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MODERN APPROACH TO NEUROPSYCHOLOGICAL ASSESSMENT AS A PREDICTOR OF COMPUTERIZED COGNITIVE REHABILITATION

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SUMMARY

Neuropsychological tests are specially designed tasks used to assess cognitive function, known to be related to a particular brain structure or pathway. The modern approach in neuropsychological assessment involves the application of the test in a computer application. This approach has many advantages, simple application of other technology and sensors, to get as informative the data. The purpose of this research was to analyze the possibilities for realization of certain neuropsychological tests in the form of computer applications, with the use of an additional sensor and application of the data obtained in rehabilitation. The Wisconsin Card Sorting Test - WCST, a card sorting test, was used as an example of the test. The survey included 20 respondents from the regular population, ages 17-29, selected by the random sample method, who voluntarily accepted to participate in the research. Respondents solved the test in a computer application with an additional sensor attached to an Emotiv Epoc Electroencephalograph. The results show that it takes less time to solve the test in a computer application and that errors that the examiner may make are excluded. Moreover, the additional sensor provides accurate data on registered features that can be used in diagnostics as well as in rehabilitation. All this information cannot otherwise be obtained by the usual test method.

Key words: neuropsychological assessment, computer test application, electroencephalograph

INTRODUCTION

Neuropsychological tests are specifically designed tasks used to measure a psychological function known to be linked to a particular brain structure or pathway. Tests are used for research into brain function and in a clinical setting for the diagnosis of deficits. Detailed neuropsychological evaluation can provide data on different cognitive domains as well as neuropsychiatric and behavioral features (Harvey, 2012).

The rapid advancement of technology, including improved computer programming, has enabled an increasing number of researchers and clinicians to begin using different technologies to improve the efficiency, reliability, and cost-effectiveness of neuropsychological assessment (Zucchella, Federico, Martini, Tinazzi, Bartolo, & Tamburin, 2018).

A computer-assisted test enables the synchronized application of other technologies and additional sensors in order to obtain different and significant data (Parsey & Schmitter-Edgecombe, 2013).

It is considered that the potential of technology use in neuropsychological assessment has not yet been realized, and continued adoption of new technologies could result in more comprehensive assessment of cognitive dysfunction and in turn, better informed diagnosis and treatment (Bilder & Steven, 2018).

Research to date has shown of advantages of computerized assessment, including simplicity; precision of measurement; shorter assessment time; standardization; automatic scoring; and minimization of subjectivity, as well the impact examiners may have on participant. Research has shown disadvantages too, for example reliance on the visual modality; provision of less qualitative information than pencil-and-paper tests, and participant unfamiliarity with computers (Howieson, 2019).

Computerized tests have the advantage of algorithmic design, which can be used to tailor testing for specific populations (Germine, Reinecke, & Chaytor, 2019).

By embracing the utility of technology to provide additional measures, neuropsychological assessment could expand the ways in which cognitive deficits are evaluated and ultimately treated. In the case of conducting cognitive rehabilitation using a computer, it is easier to induce motivation for therapy because direct feedback can be given to patients regarding the performance result in comparison with cognitive rehabilitation, and this type of training can not only provide flexibility but may also shorten rehabilitation time.

An important aspect of neuropsychological assessment is qualitative, that is, observations of the processes by which the subject responds to the test situation (Barr, 2008). This is the basic basis for defining algorithms in the design of computer cognitive rehabilitation. Some studies suggest that continuous computerized cognitive rehabilitation of several months or longer may improve the cognitive abilities of individuals with low cognitive abilities (Yoo, Yong, Chung, & Yang, 2015).

Objective

This research analyzes the possibilities for realization of certain neuropsychological tests in the form of computer applications. As an example of the test, WCST was used. The possibilities for synchronized application of additional sensors during the WCST test in the form of a computer application have been analyzed. For this purpose EEG device "EMOTIV EPOC" Application My Emotivator was used, to measure and record the variability in emotional performances depending on various external factors. Finally, to anticipate opportunities for implementation of computerized cognitive rehabilitation.

METHOD

Participants

The study involved 20 participants, aged 17-29 years, selected by random sampling method. Subjects were given a computerized version of the test with an additional sensor. The criteria for inclusion in the study were the absence of neurological and psychiatric disorders, as well as addictive diseases. Be aware of the research procedure and application of the device and have voluntarily agreed to participate. Ethics committee approval was obtained for conducting this research in accordance with the principles of the Declaration of Helsinki.

Neuropsychological assessment

The Wisconsin card sorting test - WCST is most commonly used to evaluate executive functions. It is a sorting test and the most famous test for discovering perseverance and mental rigidity. The WCST may be performed on a computer (Heaton & Staff, 2003). The possibility of using the WCST test in a computing version is advantageous in comparison to the classic way of applying the test. The administration of the computer test solution is very simple, allowing it to be widely applied on a different population sample. The respondent watches the stimulus cards, when the offered card appears on the screen, the respondent gives the answer, the match with the stimulus card according to some criterion (color, shape, number) on the stimulus card. Respondents are not given too detailed instructions for solving the tests, the essence is that they come to a solution based on feedback in the form of a (different) sound signal that will record an accurate and incorrect response. The advantage of solving a computer test is that the test is done more easily, more efficiently and quickly, regardless of the fact that the test is not time-limited. The respondent does not have a retroactive view of the offered ticket which was an accurate or incorrect answer. This requires the respondent to remember the offered ticket. However, this has a positive effect on the capacity of short-term memory. As an example of application that we have used for HCI-MAP platform demonstration we took Wisconsin Card Sorting Test.

Detection of tested properties by EEG device "EMOTIV EPOC"

WCST application is developed as a Web application, by using the JavaScript, HTML5 and CSS languages. The application consists of 4 different screens: initialization, begin form, card selection and results. The initialization screen is displayed while the WCST application is loading, and the most important part of this process is time synchronization with HCI-MAP server. After the time is synchronized, the begin form screen is displayed.

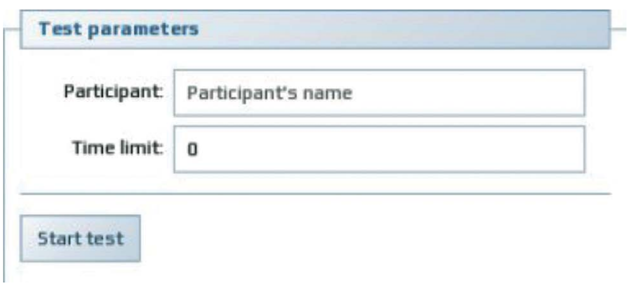

Figure 1. Begin form screen of the WCST application

The begin form is displayed at Fig. 1. This form contains only two fields - one for participant's name and one for test time limit. The time for taking this test could be limited by inserting number of seconds in the *Time limit* field. After entering these values, the participant can click the *Start test* button and proceed to the test itself.

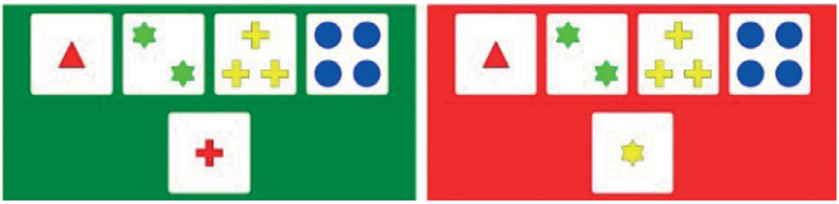

Figure 2. Screen after selecting a correct (left) or incorrect card (right)

The test's main screen is given on the Figure 2. The screen consists of five cards - four static, displayed as a stimuli, and one active card, displayed at the bottom row. The active card is picked from the deck (128 cards total), and the participant is asked to choose one card from stimuli set, according to some criteria (shape, color, or number). If the chosen card is correct, the screen background color is changed to green, and an appropriate sound is played. Otherwise, if chosen card is not the correct answer, the screen goes red and an appropriate sound is played. The test is over when all 128 cards from deck are displayed. After that, the result screen is displayed (Fig. 3).

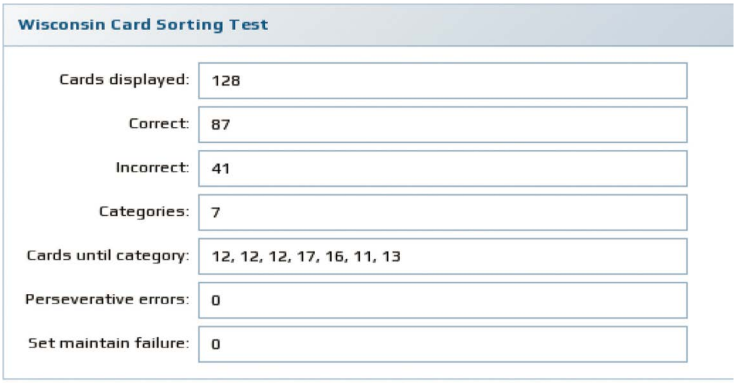

Figure 3. The results screen

First, we extract features from the EEG signals in order to characterize states of mind in the arousal-valence 2D emotion model. Using these features we apply machine learning techniques to classify EEG signals into high/low arousal and positive/negative valence emotional states. The obtained classifiers may be used to categorize emotions such as stress, relaxation, excitement, and calm based on EEG data (Ramirez & Vamvakousis, 2012).

Application My Emotivator measures and records the variability in emotional performances depending on various external factors, with the EMOTIV EPOC+ device (Fig. 4). Using algorithms to calculate the values of six emotional states (interest, engagement, excitement, stress, relaxation and focus) based on gathered EEG data, this

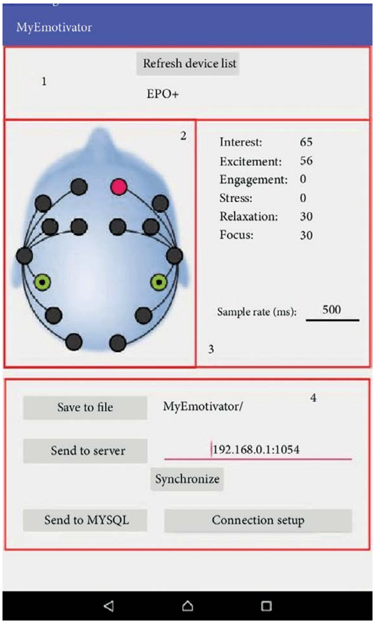

Figure 4. Sections of My Emotivator app Main window

application is capable of displaying, processing and saving the measured information for use in real-time analysis by other services or humans. Within a wider platform, we implemented an option for synchronized pairing with other human-computer interaction (HCI) components to obtain a complete picture of the user–environment interaction.

The recommended procedure for connection to the EMOTIV EPOC+ device involves turning on the device and searching for active devices in the Bluetooth domain (Fig. 4, Section 1). When the desired EPOC+ device name is selected by the user, the application begins the process of connecting with the device. Under normal conditions, this process takes 1–2 seconds, although this may be increased when there is a large physical distance between the EPOC+ and the mobile device or if the battery is low. After successful pairing, the application stops the scanning process and starts the quality testing phase of the channel contact.

The application can uniquely determine the name of the channel that is sending the signal and can visually display its position on the head. There are three levels of signal strength: no signal, bad signal and good signal. Based on the detected level of signal quality, the connector positions are shown in a different color in the corresponding picture on the main window: red, orange or green (Fig. 4, Section 2). Data about the emotional performances are gathered simultaneously with the quality information. The default reading frequency is set to twice per second (500 ms). Each of the six values examined fall into the range 0–100, where 100 is the maximal emotional level for the user, and 0 represents a theoretical minimum (Fig. 4, Section 3). In addition to the six main emotional states, the application also saves the exact time of the measurement in the UNIX timestamp format for use in later analysis.

Statistical analysis

Comparison of the obtained results of the subjects with the reference values of the test used was performed by arithmetic mean, standard deviation, t test. Data processing was performed in SPSS Statistical Package, version 17.

RESULTS

Table 1. *Characteristics respondents included in the study*

Characteristics		Respondents	
		number (n=20)	% (percent)
Gender	Male	17	85%
	Female	3	15%
Age	Mean (SD)	23 (3.68)	
Education	Basic (8 years)	0	0%
	High school (12 years)	7	15%
	College /Higher (16 years)	13	86%

Table 2. *The results of the examined executive functions by the WCST test with computer application*

Parameter	Normative test values M (SD)	Group of respondents M (SD)	Differences in relation to normative values (t)	p-value
Number of categories reached	5.9 (0.5)	3.90 (2.49)	t(3.59) = 2.09	< 0.05
Number of attempts to first category	12.2 (3.9)	37.40 (32.61)	t(3.45) = 2.09	< 0.05
Persevering errors	10.3 (6.4)	4.80 (3.82)	t(6.44) = 2.09	< 0.05
Errors in maintaining the set	1.83 (1.87)	1.00 (0.97)	t(3.81) = 2.09	< 0.05

Legend: M – arithmetic mean; SD – standard deviation; t – test; p< 0.05

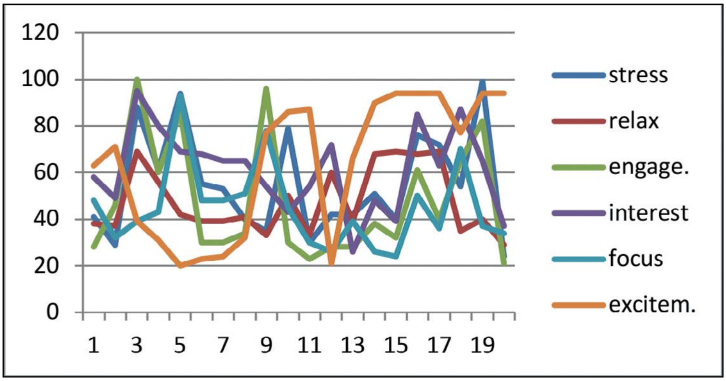

Figure 5. Graphical representation of the registered properties using EEG device at the beginning of the test using the WCST test application

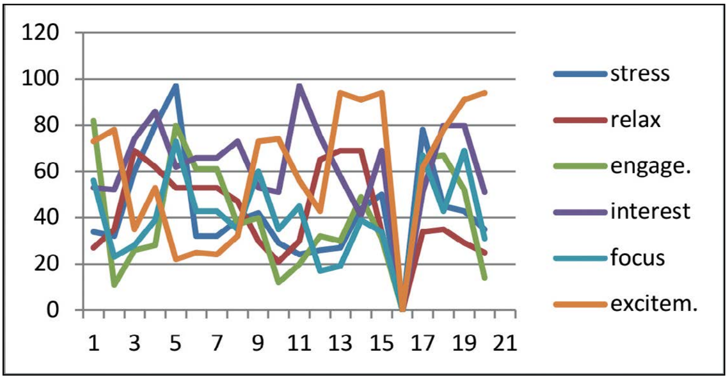

Figure 6. Graphical representation of the registered properties using EEG device at when achieving the first category in the test using the WCST test application

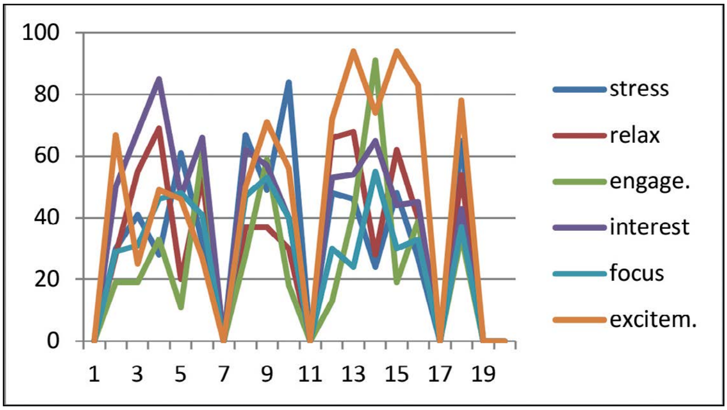

Figure 7. Graphical representation of the registered properties using EEG device for persevering errors in the test using the WCST test application

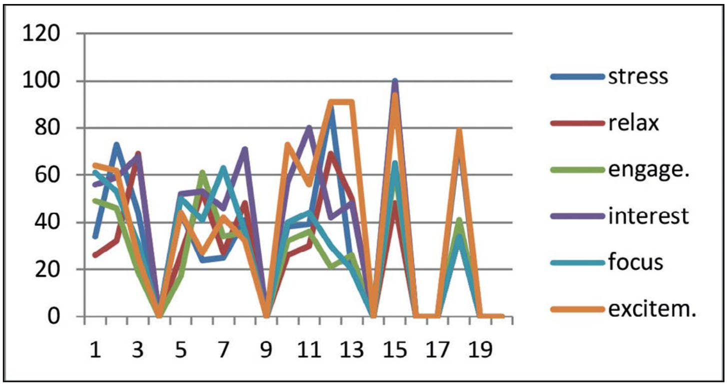

Figure 8. Graphical representation of the registered properties using EEG device in the abandonment errors in the test using the WCST test application

Comparing the obtained values of the examined variables with the normative values of the test in the respondents who did the test in a computer application with an additional sensor included, a statistically significant difference in the number of perseverative responses was obtained $p = 0.00$; $t = -17.152$; $df = 19$; $p < 0.05$ and in the number of attempts to reach the first category $p = 0.00$; $t = 3.455$; $df = 19$; $p < 0.05$ (Table 2).

The results of the electroencephalographic EEG device "EMOTIV EPOC" for detecting certain properties indicate that engagement and stress were present in a high percentage in the majority of the subjects at the beginning of the test (Figure 5). Excitement and interest were detected when reaching the first category (Figure 6). With perseverative responses, excitement was registered (Figure 7), whereas with failure to set off, stress was registered (Figure 8).

DISCUSSION

The application of the neuropsychological test provides an opportunity to examine each of the brain functions separately, specific enough and sensitive enough to make the test reliable and objective. Therefore, it is very important how the neuropsychological assessment will be applied and in what way. A Wisconsin card sort test in a computer application was used for research purposes (Jevremovic, Arsic, Antonijevic, Ioannou, & Garcia, 2018). Basically it is a test for evaluating executive functions. They make our behavior conscious, controllable and adaptable (Galindo-Aldana et al., 2018). Execution processes are multiply connected with other cognitive systems via a rich neuroanatomical network, so the choice of the test to design this study was appropriate.

Despite the new and still poorly implemented computerized testing method, the majority of respondents had high motivation during the testing process. This observation is compatible with the results of a research study that found out that there was generally a more positive view of computerized tests, primarily because they are simple to use and they need less time for solving (Ling, Attali, Finn, & Stone, 2017).

The design of the WCST test itself does not limit the time it takes to complete, therefore the total time depends on the subjects. In the standard version of the test solving, as well as in the computer application, time can be extended by the latencies present between the responses. However, the latency effect is much shorter by using computer application. This kind of test solving in a computer application seems to trigger maximum mental engagement, activate short-term working memory and maintain the quality of attention. Theoretically, significant engagement of attention and short-term working memory, as a part of executive functions, increases multifactoriality in assessment and contributes to the quality of the results obtained. As neuropsychological assessment is multidimensional in nature, the quality of the results obtained may facilitate identification of primary and secondary cognitive deficits, may determine functional limitations, and contribute to the treatment planning (Casaletto & Heaton, 2017). The results of this study may serve to construct a platform for the application of a computerized cognitive rehabilitation system. For the purposes of this study, a test was used to evaluate execute functions (which, among other things, control a person's behavior), so that the basic design of computer-cognitive rehabilitation would find tasks that closely mimic social reality. However, the generalization of the results obtained is limited by the small sample used in this study. Although, according to some studies, small samples are often used in EEG studies.

The design of our study allowed us to attach an additional EEG EMOTIV EPOC electroencephalograph sensor during applying the computer test application. An additional sensor registered excitement, engagement, relaxation, stress and focus. Besides detection, it recorded the time of occurrence as well as the percentage representation of these features during significant periods in the test itself. The values of the detected traits were monitored at the very beginning of the test, at the achievement of the first category, at errors in maintaining the set, and at perseverative responses. The precise recording and measuring of these traits contribute to a qualitative analysis of the results relevant to the field of cognitive and emotional (López Gil et al., 2016).

The use of an additional sensor is useful and provides additional and important data, which cannot be obtained by the conventional method (Justin & Barr, 2017).

In recent years, considerable attention has been directed towards analyzing the presence of certain emotions at the time of rational decisions. Using an additional sensor while solving a test in a computer application, allows you to get accurate information about the emotions involved (Schwarz, 2010).

Digital devices are now widely available and have the ability to measure aspects of human behavior accurately. This advantage of using a computer application in neuropsychological assessment certainly affects the precision and efficiency of diagnostics but also to rehabilitation planning. Based on a qualitative and quantitative analysis of achievement using a computer-aided neuropsychological assessment method with the synchronous inclusion of an additional sensor, it would be possible to adapt to the capabilities and difficulties of the test person. Based on immediate feedback, an appropriate program would be constructed that would be effective, fit for therapeutic purpose, and based on verified results. The positive effects of computerized cognitive rehabilitation could be the quality of visual perception, visual learning, memory as well as attention performance. Adjusting for achievement performance rather than trait characteristics could be a problem in creating a platform for computerized cognitive rehabilitation. Perhaps a more comprehensive study will offer better opportunities.

Limitations of study

The limitation of the study is reflected in a limited number of subjects, which may limit the reliability of the conclusions. The study was done only on healthy subjects. It would be desirable to expand the research to include persons with neurological impairment. With more diverse data, there would also be more options in defining computer cognitive rehabilitation.

CONCLUSION

Computerized neuropsychological testing has many advantages over traditional testing as it is characterized by reliability and sensitivity to very discrete changes in cognitive functioning, standardization in the administration and processing of tests, the ability to create numerous variants of tests for repeated testing, precise control of stimuli, the ability to monitor different aspects of respondent responses and the ability to create reliable databases.

Considering the advantages of using the computer-based testing method shown by the results of this study, especially with regard to the results obtained, suggests that computer availability would be very important in the process of neuropsychological testing and most importantly, enables synchronous incorporation of other technology to obtain more informative data. In addition, the modern approach in neuropsychological assessment offers great opportunities for the application of the modern approach in cognitive rehabilitation.

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