The Evaluation of BCI and PEBL-based Attention Tests

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New technological advances of the 20th and 21st Centuries provide several new opportunities for engineers in the future. Modern engineering methods feasible by these new technical solutions, however, cannot meet expectations in all fields and situations without adequate knowledge and competence. Spreading new and modern engineering methods as well as acquiring new applications is a crucial issue in education. In brain research, which is one of the most significant research areas of the past decades, many new results and meters have appeared that could be used in engineering methods, too. Based on brain activity observation, new meters open up new horizons in engineering applications. Electroencephalogram-based brain activity observation processes are very promising and have been used in several engineering research primarily for implementation of control tasks. In this paper, an EEG-based engineering research work is demonstrated, which supports the acquirement of practical knowledge and can measure cognitive ability with a device capable of brain activity observation. In the engineering research task, a brain-computer interface (BCI) had to be developed for the measurement of the average level of attention. The results of the BCI have been compared and contrasted to the results of two tests applied in cognitive psychology, the PEBL Continuous Performance Test (pCPT) and the PEBL Test of Attentional Vigilance (pTOAV). It can be stated that the results of the procession developed in this research and the results of the pCPT and the pTOAV tests are in correlation.

Keywords: brain-computer interface; Continuous Performance Test; Test of Attentional Vigilance; electroencephalogram; PEBL

1 Introduction

With the continuous development of IT systems, new opportunities have also become available in human-computer interaction. These human-machine interface systems have appeared in many applications and research areas, basically called the field of cognitive infocommunications (CogInfoCom). CogInfoCom, involves the speechability, communication, linguistic and behavioural interaction analysis, face and gesture recognition, brain-computer interface (BCI), human cognitive interface – virtual and real avatars dealing with the complex mixture of human and artificial cognitive capabilities in human computer interaction processes [48-63]. The socio-cognitive ICT field includes collective knowledge, cognitive networks and their intelligent capabilities. Education and learning are closely related to this area, the CogInfoCom based learning abilities investigating capabilities for learning through modern informatics-based education, the educoaching including education through online collaborative systems and virtual reality solutions for example [64-80]. The human computer interaction processes including CogInfoCom aided engineering also cover this area, the industrial applications of CogInfoCom including production engineering, production management, the cognitive control contains theoretical solutions based on or targeting cognitive and other human body related processes, cognitive robotics and autonomous mental development [81-90].

Owing to research in cognitive neuroscience, several specific functions of brain activity are known, but to deeply understand the basic physiology of the brain and nervous system several revolutionary developments are now affecting this research [1]. Understanding the operation of the brain is of great importance in measuring and interpreting brain waves. The electrical and magnetic phenomena of the neural functions can be observed during brain operation by electrophysiology [2]. The most common device for the electrophysiological observation of the neural functioning of the brain is electroencephalography, which is used for observation and registration of brain electrical signals generated by brain activity [3]. EEG signals are mostly processed by the quantitative EEG (QEEG) method, where the frequency spectrum of the EEG signals is observed [4].

The EEG-based observation methods are used in several clinical and psychological examinations [3]. Brain Laboratories at New York University Medical Center have already published a computer-assisted differential diagnosis of brain dysfunctions in 1988 [5]. In this research, a computer analysis-based QEEG signal processing was used, which is a highly sensitive way to give specific interpretation of measurement results and can evaluate human electroencephalography, [6]. In the nineties, the primary use of QEEG in clinical practice included organicity detection, diagnoses of discriminant functions and epileptic source localization. [7] The earliest psychiatric use of EEG was imaging human cortical brain activity, but other application possibilities of the EEG have diagnosed the Attention Deficit Disorder [8], Learning Disability [9], sleep disorders, Alzheimer's disease [10] and stroke [11], for example. Attention-deficit/hyperactivity disorder (ADHD) has been researched to characterize and quantify the main characteristics of this disease for decades. [8]

Measuring electroencephalogram (EEG) activity requires complex, expensive, intimidating and immovable equipment. As a result of continuous development in recent years, new, mobile EEG biosensor-based embedded devices are available for new entertainment applications, cognitive infocommunications [25] or educational purpose [36-46]. In these applications, the connection between brain activity observed by the EEG and the induced function is effectuated by a brain-computer interface (BCI) [12]. The latest brain-computer interfaces applied with biosensors, and modern signal processing units have become cheaper and mobile because of their simple structure, while their accuracy is similar to that of the clinical EEG devices [12, 13]. This technology is mainly used for solving control tasks in engineering research, for example robot [14], helicopter [15], car [16] or prostheses [30] control.

The paper is organised into five sections. Section II describes the primary objectives of the EEG-based engineering research, the theoretical background of the EEG-based measurement method and the connection between brainwaves and attention. Section III presents the main steps of designing a computer-based EEG system, in this case, an attention level measurement system. The detailed implementation is described in Section III as well. In Section IV, the evaluation of the BCI-based attention level test is compared to the results of two neuropsychological attention tests, the PEBL Continuous Performance Test (pCPT) and the PEBL Test of Attentional Vigilance (pTOAV). In Section V, the main conclusions are drawn.

2 The EEG-based Engineering Research

2.1 The EEG Measurement and Brain Waves

Electrical activity in the brain and the electrical signals resulting from ionic current flows within neurons can be measured by the EEG method placing a sensor on the scalp [17], [18]. There are millions of neurons in the brain and each of these neurons generate a minimal electric voltage field. The aggregated amplitude of these electrical signals typically ranges from about 1 uV to 100 uV in case of a healthy adult, and these messages can be detected and recorded on the scalp [17], [18].

Patterns and frequencies of these emitted analogue electrical signals are typical in different brain activities. The brain signals are commonly referred to as brain waves and their frequency spectrum are typical in different mental states [19] and can be readily determined by digital signal processors. Several new EEG-based headsets can detect these signals, for example, NeuroSky [20] or Emotive [21].

The strength of different brain wave types can be calculated by FFT (Fast Fourier Transform) algorithm, which is a mathematical method used in EEG analysis to investigate the composition of an EEG signal. In this way, the frequency distributions (as a spectrum of brain waves) can be observed by using FFT algorithm after filtering, for example Kalman filters [47]. The spectrum of brain waves is very sensitive to the mental and emotional states of the brain, so this attribute is used to monitor mental activity [19]. Table 1 below contains the commonly-recognized brain wave frequencies, which are generated by different types of brain activity [22].

Table 1
Properties of Brain Waves [20]

Brainwave Type	Frequency range	Mental states and conditions
Delta	0.1Hz to 4Hz	Deep, non-REM sleep, unconscious
Theta	4Hz to 8Hz	Intuitive, creative, recall, fantasy, imaginary, dream
Alpha	8Hz to 13Hz	Relaxed, but not drowsy, tranquil, conscious
Low Beta	13Hz to 16Hz	Formerly SMR, relaxed yet focused, integrated
Midrange Beta	16Hz to 20Hz	Thinking, aware of self and surroundings
High Beta	20Hz to 30Hz	Alertness, agitation
Gamma	30Hz to 80Hz	Motor functions, higher mental activity

2.2 A NeuroSky EEG-based MindWave Headset

NeuroSky has been developing EEG-based measuring devices for years with the co-operation of some universities, for example, Stanford University, Carnegie Mellon University, University of Washington, University of Wollongong and Trinity College [23]. Measured and processed data provided by a NeuroSky's device has been compared and evaluated with the Biopac system, in which traditional, wet electrodes are used widely in medical examinations and research [24]. The power spectra in the 1-50 Hz range were observed based on the measurement data provided by the NeuroSky's and Biopac device, which is the frequency spectrum of specific brain waves. According to the validating results, the correlation factor between the power spectra provided by the two devices is larger than 0.7, and this means that results produced by the two devices are nearly identical [13]. The MindWave EEG headset (Figure 1) is a lightweight, portable device with wireless communication supporting Windows and Mac Operating Systems [24]. It uses only one AAA battery, and the device can run 6-8 hours. The main parameters of this device are [24]:

- Weighs 90 g;
- 30 mW rated power;
- 50 mW max power;
- 2420 – 2471 GHz RF frequency with 10 m range;
- 57600 Baud;
- 1 mV pk-pk EEG maximum signal input range;
- 12 bits ADC resolution with a 512 Hz sampling rate;
- 1 Hz calculation rate.

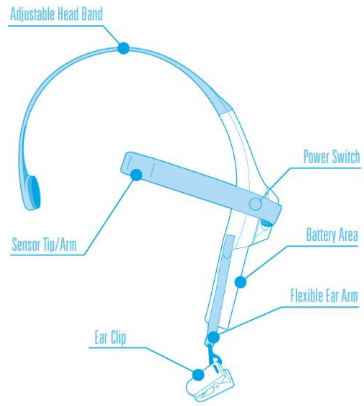

Figure 1
MindWave EEG headset structure [24]

2.3 The Attention Level and Brain Waves

The connection between attention and brain waves was observed in the 1970s, and an EEG-based attention analyser was patented [26]. The method of attention measurement is based on the FFT spectrum intensity examination of brain waves [20]. From the observations, it could be claimed that the components of brain waves, the amplitude of alpha brain waves is rather low, while in the inattentive state it is high [26]. For examination of attention, the Frontopolar1 (Fp1) measuring position is the most suitable [27] which is located on the frontal lobe such as MindWave EEG headset uses. The difference in alteration of brain waves is the base of the patented attention analyser. Several parameters of brain signals can be determined with digital signal processing algorithms. Power spectra could be calculated using discrete Fourier-transformation (DFT) algorithm and based on the resulting brain wave intensity, results can be evaluated [28]. Using the FFT on EEG signals, the intensity of brain waves and the level of attention can be determined, which is higher when the spectrum of Beta activity is stronger and Alfa is weaker, according to Table 1.

3 The BCI Software

Brain signals are measured by EEG technology – measuring, digitalization, screening of voltage variation resulted from electrical activity of the brain – and during partial evaluation, BCI systems supply processed information. [33], [34]. With the consumption of new information, we can operate other applications and instruments. The BCI system accomplishes a sort of connection between the individual and the working system. When carrying out BCI-based directions, the following viewpoints need to be taken into consideration [29]:

- the special features and different types of BCI instrument users.
- the way of signal processing and evaluation of the BCI instrument.
- the way of feedback and proper directions.
- the application directed by the BCI.

The whole of the effectiveness of the usage and the user's contentment determines the ISO 9241-210 (2010) with the use of the product. The efficiency determined in international standard shows how precisely individuals can fulfill the appointed purpose with their usage. The effort and time invested by users determine effectiveness. The contentment of an individual depends on convenience, efficiency and satisfaction according to user's expectations. [31]

The purposes of interface integration in brain computers are summarized in the following points [32]:

- functions required from user must be practicable, and its basis is to recognize and to forward the intention of the individual.
- representation of available functional opportunities for the user.
- control of action and connected actions execution.
- service of appropriate responses and representation for user to carry out appointed function with assistance of application's graphic user interface.

Different structural alternatives and possible limits of the forming system have to be taken into consideration during brain computer interface design. During the planning process, various solutions were needed to search and analyze for the emerging problems and validation was applied. For the end of the planning process, only those valid tests were needed to work out which refer to the implementation.

3.1 The Design of BCI the Software

As a first step, a valid and logical design had to be worked out that represents well the operation of the system and writes down its main process readily transparent. Figure 2 illustrates well one possible solution to the problem. The flowchart represents how the whole system communicates interactively with the user. To read files supplied by the EEG headset, a serial communication was needed, where the control of the appropriate work of the port is prominently essential. After setting the port successfully, the program starts a different thread to process file packages, which arrive from the headset: validating values in packages, appropriate processing of file packages and representing proper and processed items in file packages. The creation of the class diagram from UML's static diagram is based on logical diagram, as a well-planned and specified class diagram makes the implementation task easier. The execution of the software implementation of two classes is necessary; its object samples process the data arriving from the headset and represents it on the computer screen in the form of a column graph. Furthermore, the implementation of two partial classes is needed; its objects are responsible for visual appearance and case variation of different graphical items. With the use of the logical and the permanent models, one of the most significant design tasks is the planning of the transition and co-operation of the status of the variable object. As several dynamic models are used in UML language, we used the so-called sequence diagram. Besides the static and the dynamic point of system view, it was essential to design the application from the aspect of user case of the system because with this we can easily measure the system function and behaviour with appointing characters and tasks from the user aspects.

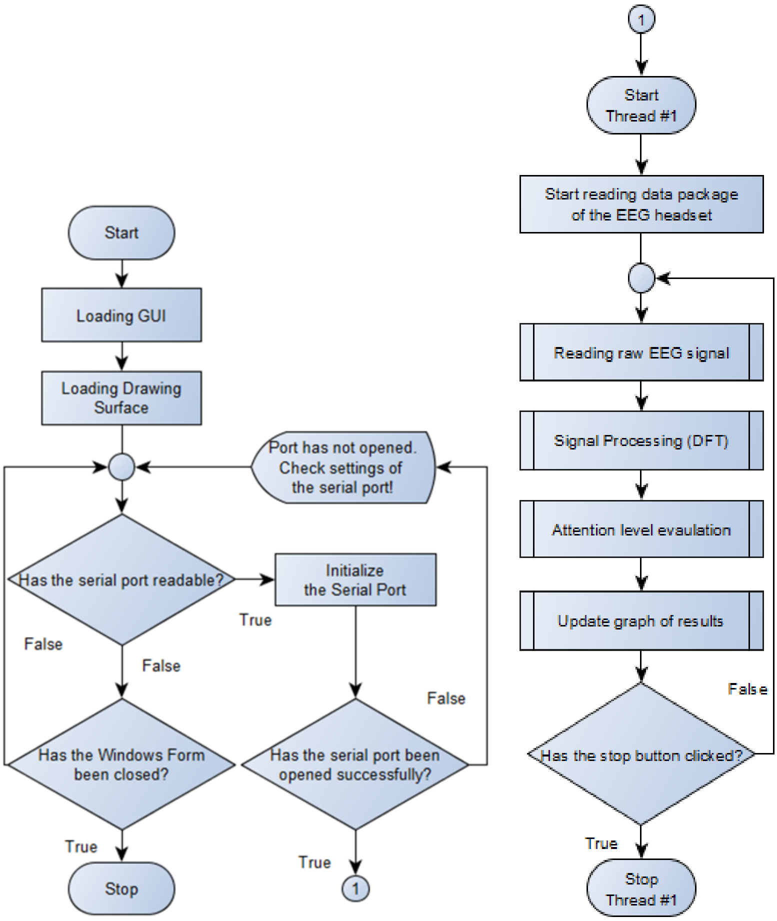

Figure 2
Logical functioning of the brain-computer system

3.2 The Implementation of the BCI Software

The software has been implemented in Microsoft Visual Studio. The development environment supports object-oriented high-level C# programming language, which is the most widely used language in Windows operating system programming. The program was divided into two main sections: data-processing and view. The data-processing component performs reading, conversion and processing of the data which arrive from the headset through serial connection, and the view part fulfills the representation of the appointed signs with the help of column and timing diagram (Figure 3). The serial port parametrization menu is visible in the window bottom left corner. After the setup of the serial port, a popup window appears to open the selected port. After successfully establishing the communication channel, we can start the measurement of brain activity by clicking "Reading Waves" button. The calculated and average values of the recorded data are visible in column graph form. The time functions of a given measurement can be examined in the top right part.

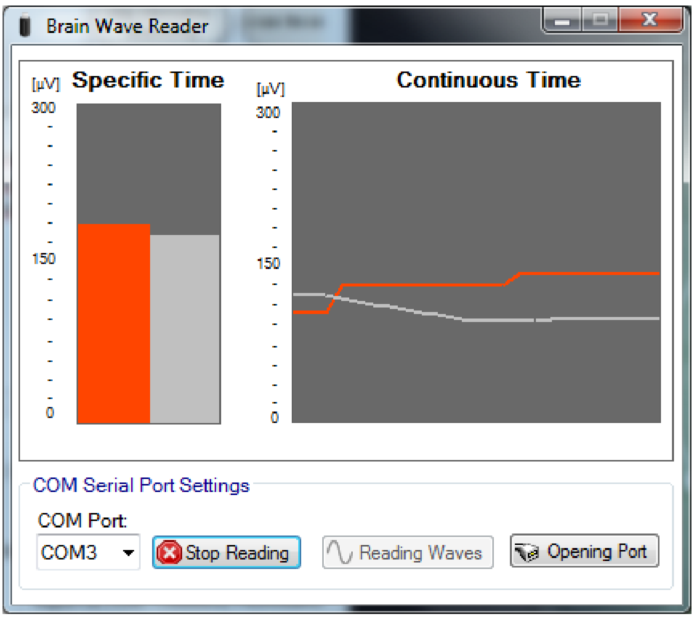

Figure 3
User Interface of the Brain-Computer Interface software

4 The Tests and Examination Results of Attention Level Meter Compared to pCPT and pTOAV

4.1 The pCPT and pTOAV Neuroscience Tests

The pCPT and pTOAV neuroscience tests are used to evaluate the attention level meter [35]. The pCPT test (Figure 4) examines concentration during a test that runs for a relatively long time, for approximately 14 minutes. During this examination, 360 letters are shown to the test subjects who should press the space key if the shown letters are not X. Having finished the pCPT, the software evaluates the results immediately, and it is available in report format.

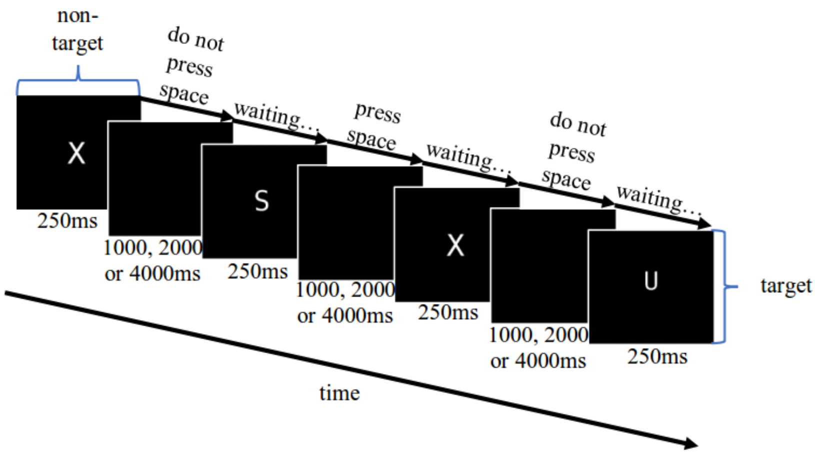

Figure 4
Test subjects must respond by pressing the space bar to all stimuli except the X.

T.O.V.A. was first used by psychologists and neurologists to examine attention deficit disorder, but it is also used in non-medical areas, such as schools or rehabilitation programs. The pTOAV test is a simple implementation of T.O.V.A.; it is a concentration/alertness test, which only examines the reaction to visual stimuli. As with Conner's continuous performance test, target gems are distinguished for this type of test as well as anti-target stimuli. In the test, a black square is located in a white square on the computer screen, randomly on either the bottom or top parts (Figure 5). Test participants should press the space key if the black square is located on the top.

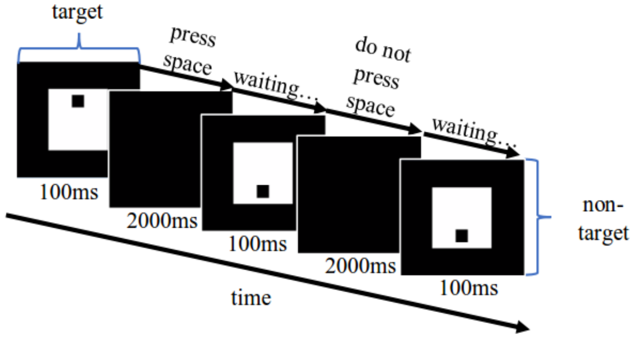

Figure 5

A black square appears randomly on the screen in a white square. Test subjects must respond only to targets when the black square is on the top. For the first half of the test, targets are rare; for the second half, they are frequent.

4.2 The Test Subjects

34 high school students participated in this experiment. All test subjects were healthy, with no history of psychiatric or neurological disorders. The age range was 14-18, the average age was 16.2, range ±1.4; 47% of girls.

4.3 The Statistical Analysis

The statistical evaluation of data in the case of the PEBL tests was made by an interval scale, while the SPCI 23 (SPSS, Inc., Chicago, IL) program pack was used on an ordinal scale for the BCI, therefore, non-parametric tests were applied for BCI results, and parametric tests were carried out with PEBL test results if parametric test conditions were fulfilled. Regarding the differences between the morning and afternoon results of PEBL tests, where test subjects are independent of each other, the pattern of results followed a normal distribution. Therefore, a related-pattern t-test was applied where the effect size was determined by Cohen d-value. As during the PEBL tests, the average attention registered by the BCI system was measured on an ordinal scale, Wilcoxon-signed rank test was carried out. In the case of the used statistical tests, the $p<0.05$ value was found to be significant.

4.4 The Results and Discussion

During the first quantitative experiment, dependency relationship and collected metric data were examined and correlation was analysed. The next step was to find connections with the help of an independent and a dependent variable between pCPT/BCI and pTOAV/BCI attention level results.

4.4.1 Comparing the pCPT and BCI Results

The correlations and relationships between the obtained test results and BCI system results can be estimated and evaluated on the whole sample, i.e., on all test participants. To observe the correlation between individual measurements, Spearman's correlation was used, because the BCI variable was determined on an ordinal scale type, and our data was monotonic. It can be concluded that the pCPT and BCI results obtained in the morning show a significant positive correlation (Figure 6a), where r_s=0.693 p<0.01 (2-tailed). Moreover, the pCPT and BCI results obtained in the afternoon also show a significant positive correlation (Figure 6b), where r_s=0.710 p<0.01 (2-tailed).

Furthermore, a significant difference was found between morning (M±SD=315.34±5.19; D(32)=0.133 p=0.158) and afternoon (M±SD=308.81±5.92; D(32)=0.105 p=0.200) t(31)=16.16 p<0.01 (2-tailed), d=1.17 pCPT test results.

According to the Wilcoxon signed-rank test results, a significant difference (T=0 Z=-4.94 p<0.01 (2-tailed) r = 0.87 was observed in pCPT and BCI results, in the morning (Mdn=52.05) and afternoon (Mdn=45.05) hours.

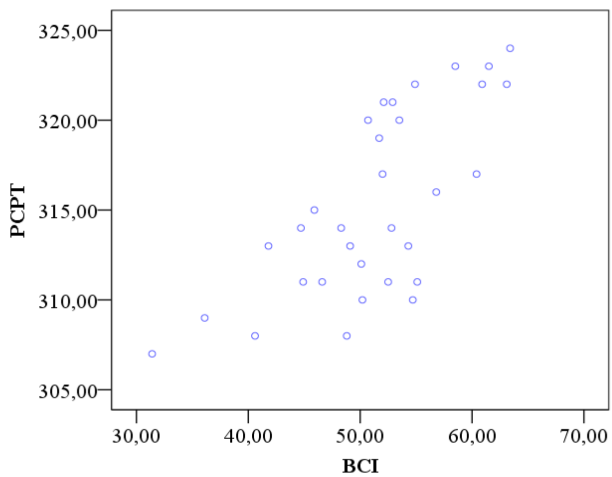

Figure 6a
Based on the results, it can be concluded that the pCPT and BCI results, obtained in the morning, show a significant positive correlation

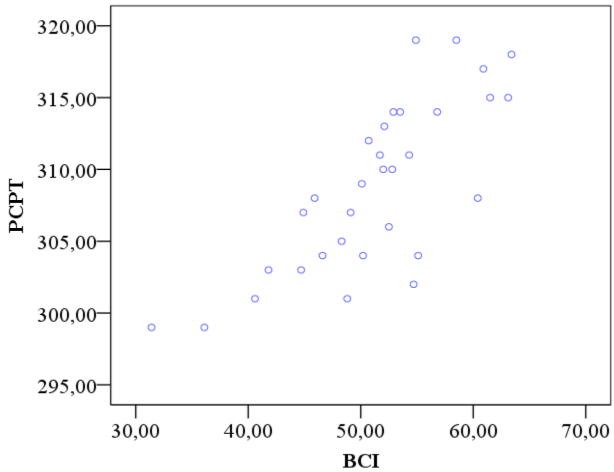

Figure 6b
The pCPT and BCI results, obtained in the afternoon, also show a significant positive correlation

A more detailed overview of correlation evaluation is given in Table 2.

Table 2
Spearman-correlation analysis for the whole sample (N = 32) on the results of the pCPT test and the difference of the mean value characteristic of the level of attention determined by the BCI

Period	Test	*M*±*SD*[1]	Correlation	*p*-value
morning	pCPT	315.344±5.191	0.69	<0.01 (2-tailed)
	BCI	51.259±7.401		
afternoon	pCPT	308.813±5.916	0.71	<0.01 (2-tailed)
	BCI	44.975±6.635		

[1]The arithmetic mean of the difference of the correct responses of test subjects for target stimulus

As seen in Figure 7a, medians differ in comparison to the bottom and top quartiles, so it generally appears that test subjects achieved better results in the morning hours, in addition, data grouping is rather above the median, while the results were weaker in the afternoon hours from all aspects and data disposition from the median was even smoother. Figure 7b shows that medians differ in comparison to the bottom and top quartiles and it generally appears that test subjects achieved higher level of attention in the morning hours. In the afternoon hours, the tests show decreased level of attention and data grouping from the median was smoother, too.

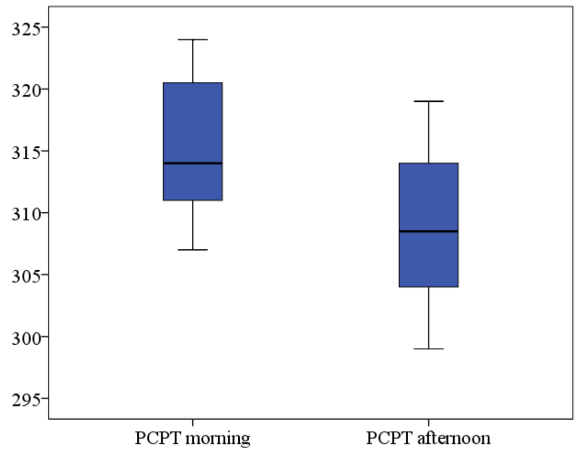

Figure 7a

a) There is a significant difference between the results measured by the pCPT in the morning and afternoon hours.

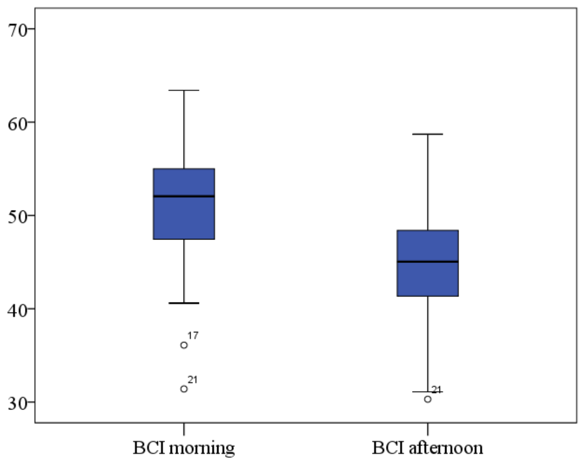

Figure 7b

b) There is a significant difference between the results of average attention level measured by the BCI system in the morning and afternoon hours.

4.4.2 Comparing the pTOAV and BCI Results

Another aim of this study was to examine the relationship between the pTOAV test and the average level of attention provided by the BCI system. The obtained correlations and relationships between the test results and the measurement provided by the BCI system can be estimated and evaluated on all samples, on all test subjects. Spearman's correlation was used with two-sided tests to specify the correlation because in case of the BCI variable, ordinal scale type was determined, and our data were monotonic.

The results show that pTOAV and BCI results obtained in the morning have a significant positive correlation (Figure 8a), where r_s=0.73 p<0.01 (2-tailed). The pTOAV and BCI results in the afternoon also show a significant positive correlation (Figure 8b), where r_s=0.72 p<0.01 (2-tailed).

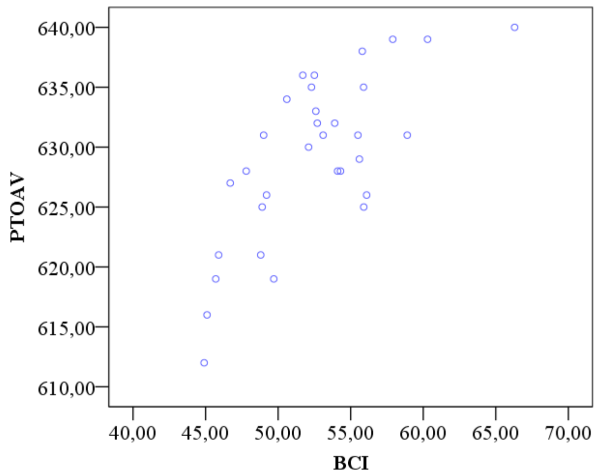

Figure 8a
The results show that the pTOAV and BCI results obtained in the morning show a significant positive correlation

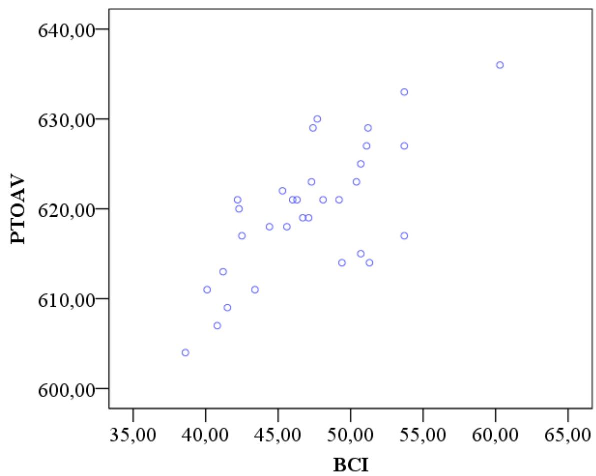

Figure 8b
pTOAV and BCI results in the afternoon also show a significant positive correlation

More details of the evaluation of correlation can be seen in Table 3.

Table 3
Spearman-correlation analysis for the whole sample (N = 32) on the results of the pTOAV test and the difference of the mean value characteristic of the level of attention determined by the BCI

Period	Test	M±SD[1]	Correlation	*p*-value
morning	PTOAV	629.156±6.933	0.73	<0.01 (2-tailed)
	BCI	52.493±4.803		
afternoon	PTOAV	619.843±7.445	0.72	<0.01 (2-tailed)
	BCI	47.184±4.842		

[1]The arithmetic mean of the difference between the correct response of test subjects for the target stimulus

Moreover, pTOAV tests in the morning ($M \pm SD$=629.16±6.93; $D(32)$=0.105 p=0.200) and afternoon ($M \pm SD$=619.84±5.92; $D(32)$=0.095 p=0.200) have a significant difference $t(31)$=13.29 p<0.01 (2-tailed), d=1.29

The results of the Wilcoxon-signed rank tests show that the difference between the average level of attention measured by the BCI system was significant (T=0 Z=-4.94 p<0.01 (2-tailed) r=0.87) in the morning (*Mdn*=52.55) and afternoon (*Mdn*=47.20) hours.

According to Figure 9a medians differ in comparison to the bottom and top quartiles and it can be seen that in the morning, the test subjects achieved a higher level of attention and data disposition of the afternoon results is more noticeable below the median.

Figure 9b shows that the medians differ in comparison to the bottom and top quartiles and it can be seen that in the morning, the BCI system recorded higher level of attention, while the data disposition is smoothly distributed around the median. In the afternoon hours, the results of the BCI system and the pTOAV test have decreased, and distribution from the median was even smoother.

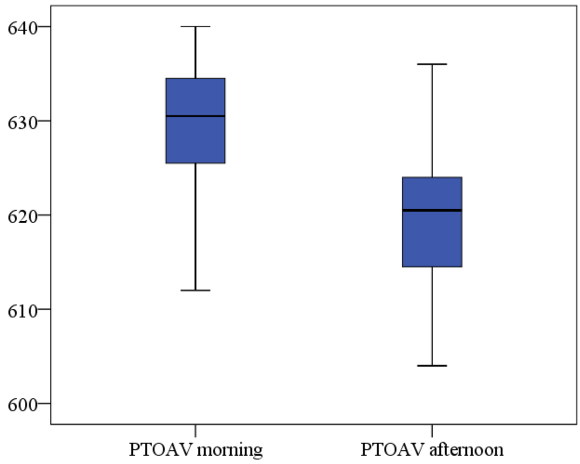

Figure 9a
There is a significant difference between the pTOAV test results in the morning and afternoon

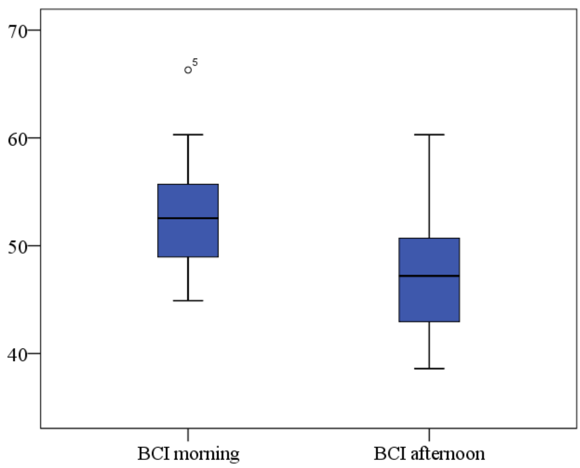

Figure 9b
There is a significant difference between the results of average attention level measured by the BCI system in the morning and afternoon hours

Conclusions

With regard to the advantages of the processed BCI system, it is visible based on the test results that relatively high, above 0.6 correlation is shown between the test results of both the morning and the afternoon hours, and it shows a strong relationship between the observed characteristics. This means that comparing to the applied test-based measuring methods of the examination of attention; the implemented BCI system could be an alternative method to investigate attention level.

The paper presented a new application area of the BCI system with psychological measurement tests. The research implementation includes the BCI system, the evaluation of test results and calculation of the relationship between the BCI and the related PEBL tests.

Acknowledgement

This work is supported by the European Union, EFOP-3.6.1-16-2016-00003 project.

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