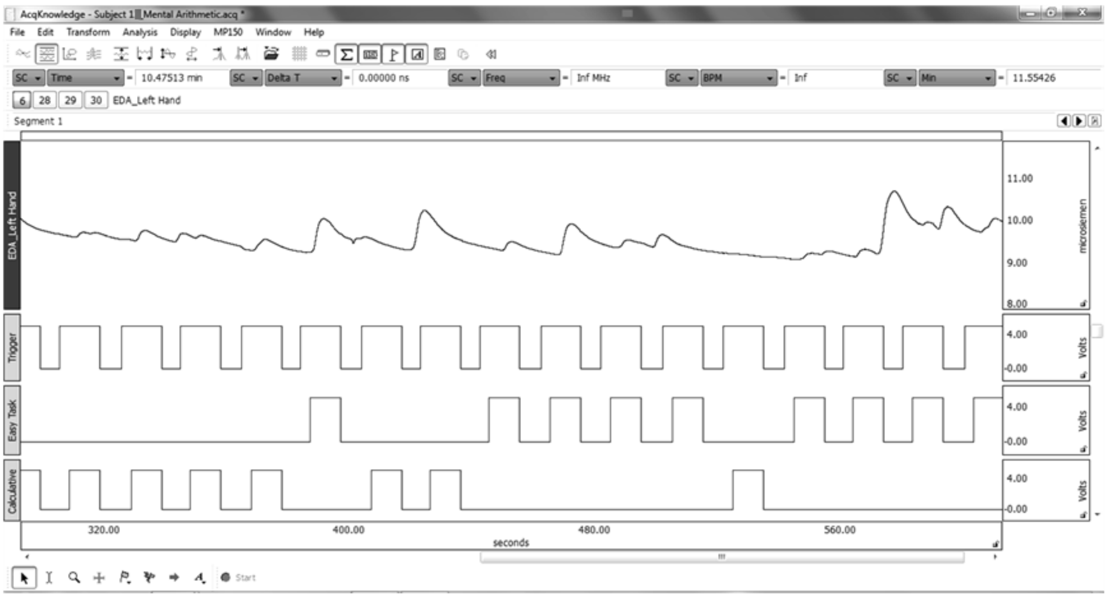

Figure 2: Representation of Recorded Signal along with the cue.

Statistical Analysis:

The statistical analyses were performed on MS Excel (MS Office 2007, Microsoft Inc) and also verified manually. Significance of the changes in EDA during the easy mental arithmetic task and the calculative mental arithmetic task were calculated using the Student's *t*-distribution. For analysis the mean EDA of the averaged subjects for both the easy and the calculative tasks were analyzed. A brief description of the Student's *t*-distribution analysis is given below.

The "*t*-statistic" is defined as:

$$t = \frac{\bar{X} - \mu}{S} \times \sqrt{n} \quad (1)$$

Where,

$$S = \sqrt{\frac{\sum (X - \bar{X})^2}{n-1}} \quad (2)$$

The t-distribution has been derived mathematically under the assumption of a normally distributed population.

It has the following form

$$f(t) = C\ (1 + \frac{t^2}{v})^{-(v+1)/2} \quad (3)$$

Where

$$t = \frac{(\bar{X} - \mu)}{S} \times \sqrt{n}$$

C = a constant required to make the area under the curve equal to unity
v = *n – 1*, the number of degrees of freedom.

Results
Analysis of Electrodermal Activity:
A total 45 trials each of easy and calculative MA tasks were used for the analysis of outcomes. For getting the results of the Easy task, the subjects did not take more than 5 seconds. However, for the calculative task, the subjects remained busy during the entire trial period. This was also confirmed from the subjects by getting their responses in answering the assignments.

Raw EDA signals recorded for the easy and the calculative MA tasks can be seen as in figure 3. The comparative results for the calculation of EDA for both Easy and Calculative MA are presented in figure 4 & 5, respectively. The figure 4 depicts relative plot for all the 12 subjects along with their averaged graph. A similar representation has been shown in figure 5 for the Calculative MA task. The EDA of all the twelve subjects is showing almost the same results. During the calculative MA tasks, fall in EDA is evident in all the twelve subjects, but at the same time, it was showing elevation just after the start of easy tasks. A similar trend in the graph can be seen in the raw EDA signal also as depicted in figure 3.

Further close visual analysis of the graph in figure 4 clearly illustrates a pattern being followed by the EDA of twelve subjects, and this is in close association with their average signal that is represented by a dashed line. Here it can be seen that the EDA for all the subjects maintained a proximity to the baseline to the 6th second and swayed away above the baseline after that. However, 9 out of 12 subjects have followed a particular pattern; 9 subjects can be seen to move below the baseline after 6th second from the onset of the task, whereas one subject does so after the 8th second. The average of the 12 subjects for the calculative tasks maintains proximity to the baseline till 4 seconds and gradually moves below to the lower side after that. This gradual descent is continued till the 8th second and after that it moves away from the baseline in quick successions.

A comparison between the averaged Easy and the averaged Calculative tasks for all the 12 subjects has been shown in figure 6. Here it can be clearly seen that there is a latency of 2 seconds in the EDA signals after the start of tasks (both easy and calculative). The separation of the signal begins just before the 6th seconds which is in agreement with the pattern shown by the individual subjects. All the 12 subjects showed significance in the *t*-test. The overall average obtained for all the subjects was significant for P<0.01.

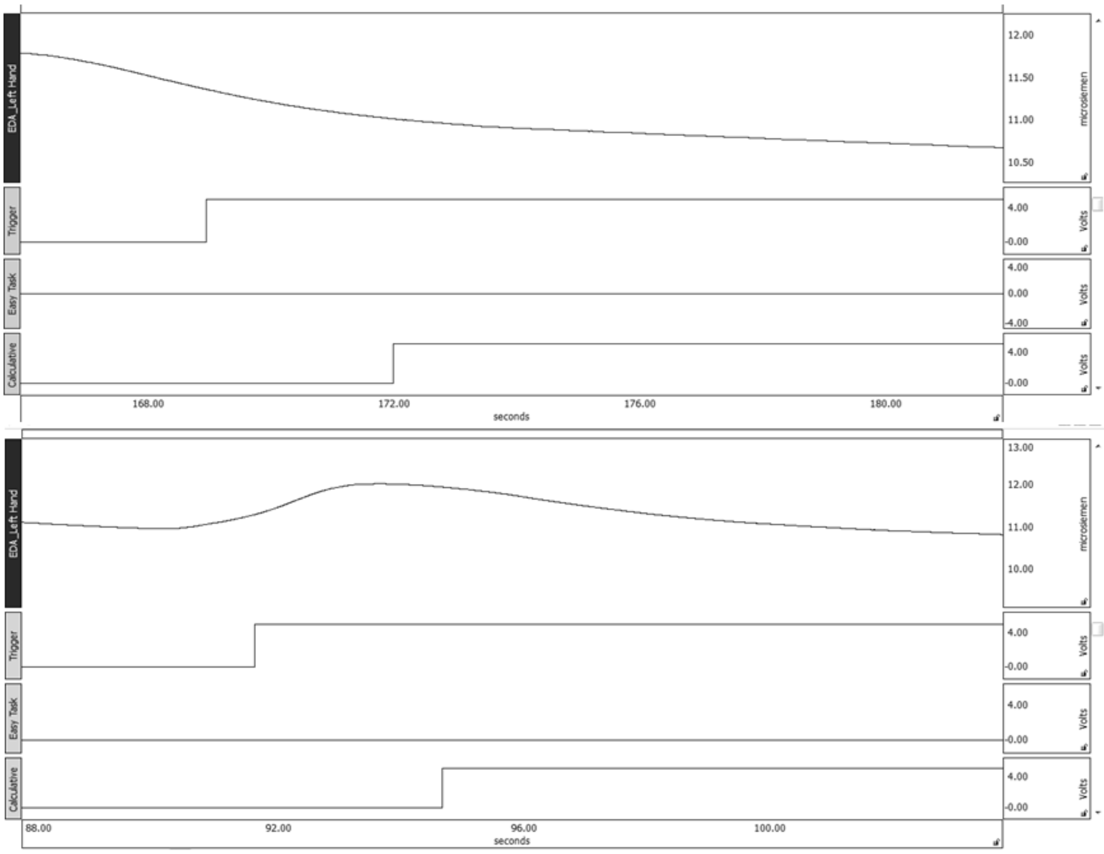

Figure 3: Raw EDA signal of Easy vs. Calculative Mental Arithmetic tasks.

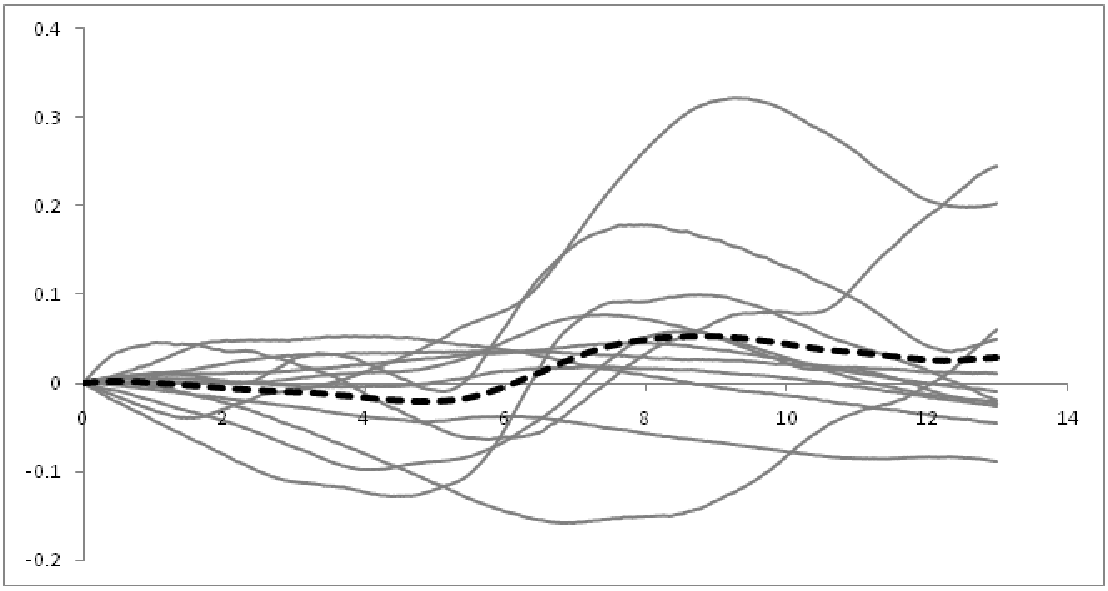

Figure 4: Significant changes during performance of easy MA task of 12 subjects along with their averaged result (dotted line).

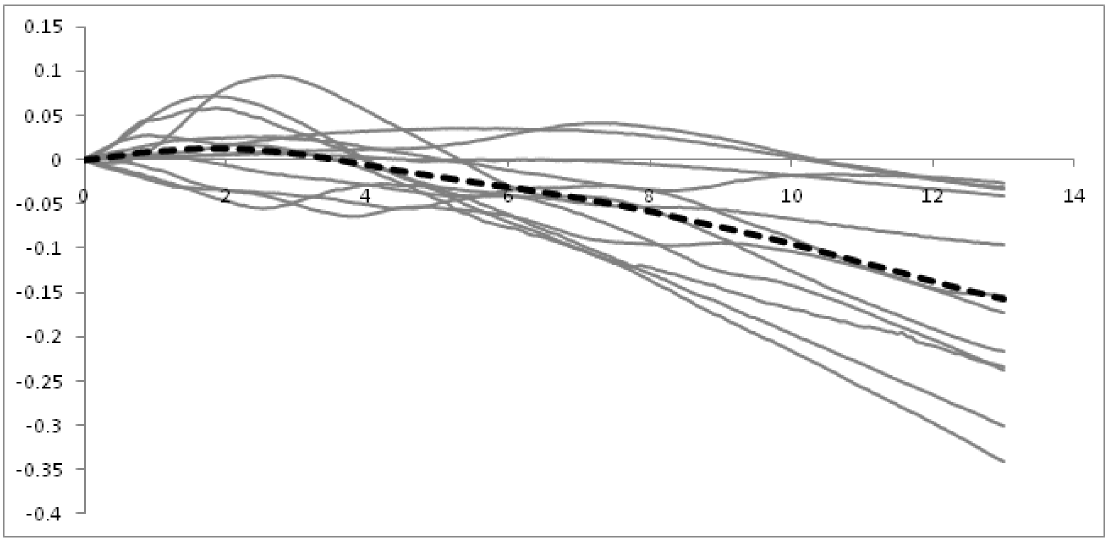

Figure 5: Significant changes during performance of calculative MA task of 12 subjects along with their averaged result (dotted line).

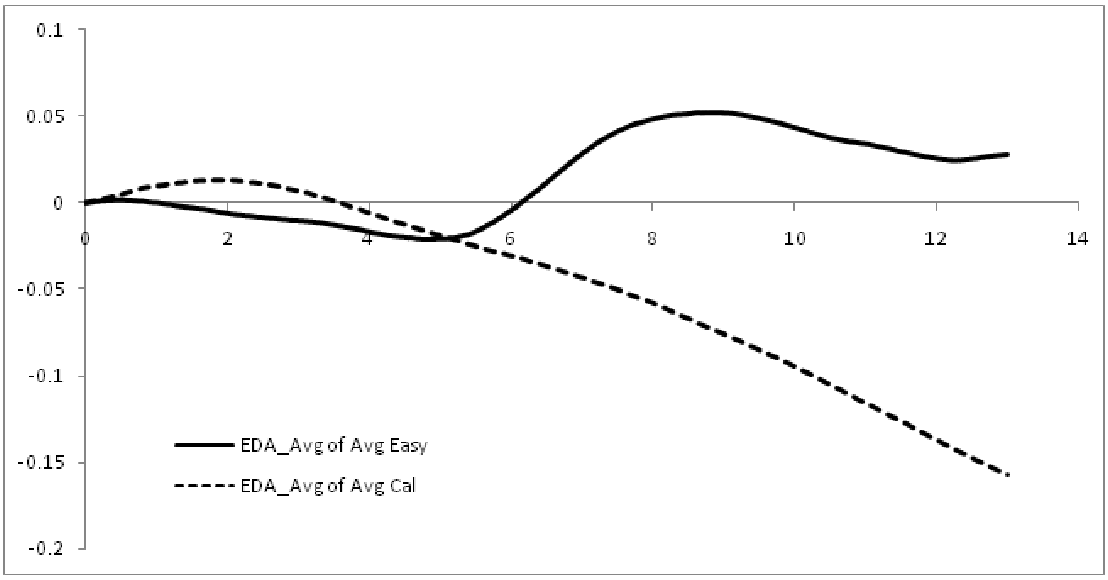

Figure 6: Comparison of the average of 12 subjects on performance of Easy and Calculative MA tasks.

Discussion

In this study, the variations caused in EDA upon subjection to two levels of MA tasks, *i.e.*, easy and calculative, have been analyzed. A clear pattern of separation can be identified among the two different tasks in EDA signals. During the time when the brain is focused on task performance, there is a decrease in EDA response and vice-versa when the task is complete. This can be clearly understood from the fact that the easy task took about 4-5 seconds for the subjects, and there is a variation in the signals that were observed only after easy task performance time. Whereas, the calculative task kept the subjects focused and the entire time was spent in task performance; the signals maintained a proximity to the baseline. It was observed that upon statistical analysis using *t*-test, the average of all the 12 subjects gave a significant result for $P<0.01$.

The Electrodermal Activity (EDA) has shown an increase in the EDA response for easy tasks in comparison to the calculative tasks which depicts sympathetic suppression in response to the cognitive suppressor that is mental arithmetic here. This result is in contrary to that obtained in some of the previous studies [12, 13]. As EDA is solely defined by the sympathetic branch of ANS, which is seen here in this experiment to be of a lesser value in increased task difficulty situation, thus it can be said that there is a decrease in the sympathetic activity of the ANS during the calculative task when compared to the easy MA task. Based on the results obtained, the MA can also be advocated as a suitable alternative to motor imagery for implication in Brain-Computer Interfaces.

Conclusion

In the present study, dual levels of mental tasks have been analyzed. The results show that there is a clear separation of the EDA signal of all the subjects for the easy and calculative MA tasks. This separation occurs in a definite initial period of task propagation and can be used as an important feature in the application for MA-based Brain-Computer Interface system. Further studies in using MA-based systems using EDA need to be carried out and it has the potential for development of a communication device who are in a locked-in state through a binary switch governed by changes in the skin potentials of such individuals.

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References

[1] Kaplan, D. M. (1999), 'Stroke: Pathophysiology, Diagnosis, Management', *University of Toronto Medical Journal* **76**(3), 196--197.

[2] Krasnianski, M.; Gaul, C.; Neudecker, S.; Behrmann, C.; Schlüter, A. & Winterholler, M. (2003), 'Yawning despite trismus in a patient with locked-in syndrome caused by a thrombosed megadolichobasilar artery', *Clinical neurology and neurosurgery* **106**(1), 44--46.

[3] Kotchoubey, B.; Lang, S.; Winter, S. & Birbaumer, N. (2003), 'Cognitive processing in completely paralyzed patients with amyotrophic lateral sclerosis', *European Journal of Neurology* **10**(5), 551--558.

[4] Isreal, J. B.; Chesney, G. L.; Wickens, C. D. & Donchin, E. (1980), 'P300 and Tracking Difficulty: Evidence For Multiple Resources in Dual-Task Performance', *Psychophysiology* **17**(3), 259--273.

[5] Vaughan, T. M.; Wolpaw, J. R. & Donchin, E. (1996), 'EEG-based communication: prospects and problems', *Rehabilitation Engineering, IEEE Transactions on* **4**(4), 425--430.

[6] Wolpaw, J. R.; McFarland, D. J.; Neat, G. W. & Forneris, C. A. (1991), 'An EEG-based brain-computer interface for cursor control', *Electroencephalography and clinical neurophysiology* **78**(3), 252--259.

[7] Bauernfeind, G.; Steyrl, D.; Brunner, C. & Muller-Putz, G. (2014), Single trial classification of fNIRS-based brain-computer interface mental arithmetic data: A comparison between different classifiers, *in* 'Engineering in Medicine and Biology Society (EMBC), 2014 36th Annual International Conference of the IEEE', pp. 2004--2007.

[8] Nijholt, A. & Tan, D. (2008), 'Brain-Computer Interfacing for Intelligent Systems', *IEEE Intelligent Systems* **23**, 72--79.

[9] Bauer, R. M. (1998), 'Physiologic measures of emotion', *Journal of clinical neurophysiology* **15**(5), 388--396.

[10] Ryu, K. & Myung, R. (2005), 'Evaluation of mental workload with a combined measure based on physiological indices during a dual task of tracking and mental arithmetic', *International Journal of Industrial Ergonomics* **35**(11), 991--1009.

[11] Yamamoto, K.; Sobue, G.; Iwase, S.; Kumazawa, K.; Mitsuma, T. & Mano, T. (1996), 'Possible mechanism of anhidrosis in a symptomatic female carrier of Fabry's disease: an assessment by skin sympathetic nerve activity and sympathetic skin response', *Clinical Autonomic Research* **6**(2), 107--110.

[12] Poh, M.-Z.; Swenson, N. & Picard, R. (2010), 'A Wearable Sensor for Unobtrusive, Long-Term Assessment of Electrodermal Activity', *IEEE Trans. BME* **57**, 1243--1252.

[13] Visnovcova, Z.; Calkovska, A. & Tonhajzerova, I. (2013), 'Heart rate variability and electrodermal activity as noninvasive indices of sympathovagal balance in response to stress', *Acta Medica Martiniana* **13**(1), 5--13.