Influence of Stress Factors on Cognitive Tasks Performance

Taras Medvedyk, Irena Antoniuk and Solomiya Lebid

January 9, 2020

Influence of Stress Factors on Cognitive Tasks Performance

Taras Medvedyk
Department of Electronics and Information Technology, Lviv Polytechnic National University,
Lviv, Ukraine
tarasmedveduk@gmail.com

Irena Antoniuk
Department of Electronics and Information Technology, Lviv Polytechnic National University,
Lviv, Ukraine
irena.antoniuk.bi.2017@lpnu.ua

Solomiya Lebid
Department of Electronics and Information Technology, Lviv Polytechnic National University,
Lviv, Ukraine
solomiya.y.lebid@lpnu.ua

***Abstract*—Human-machine interactions in the modern world are becoming more complex and require even higher levels of understanding and attention from the person, especially in the military or medical industry. Wireless electronics, innovations in the field of nanoelectronics and nanosensors, a new approach to software systems design and information exchange enable the creation of complex systems that were unthinkable decades ago. This preliminary study focuses on the problem of the stress factors influence on the ability of a person to perform mental work. Within the framework of the study, the analysis of changes in human physiological parameters in stress conditions was monitored and experimental studies of the influence of stress factors on solving cognitive tasks using pupillometry were conducted. Objects of the current research were aged 16-25 years. Measurement of the size of the pupil and the pressure was carried out during the execution of cognitive tasks. The purpose of these studies is to to create a simple and optimal system for monitoring the quality of cognitive tasks under the influence of external stressors (noise, interference, vibration, etc.) for application in field conditions, verify if the reliable measurement is possible and to determine the recommendations to the measuring system sufficiently simple and sufficiently precise to carry out such measurements.**

***Keywords*—stress influence, cognitive task, pupillometry, pulse, human-machine interaction**

I. Introduction

The deeper implementation of information systems in every day and work life of a person makes the interaction between human and machine a very complex task. In addition, certain sectors of the economy require workers to work in environments with a high level of stress, where a lot can depend on the level of attention and concentration of the worker, such as the military or medical sector. At the same time, new developments in wireless electronics, innovations in the field of nanoelectronics and nanosensors, a new approach to software systems and the exchange of information heighten the stress levels and in the same time allow to create monitoring systems that were unthinkable decades ago.

The purpose of this pilot project is to create a simple and optimal system for monitoring the quality of cognitive tasks under the influence of external stressors (noise, interference, vibration, etc.) for application in field conditions and verify if the reliable measurement is possible. The task included theoretical and experimental analysis of the influence of stress factors on solving cognitive tasks, creation of the simple protocol to test mental task influence, and analysis of the problem of creating a system for monitoring physiological indices of a person to study the limitations of qualitative tasks due to loads caused by stress.

I. Investigation Of Stress Influence

Methods of cognitive science were applied to assess the impact of stress on the human body. A typical analysis of cognitive science encompasses many levels of an organization, from learning to logical decisions and planning; from the neural circuit to the modular organization of the brain. One of the tasks that cognitive science is pursuing is the study of the interaction between man and machine. Overloading information flows is a fact of life in the modern society of global networks. Potentially rich data sources are not used enough because they are difficult to use quickly and easily. The brain can be seriously affected by factors such as fatigue, stress, boredom, illness, and so on.

An approach to expand human information processing capabilities is to fundamentally review the design of the human-computer system interface and to optimize the data flow exchange between a person and a machine. This research is a part of the neuroergonomics, which is an interdisciplinary area of research that includes the integration of the understanding of the neural foundations of knowledge and behaviour with the design, development, and implementation of various technologies [1]. A promising area of research in neuroergonomics is the development of methods to control the individual level of fatigue, attention, engagement in the task and mental load in the conditions of operation using physiological parameters [2-4]. These psycho-cognitive monitoring systems have a wide range of potential applications. They can significantly boost productivity, performance, and security in the military, educational and industrial environments, including the evaluation of alternative interface designs, advanced training, and optimization of how people interact with the technology. Several pilot studies conducted within the framework of the Defence Advanced Research Projects Agency (DARPA) program included an augmented cognition program that explored how integration of users physiological indices real-time monitoring can help to manage information load during the Human-Computer Interface (HCI) [3]. Physiological indicators allow understanding when the user is overloaded or underloaded with information processing and cause an increase in the flow of information or redistribution of the task. Previous research suggests that performance can be enhanced in closed loop systems [5].

Such methods as monitoring of the heart rate variability [6], respiration, eye-motor activity, galvanic skin response and visual scanning, or pupillometry [6], as well as systems such as functional infrared tomography (fNIR) [7], optical photon counting system [8] and an electroencephalography (EEG) are implemented to detect changes in cognitive studies. The EEG, at the moment, is the only technique that can reliably and accurately measure the smallest changes in attention, presence, and load that can be recognized and quantified in a millisecond period [2, 9-11]. However, the application in field conditions requires significant changes to the system, which entails a sharp increase in its value.

Due to requirements of mobility, a standard oximeter was used to monitor the subjects pulse during the research protocol and the method of pupillometry was applied to monitor the cognitive load.

A. *Cognitive Load Estimation*

To measure cognitive load, direct methods or objective evaluation allow controlling changes in the reaction rate of respondents or comparing the significance of their physiological characteristics before and during loading. There can be applied more precise methods, but measurements of such parameters as the heart rate variability, respiration, visual scan, etc., which change in accordance with mental effort during the cognitive process are difficult to integrate into the field research. Complex methods are often used in a variety of combinations to develop research protocols in these conditions, which includes the problem of synchronizing the results. At present, it can be confidently asserted that there are no universal, automated methods for assessing the cognitive load in the research area of human-machine interface.

There are also simpler and well-studied methods to study cognitive load, as, for example, the problem of mental arithmetic [12]. For the "task of addition", participants are usually encouraged to add numbers with a different number of digits. In the current research, this method was implemented for studying cognitive load.

B. *Estimation Of Previously Perceived Stress*

Various tools were developed and investigated over the past 20 years to assess previously perceived stress. In this study, the evaluation method using the Perceived Stress Scale (PSS) was selected [13]. This scale is a classic approach to assessing stress levels perceived by individual that was developed in 1983 and remains a very common tool to help understand how different situations affect the way an individual perceives stress.

II. Measuring Physiological Parameters Of The Subject

At the moment, non-invasive approaches to measure physiological parameters include quite a lot of diverse monitoring technologies. The simplest mean to monitor heart rate, for example, is pulse oximetry, which is a simple and inexpensive optical technique. This technology, also called photoplethysmography (PPG), is used to detect changes in blood volume in the microvascular tissue. Some studies have argued that haemodynamic signals, measured by infrared low-spectrum spectroscopy (NIRS) at the head of the subject, show different patterns during the verbal fluency task (VFT) with various mental disorders, while many studies note, that NIRS signals may reflect changes associated with blood flow problems near the skin surface. A measure of the haemodynamic response at the skin surface using the NIRS (on the forehead) and the PPG (on the fingers) of the systems during the verbal smoothness problem demonstrated that, despite the delay in the signal measured on the finger, there is a clear correlation between the signals [8, 14].

There is also an interesting enough and well-studied technique to monitor brain activity during cognitive tasks, which is to measure changes in the diameter of the pupils or pupillometry. Previous studies have shown that cognitive and emotional brain activity is associated with changes in the size of pupils [6, 12]. One study reported that the pupil size of healthy participants was measured at five different levels of illumination (0, 0.5, 4, 32 and 250 luxes). Ninety images were displayed in 3 seconds. This study analysed 490 eyes from 245 subjects (mean age: 51.9 ± 18.3 years, range: 6-87 years). On average, the diameter of the pupils decreased with an increase in the intensity of light for both eyes, the mean diameter of the pupil in diameter of 5.39 ± 1.04 mm at 0 luxes, 5.20 ± 1.00 mm at 0.5 luxes, 4.70 ± 0.97 mm at 4 luxes, 3.74 ± 0.78 mm at 32 luxes and 2.84 ± 0.50 mm at illumination 250 luxes [6].

For current studies, it was decided to focus on pupil size measurements using a simple built-in computer camera and apply computer vision technology to monitor the size of the pupil and, in addition, measure the pulse of the subject using portable device based on the pulse oximetry technique. These mobile, compact technologies allow monitoring the response of the subject to stress factors. It should also be noted that eye flickering artifacts constitute a common problem in the recording of the experiment with most systems in which the size of the pupil is established after processing of the eye image. The camera cannot detect the subject during blinking or flickering of eyes and since the system can not detect the subject, information is lost and it is not possible at the moment to create a universal procedure for information recovery. It is also important to control the quantity and quality of light during the measurement of the size of the pupil.

III. Development Of Research Protocol

Based on the analysis of previous studies, it was decided to create a protocol for studying the impact of stress on solving cognitive tasks. At the first stage, the procedure of the experiment is explained to the participants, and they get acquainted with the tasks. At the second stage, each participant is tested on a scale of pre-perceived stress in order to assess the previous level of stress. In the third stage, the training of the participants of the experiment takes place within five minutes in the task of mental arithmetic in order to familiarize participants with the tasks.

The protocol of the task consisted of four cards on which four figures were depicted from zero to nine and was grouped into three blocks. The first block was the “+1” task, the second was "+2" task and the third was "+3" task. The answer to each task was recorded in order to verify the correct execution. Measurements of heart rate and pupil size were performed in real time. During the fourth stage, the participants were asked to answer the questions as soon as possible. Finally, the entire protocol was executed with the addition of a noise factor and a relaxation period. Participants were asked to perform mental arithmetic in a block of four tasks, after which a picture with the image of nature was proposed and then the next block of four tasks arrived. To monitor the size of the pupils, the camera was used, for monitoring of the heart rate, the mobile device for recording pulse Xiaomi Mi Band 2 was used.

IV. Results

For this preliminary study, there were selected ten subjects aged 16-25. According to the above mentioned protocol, each subject was placed in front of a laptop with a camera, which recorded the course of the experiment and allowed to monitor changes in the size of the pupil of the eye. Additionally, each subject had a wrist fitness bracelet

(Xiaomi mi band 2) to monitor pulse changes. As an example below are results obtained in the case of one subject whose age was 19 years, physically healthy.

Before the beginning of the experiment, the data recorded by the fitness bracelet of the subject were analysed for information on the previous stress levels (see Fig. 1). In this case, data allowed to predict a moderate level of total load, which confirmed the assessment of the level of previously perceived stress with PSS, which was a total of 20 points, that is, the level of stress was indeed moderate.

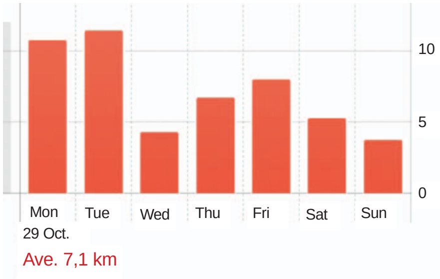

Fig.1 Physical load of the subject during the week before the experiment.

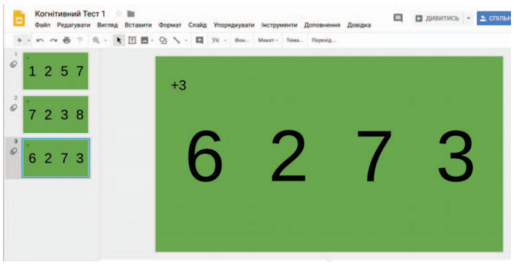

Fig. 2. A sample of a cognitive test.

A. *Cognitive Task*

The protocol for the test during the cognitive task is described in detail above (see Fig. 2). The first protocol without adding a stress took about 22 seconds. Significant changes in pupil size were not observed and the heart rate was 61-70 beats / min.

B. *Protocol With The Stress Factor*

In the next step, stress factors were added by introducing high levels of noise and distraction to the subject. It immediately showed the drop in attentiveness, significant changes in cardiac rhythm which jumped from 65 to 79 beats/min, and changes in the size of the pupil. In such circumstances, the subject coped with the tasks well but it took him 46 seconds. Results of ten subjects which participated in the study, showed a significant drop in productivity.

Human productivity directly depends on the level of stress. The result is based on the study of ten subjects who were physically healthy. After that, the same actions were repeated, but as a stress factor, the reminder was used that the test should be completed as soon as possible. The analysis of this stage of one of the tests showed that the size of the pupils was changing ~12.5%, which is roughly typical for subjects.

C. *Research Protocol Based On The Stress Factor And Built-In Relaxation Periods*

During the final stage, the protocol for testing was changed. The cognitive tasks were grouped into three blocks of four cards as previously but there was a picture card (the seascape) built in between with a purpose to readjust brain before the next task. Each card was displayed for 4 seconds (see Fig. 3). The purpose of the demonstration of cards without a task was to help embed the relaxation time in the course of the experiment and was expected to be reflected in the obtained results in reducing the activity of the pupils. The course of the experiment was recorded by the camera at 30 frames per second. Light ranged from 20 to 60 luxes.

TABLE 1. DATA COLLECTED DURING THE RESEARCH PROTOCOL.

No	PSS	Total time in a state of rest ttr, s	Total time in a state of stress ts., s	tr-ts	Heart rate, beats/min.
1	20	22	46	-24	61-79
2	19	20	41	-21	62-75
3	15	19	38	-19	60-80
4	17	22	40	-18	67-78
5	30	25	49	-24	64-77
6	25	23	48	-25	62-76
7	22	24	46	-22	65-81
8	10	18	32	-14	63-82
9	7	17	33	-16	59-77
10	28	21	40	-19	63-78

Image recognition was carried out in the next step using the blender program. The program allows markers to be placed on objects to be tracked, as well as the removal of unwanted frames and smoothing the image.

Pupils are quite easy to recognize for the program due to the contrast (see Fig. 4). Frames with blinking artifacts, as already noted, were deleted. It should be noted that image processing took place after the experiment was completed. The disadvantage of this is the fact that in the event of recording failure, the data was impossible or difficult to process.

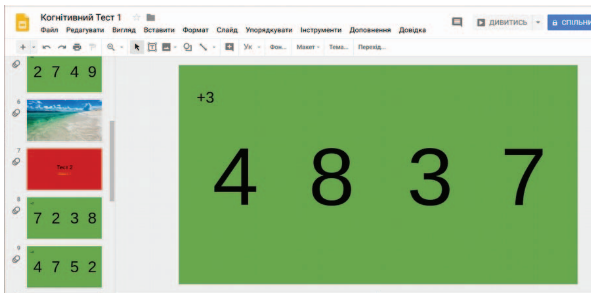

Fig. 3. A sample of a cognitive test.

The data obtained as a result of the analysis were grouped separately for the right and left eye. The calculations are presented in the form of a graph of the relative increase or decrease of the pupil during the time of the test (in this case, the frame) in Fig. 5.

Fig. 5 clearly shows the built-in relaxation periods during the task and the increase in activity during the addition task. During the mental activity of the expansion of the pupils, there was a fluctuation within ± 20%. However, it was decided not to complicate the cognitive task because of the expected drop in efficiency due to the addition of stress factors to the developed protocol of research.

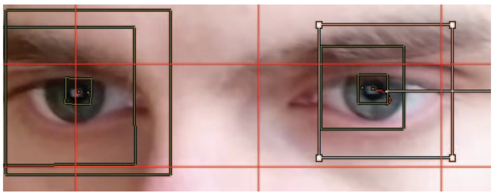

Fig. 4. Placing markers for tracking the pupils of both eyes.

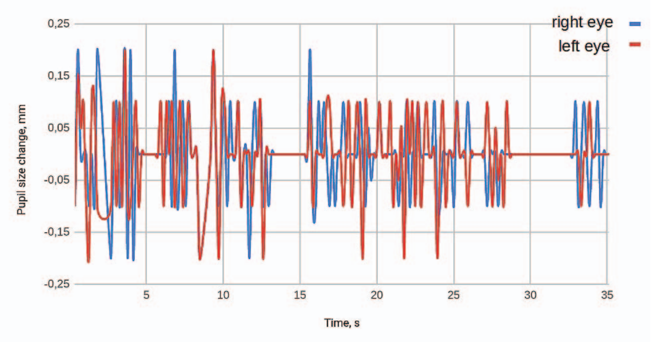

Fig. 5. Change in the pupil size recorded during one test.

The phase of the study of the impact of stress on the ability to solve cognitive tasks was to reduce the time to respond and add distraction moments (attitude questions, interference, etc.). Fig. 6 showed no visible embedded relaxation periods during the task, and an increase in activity during the addition task is observed throughout the period. During the test, the variation in pupil dilation was observed within ± 30%. The level of light had not changed. Since it was difficult to separate the effects of stress and cognitive load, the protocol was changed so there were cards with an abstract image between blocks with tasks, which was displayed for 4 seconds. The built-in demonstration of cards without a task helped to integrate the relaxation time in the course of the experiment and was reflected in the results obtained. The course of the experiment was recorded by the camera at 30 frames per second. Light ranged from 20 to 60 luxes. The results clearly showed the built-in relaxation periods during the task and the increase in activity during the mental arithmetic.

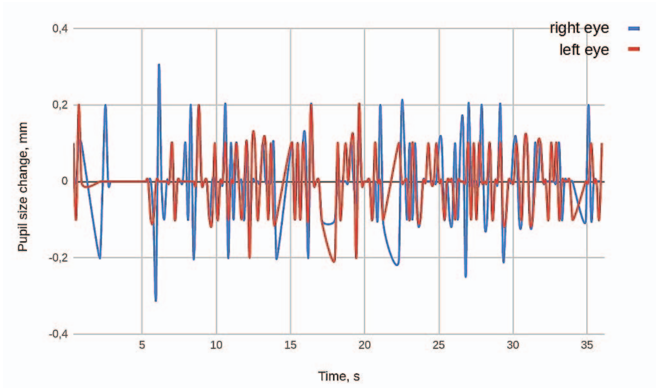

Fig. 6. A pupil's change is recorded during one test with a stress factor (shortening the time of performance).

V. Conclusion

It is necessary to conduct an examination of existing measurement methods to determine their suitability for studies within the human-machine interface framework. To conduct a preliminary research, ten subjects were selected. During the first protocol of the experiment – a mental arithmetic task, minor changes in the size of the pupils were observed contrary to research done in this area for the last 30 years; the cardiac rhythm remained unchanged. In the next step, there were noticed increased levels of stress, by adding high levels of noise and distraction of the subject. As a result, it was possible to notice a drop in attention, changes in the cardiac rhythm - heart rate from 65 to 79 beats/min, and changes in the size of the pupil up to 12.5%. In such circumstances, the subject coped with tasks in an average of 46 seconds. Full implementation of the study protocol showed that the performance of a person directly depends on the level of stress applied. The more stress a person gets, the worse he solves cognitive tasks. During mental activity, there was a variation in pupil dilation within ± 20%. The final stress-addition protocol did not reflect the built-in relaxation periods during the task, and an increase in pupils activity during the addition task was observed throughout the period. During the test, the variation in pupil dilation was observed within ± 30%. To summarise the results of this study it is crucial to underline that the first step was made and the current system could be used during field investigation of stress load on mental task performance. To obtain more reliable data it is important to continue and do more thorough research and refine the measurement technique.

References

[1] A. Kramer and R. Parasuraman, Neuroergonomics-application of neuroscience to human factors. Handbook, 2nd ed. New York: Cambridge University Press, 2005.

[2] C. Berka, D. J. Levendowski, M. N. Lumicao, A. Yau, G. Davis, V. T. Zivkovic, R. E. Olmstead, P. D. Tremoulet, and P. L. Craven, “EEG correlates of task engagement and mental workload in vigilance, learning, and memory tasks”. Aviat. Space Environ. Med. 78, B231–B244, 2007.

[3] G. F. Wilson, “Operator Functional State assessment for Adaptive Automation Implementation, Orlando, FL, USA: SPIE, 2005. p. 100-104.

[4] R. Parasuraman, and M. Rizzo, Neuroergonomics: The Brain at Work. New York: Oxford University Press; 2005.

[5] N. Morizio, M. Thomas, and P. Tremoulet, “Performance Augmentation through Cognitive Enhancement (PACE)”. Int. Conf. on Human Computer Interaction; July 2005, Las Vegas, NV, 2005.

[6] A. Rickmann, M. Waizel, S. Kazerounian, P. Szurman, H. Wilhelm, and K. T. Boden, “Digital Pupillometry in Normal Subjects”. Neuroophthalmology. 2016;41(1):12-18.

[7] S. Lebid, “Optical non-invasive brain-computer interface system”. 2018/2/20, Proc. of Conf. TCSET, 2018 14th International Conference, IEEE, pp. 743-747.

[8] S. Lebid, R. O'Neill, Ch. Markham, T. Ward, and Sh. Coyle, “Functional Brain Signals: A photon counting system for brain activity monitoring”. Proc. of Irish Signals and Systems Conference, 2004, p. 469 – 474.

[9] J. B. Brookings, G. F. Wilson, and C. R.Swain, “Psychophysiological responses to changes in workload during simulated air traffic control”. Biol Psychol 1996;42(3):361-77.

[10] M. B. Sterman, and C. A. Mann, “Concepts and applications of EEG analysis in aviation performance evaluation”. Biol Psychol 1995;40(1-2):115-30.

[11] G. F. Wilson, and F.T. Eggemeier, Physiological measures of workload in multi-task environments. London; 1991.

[12] D. Kahneman. Thinking fast and slow. - 2017. Nash Format, p. 480.

[13] S. Cohen, P. J. Gianaros, and S. B. Manuck, (2016). “A Stage Model of Stress and Disease”. Perspectives on psychological science: a journal of the Association for Psychological Science, 11(4), 456-63.

[14] T. Takahashi, Y. Takikawa and R. Kawagoe Differences in the Pulsatile Component of the Skin Hemodynamic Response to Verbal Fluency Tasks in the Forehead and the Fingertip. Scientific Reports volume 6, Article number: 20978 (2016).