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CHAPTER 9

DISORDERED READING AND WRITING IN POST-COMATOSE PATIENTS EMPLOYING A VIDEO-BASED EYE-GAZE TRACKING SYSTEM

INTRODUCTION

Data collected in European Union countries indicate that the number of people falling into coma may reach up to about 5-6 thousand annually (adults and children) mainly due to the increase in the number of road accidents. A great number of patients shortly pass away however there is a good number of people who regain consciousness and recover. It is worthwhile to recognize two states: consciousness and awareness (Talar, 2002) Consciousness disorders (Kaiser, 2007) are part of the syndromes of global cerebral reaction to pathogenic factors. Disturbed homeostasis, including neural processes responsible for perfusion and metabolism, results from a sudden cerebrovascular trauma such as a stroke or a craniocerebral trauma.

Coma is characterized by a lack of wakefulness, arousal and thereby consciousness (Damasio, 2000). This state is connected with various vegetative disorders. In severe cases brainstem deficiency occurs leading to consciousness disorders. If increased, they may result in a disruption of the link between cerebral hemispheres and brain stem. This effects in a loss of motor activity and cognitive functions. An individual does not undertake any communicative, perceptional or motor activity. Coma lasts for 2-4 weeks. During this period patients either regain consciousness or move on to any of the three: vegetative state, minimally conscious state or locked-in syndrome. The issue of coma and various related

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states of reduced consciousness is very difficult. Doctors' or therapists' approach requires careful and delicate treatment, mainly verbal, in order to enter into an interpersonal relation with a person in this condition (Dalakaki, Mantzouranis, 2012).

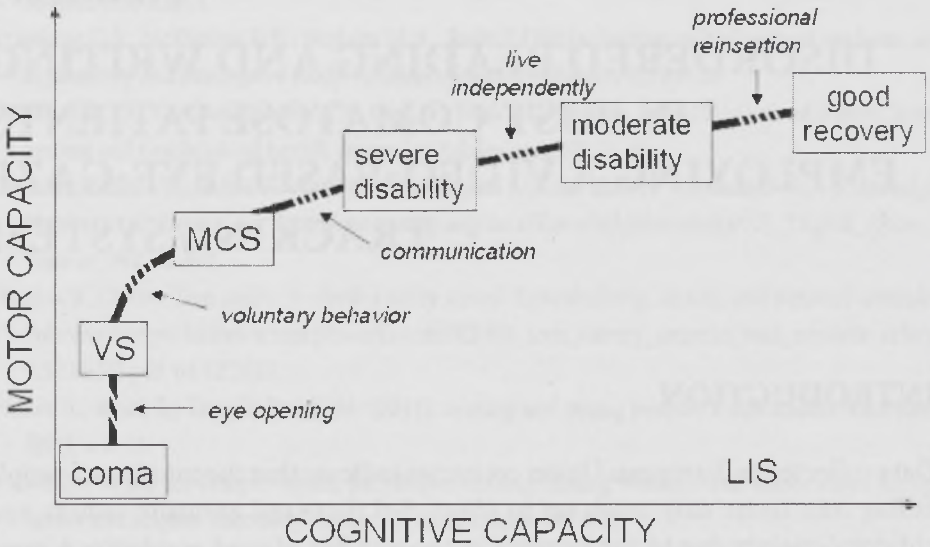

Fig. 1. Various clinical subjects during gradual recovery from coma illustrated as a function of motor and cognitive capacities. Downloaded from: http://www.coma.ulg.ac.be/ (12.12.2013)

Spontaneous or induced eyes opening is commonly acknowledged as a moment of moving from coma to a vegetative state (bilateral ptosis ought to be precluded as a complicating factor). The Multi-Society Task Force (1994) enumerates the following directives regarding vegetative states: (1) lack of evidence for self-consciousness or awareness of the environment and inability to interact with others, (2) lack of evidence for permanent, repetitive, deliberate and free behavioural responses to stimulation of sight, hearing, touch or to harmful stimuli, (3) lack of evidence for understanding language or expressions, disrupted wakefulness manifested in an absence of the sleep-wake cycle, (4) autonomous functions of hypothalamus and brain stem preserved sufficiently to maintain basic body functions. It is possible that the EEG recorded in vegetative state reveals cycles of apparent sleep and wake.

The first symptom of moving into the minimally conscious state is the maintaining of the sleep-wake cycle. Also motoric responses appear however the communication is often not coherent and not repetitive. The individuals show limited yet clearly observable evidence for self-consciousness and the awareness of the environment. They are recognised based on repetitive or prolonged occurrence of at least one of the following behaviours: (1) following simple instructions, (2) gesture or verbal yes/no response (regardless of accuracy), (3) understandable verbalization, (4) deliberate behaviour (including movements or affective behaviour which appears in connection with particular conditioned environmental stimuli and do not result from involuntary activity).

The last of the mentioned states – Locked-in Syndrome (LIS) is an extreme example of almost untouched cognitive deficit with damaged neural paths transporting motoric signals to skeletal muscles excluding those transporting signals to the oculomotor nerve. It results from a ventral brainstem damage (pons or midbrain). The term "locked-in" was first introduced in 1966 by Plum and Posner (Posner, Saper, Schiff, Plum, 2007) and it describes: (1) permanently opened eyes (bilateral ptosis ought to be precluded as a complicating factor), (2) maintained awareness of the environment, (3) aphonia or hypophonia, (4) quadriplegia, (5) basic means of communication using the horizontal and vertical eye movement as well as the upper eyelid blinking which indicates yes/no responses (American Congress of Rehabilitation Medicine, 1995). Locked-in Syndrome may be divided into three categories (Bauer, Gerstenbrand, Rumpl, 1979): (A) classic LIS - characterised by quadriplegia and anarthria with maintained consciousness and vertical eye movement or blinking, (B) partial LIS reveals remains of deliberate movement other than vertical eye movement and (C) total LIS with complete immobility including eye movement.

It is very difficult to determine clearly which of the mentioned was the patient's state during the examination. Therefore, it is difficult to rate the chances of regaining full consciousness. More and more often various examinations are used to recognise the objective signs of consciousness such as: e.g. EEP (electroencephalography), fMRI (functional magnetic resonance imaging), PET (positron emission tomography) (Demertzi, Laureys, Boly, 2009). Neuroimaging may be worthwhile as a clinical tool used to recognise if a person is in a vegetative state indeed or if there is at least a little scope of consciousness (Monti, Coleman, Owen, 2009). The most frequent means of communication with people with reduced consciousness is eyes, particularly the eye movement and blinking. Rostowski (2012) sees the types of eye movement either as gaze stabilization or gaze shifting. People with LIS and MCS (minimally conscious state) may use the preserved control of eye movement for reading. Rayner (1998) described the mechanism of controlling eye movement during reading in detail, however, we would like to draw attention to the saccades (Stenberg, 1996) and visual fixation (O'Shea, 2012). It is noteworthy as, following Zihl (1980), the accuracy of the saccades may be significantly improved through training (Rostowski, 2012). Gaze, being an eye movement independent from the movement of head, may be used as a way to develop interaction with a person with MCS and LIS.

Based on the Gerard Edelman theory of neural Darwinism we assume that only the used synaptic connections are maintained and those rarely used break (Jonkisz, 2009). This favours the necessity to stimulate and train cognitive functions of people with reduced consciousness as frequently as possible. There is an opportunity to doing so with the use of a computer. Fenton and Alpert (2008) describe the use of BCI (brain-computer interfaces) for communication with people with locked-in syndrome. This, frequently only way to communicate, is rarely used for diagnosis of people with MCS and LIS. The use of the visual interface to the appraisal of consciousness of people diagnosed as VS proves such research is worthwhile (Kunka, Czyżewski, Kwiatkowska, 2012). Further research may allow to determine the kind of cognitive functions disorder and, consequently, create a computer-aided individual communication system based on the preserved abilities. The basis here is the estimation of reading and writing disorders (Krasowicz-Kupis, 2001). There are numerous theories describing such disorders as well as definitions of reading and writing (Jurgowski, 1975; Rutter, 1972; Kaczmarek, 1969). There is a certain definitional chaos related to describing people who lost their learned abilities. The chaos concerns naming of disorders. How to name the disorders of people with LIS and MCS? Pąchalska (2007) sees language as a basis of text, both read and written. Language processes disorders influence more than one channel or modality of communication causing analogical symptoms in speech and writing. Therefore, it would mean that the ability to read and write in people with MCS and LIS is distorted because they do not communicate. It is frequently reported that pure alexia and agraphia appear without parallel speech disorders. This would imply that people with totally reduced ability to read or write do not have aphasic disorders. At the same time, speech disorders caused by damages of cerebellum or central nervous system are regarded as disarthria. Generally it is difficult to tell whether the communication disorders in people with MCS are caused by damages to central or peripheral nervous system. In relation to the earlier presented facts it cannot be told beforehand whether it is pure alexia or agraphia what occurs in this group.

We have accepted the theoretical assumption grounded in the concept of Łuria. He sees brain not as a group of separate centres or functionally undifferentiated mass of neural tissue but as an organisation of constantly cooperating elements which perform specific functions and have different functional value (Łuria, 1976). The author also widely describes the neuropsychological rudiments of reading (Łuria, 1976). He recognises the importance of the PTO area (an area located at the parietal-temporal-occipital junction) and three types of cytoarchitectural fields for this process.

Prior to undertaking research with BCI it ought to be remembered that people who underwent injuries may also suffer from neurological vision disorders (Pąchalska, 2007). They are difficult to diagnose due to the limited communication. These disorders may be caused by damages to the optic nerve, optic chiasm, optic tract or vision areas in the occipital lobe (Miner, Goodale, 2008). Also the extraocular muscles and cranial nerves which innervate the eye i.e. nerves III, IV and VI may be damaged (Prusiński, 1998). These may lead to limitation that significantly influences the process of reading an writing e.g. agnostic alexia (Konorski, 1969), optic ataxia or directional hypokinesia (Milner, Goodale, 2008).

Current research show that 40% of people are misdiagnosed (Norkowski, 2013) as being in vegetative state (Monti, Laureys, Owen, 2010). The phenomena of brain plasticity and neurogenesis (Vetulani, 2010) confirm that the abilities of our brain are not fully discovered and the very notion of consciousness (Kowalczyk, 1995) is very difficult and requires interdisciplinary analysis.

This study aims to recognise the character and degree of reading and writing disorders in 14 people with minimally conscious state or locked-in syndrome who are patients of the Health-Care Centre in Toruń.

Recognising and estimating deficits in these abilities is very important as it enables to develop effective rehabilitation of cognitive functions and create an individual code of non-verbal communication which may improve the quality of lives. A proper diagnosis and adequate therapeutic programme may also improve emotional-motivational functioning which may lead to an increase in patients' involvement in the rehabilitation procedures and exercises.

METHOD

Participants

The study comprised 14 people, 5 women and 9 men aged between 19 – 56 years. All individuals were in coma due to a craniocerebral injury (9 people) or a sudden cardiac arrest – SCA (5 people). The analysis of medical documentation indicated that 9 of them are in vegetative state and 5 are diagnosed as quadriplegia without logical contact. At the moment of the examination they were in one of the states of reduced consciousness (VS or MSC or LIS). The traumatic occurrences were from 2 months to 6 years prior to the examination.

Table 1 The characteristics of the research group

PARTICIPANT ID	AGE AT THE MOMENT OF TRAUMA	TIME SINCE THE TRAUMA (months)	CAUSE	GSC (Glasgow Coma Scale)
01	23	2 m	INJURY	9
02	37	2 m	SCA	6
03	33	11 m	SCA	6
04	31	13 m	INJURY	8
05	19	15 m	INJURY	7
06	29	19 m	INJURY	8
07	25	21 m	INJURY	7
08	57	23 m	SCA	6
09	29	24 m	INJURY	6
10	56	28 m	SCA	8
11	28	29 m	INJURY	6
12	21	60 m	SCA	8
13	40	72 m	INJURY	7
14	32	72 m	INJURY	5

We assumed that the participants did not have any infections on the day of the test and their life parameters were normal. Each of the participants had already worked with the CyberEye system (described below) which means that all of them were familiar with its functioning and knew how to operate it. One of the qualifying factors of the research was the number of GSC (Glasgow Coma Scale) points given by a doctor. 13 people received 8 or less points (unconsciousness), one received 9 points GCS (moderate consciousness disorder).

Each of the participants was interviewed and the basic demographic and clinical data was collected. The VEP (visual evoked potential) test was omitted due to possible risk of triggering epileptic seizure caused by photostimulation of eyes. Moreover, only people with maintained aural tract were approved for the research. In this respect, hearing was tested with objective audiometric methods prior to the alexia and agraphia tests.

The assessment of each patient's hearing threshold was necessary because we had to be confident that the patients can hear commands. The hearing of each patient was evaluated based on two objective methods: otoacoustic emission (OAE) and auditory brainstem response (ABR). In our experiments this examination was performed exploiting professional equipment of Vivosonic

Integrity. In order to test the sound conducting mechanism and the efficiency of the cochlea click evoked otoacoustic emissions (TEOAE) were employed. The click level was 80 dB SPL and the click duration equalled 80 μs. The artefact rejection threshold was set to 55 dB SPL. The evoked response from a click covered the frequency bands of 1, 2, 3 and 4 kHz. TEOAE was independently conducted for right and left ears of each patient. The second stage of the hearing examination was the ABR test. It was assumed that the stimulus type should be the click. In conclusion, we indicated in an objective way that all of the patients of the study group could hear commands correctly. Nevertheless, it is worth applying a hearing aid in some patients to reduce the hearing threshold.

Measures

CyberEye system, being one of the Human-Computer Interaction interfaces, is a typical hands-free eye-gaze tracking system. Eye-gaze (the point of gaze) tracking has considerable potential, both therapeutic and diagnostic. At the same time the information about the situation of the point of gaze may be used for communication between a patient and the environment. Patients are able to visually indicate a certain pictogram that represents their actual need or a particular letter on a virtual keyboard which enables them to formulate full words or sentences. Another significant and, in a way, innovative application of the eye-gaze tracking technique in post-comatose patients is the evaluation of cognitive functions and (indirectly) the level of their consciousness. The interpretation of the reaction and potential response is based on the analysis of the visual activity of a person who scans a presented image and visually indicates/chooses a graphic or textual item that matches the content of the instruction given by a therapist.

The CyberEye system includes such components as: 19" monitor (the proportion of the edges equals 5:4), four sections of LED diodes which emit infrared radiation in the corners of the screen, modified USB video camera sensitive to the range of infrared waves, standard PC and, in case of a quadriplegic patient, special arm that enables to adjust the monitor to the position of the participant. The hardware configuration of the CyberEye system used during one of the therapeutic sessions is presented in picture 2.

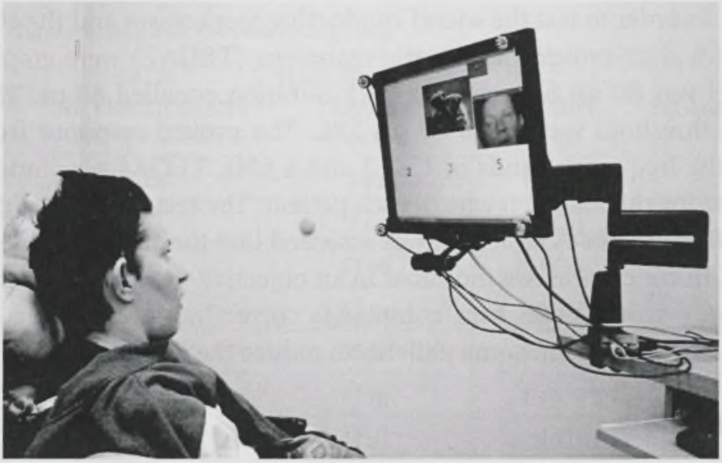

Fig. 2 The CyberEye hardware configuration during a session with a patient.

In case of eye-gaze tracking systems important parameters describing their accuracy are temporal and angular resolution. The temporal resolution of the CyberEye system is determined by the parameters of the camera used in the system. The camera takes 5 frames a second. The information about the situation of the point of gaze is refreshed with the same frequency (every 200 ms) therefore the temporal resolution of the CyberEye system equals 5 Hz. In comparison to other commercial eye-gaze tracking systems this figure is not the highest, however, its is perfectly sufficient for this group of participants. The angular resolution of the CyberEye was estimated experimentally regardless of the research presented in this article. The obtained results show that the angular resolution of the CyberEye is 3,32° horizontally and 3,38° vertically. This means that for an average user sitting 60 cm from the screen the system is going to recognize images 3,48 cm wide and 3,54 cm high. The graphic image of the accuracy of the CyberEye is shown in figure 3. The sample points of gaze (blue) which were determined by the system for a random participant. The red spots indicate the test points (model) which the participant tried to focus on during the experiment. The results of the point of gaze determining shown in figure 3 represent the accuracy of the CyberEye providing that the user had successfully completed the calibration stage.

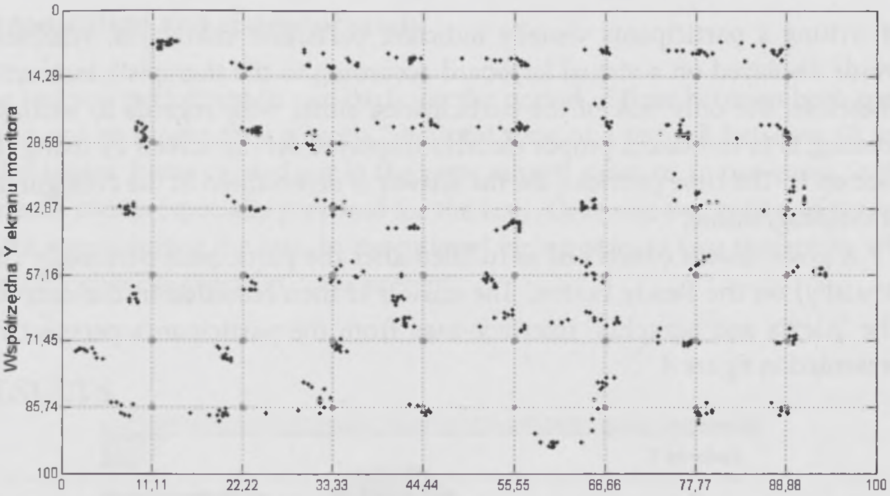

Fig. 3 Visualisation of the angular resolution testing of CyberEye for a sample participant

It has to be mentioned that with regards to the research presented in this article the high accuracy of estimating the point of gaze is not required. As assumed, an information about patient's gaze fixed within a given area of the image is required. Precise coordinates of the points of gaze measured for the right and left eye are unnecessary. Moreover the participants' heads are immobile performing particular tasks. Therefore, the technical parameters of the CyberEye proved sufficient and the tests for alexia and agraphia could have been performed in patients with consciousness disorders. A more detailed description of the CyberEye hardware and software was presented in earlier publications of the authors (Kunka, Czyżewski, Kwiatkowska, 2012).

The "Alexia and agraphia" software is a programming tool which uses universal patterns that allow for configuration of particular tasks of the alexia and agraphia test with various content. The main module is the administration panel used by a therapist to prepare the content of particular tasks, change the parameters of the programme such as the time provided for an indication of an element on the screen or the type and size of the font. All information regarding the content of tasks and parameters are recorded in an XML file which makes them easily restored. The structure of the programme is consistent with the structure of the test performed by the participants as it was prepared especially for the sake of the present research.

The programme includes two types of tasks – connected with the ability to read and write. In case of reading only a few possible elements are displayed on the screen e.g. syllables or even full sentences. A participant visually indicates a proper syllable or a sentence according to the researcher's instruction. In case of writing a participants visually indicates particular characters, syllables or words displayed on a virtual keyboard according to the therapist's instruction. Therefore, the only task of the participants, either with regards to writing or reading, is to indicate a proper element displayed on the screen by fixing their gaze on it. The time provided for the answer is determined in the configuration of the programme.

A given task is concerned as fulfilled after the participant personally clicks (visually) on the Ready button. The answer is then recorded in the data base. The "Alexia and agraphia" interface seen from the participant's perspective is presented in figure 4.

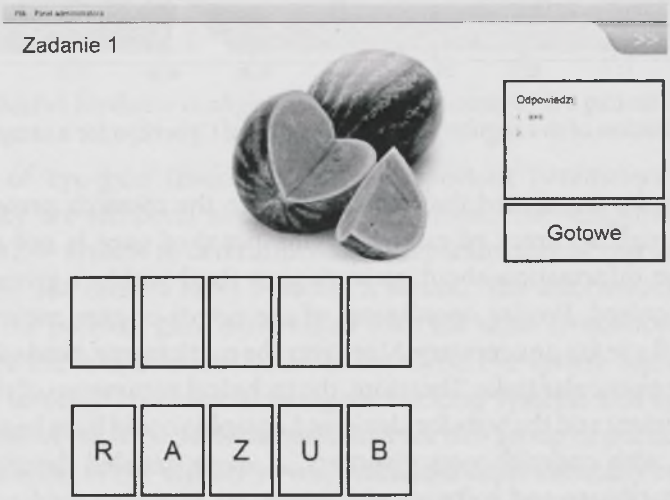

Figure 4 Sample implementation of a task in „Alexia and agraphia" software.

The test for alexia and agraphia was created especially for the sake of the present study as there is a lack of tools for appraising language functions of people with MCS or LIS. It was adapted to the technical capabilities after an analysis of available research tools (Kądzielawa, 2003) for appraising the ability to read and write (Szumska J., Pąchalska M.). The test consists of two parts. The first part is related to reading and it tests: 1. Following the text (saccades, gaze), 2. Visual identification of syllables, 3. Reading single syllables, 4. Reading sentences, 5. Recognizing mistakes, 6. Finding unnecessary sounds, 7. Matching words with sentences. The second part is related to writing. It checks: 1. The ability to write a dictation of sounds, 2. The ability to write a dictation of syllables, 3. Copying words, 4. Labelling pictures, 5. Orthographic task, 6. Filling sounds in words, 7. Filling in sentences.

Organization and course of study

The test was performed in two parts yet the period of time between both parts could not be longer than a week. The total time of a test fell between 60 and 105 minutes. It was carried out in the same, muted room or, in two cases, in the patients' rooms (specially prepared for the test). Only one therapist was present in the room during the test. In exceptional circumstances two therapists, who use the CyberEye everyday, were present.

RESULTS

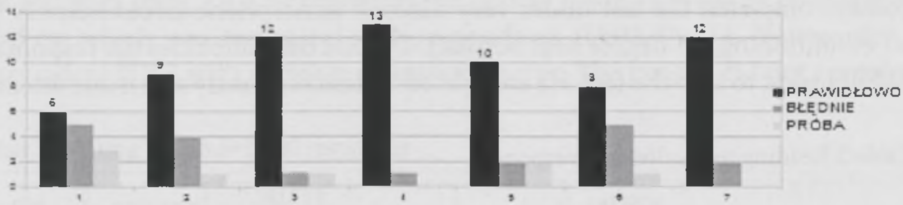

Chart 1 Reading test results

The results show that the reading ability in 14 people with MCS and LIS is maintained or slightly distorted. The best preserved is the ability to read sentences (92%) and single words (85%) as well as matching words with sentences (85%). Certain problems occurred in following the text. They were observed as a result of improper saccades and gaze (mentioned in the introduction). The majority of tasks did not present problems for the participants. Occasional repetitive mistakes appeared, especially during the visual identification of syllables – 5 people mistook syllables of similar phonetic structure.

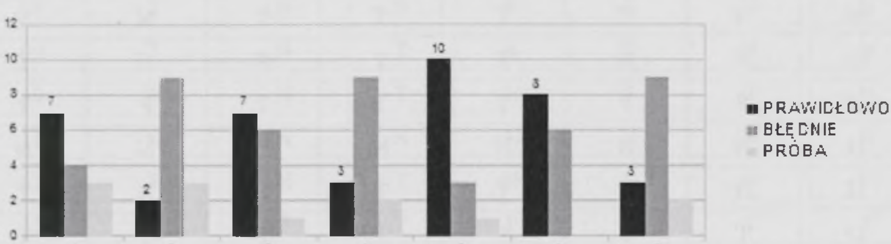

Chart 2 Writing test results

The analysis of the writing test results shows that not all of the participants maintained the ability to write. The deepest distortions occured in writing a dictation of syllables (35% completed the task or made an attempt to do it). Similar number dealt with the task of labelling pictures and filling in sentences. This indicates strong distortions in the synthesis of sounds which is proved by the preserved ability to write a dictation of isolated sounds without arranging them into a proper word in 71% of people. 78% of the respondents handled the orthographic tasks which shows that the visual memory is well preserved. 5 people were observed to use all the sounds one by one and then choose the proper answer.

It is noteworthy to analyze the results of particular respondents as they indicate the necessity of their full individualisation. Person ID07 (GSC 7, cerebral coma) completed the test under very difficult atmospheric circumstances (no air conditioning, 40-degree heat outside). Despite the difficulties the respondent did not want to stop the test. He completed 12 tasks correctly and made attempts

Table 2 Reading test individual responses

RESPONDENTS ID	FOLLOWING THE TEXT	VISUAL IDENTIFICATION OF SYLLABLES	READING SEPERATE WORDS	READING SENTENCES	RECOGNISING MISTAKES	FINDING UNNECESSARY SOUNDS	MATCHING WORDS WITH SENTENCES
01	T	T	T	T	T	T	T
02	T	N	T	T	T	T	T
03	P	T	T	T	N	T	T
04	T	T	T	T	T	T	T
05	P	T	T	T	T	T	T
06	T	T	P	T	T	T	T
07	T	T	T	T	T	T	T
08	N	T	T	T	T	N	N
09	N	N	T	T	P	N	T
10	P	P	T	T	T	P	T
11	N	N	N	N	N	N	N
12	N	T	T	T	T	N	T
13	T	T	T	T	T	T	T
14	N	N	T	T	P	N	T

T – correct response, N – incorrect response, P – attempt to complete another two. Person ID02, who had normally been very sleepy and reluctant to undertake any activity, revealed a great deal of eagerness while working with the CyberEye and completed the test with the majority of correct responses. It had been difficult to observe any attempts to communicate with the environment in everyday work with person ID03. The person had a problem with sight, precisely – gaze, although when in front of the screen, started to focus and indicated a good number of correct answers.

The individual analysis shows that the time since the trauma occurred did not influence the correct performance of the test – respondent ID13 (6 years since trauma) completed all the tasks correctly. Person ID11 – did not give any correct answer in the test despite being quite effective with the visual material. Person ID10 had a particular problem with tasks involving precise reaction of the saccades (task 1,6). Nevertheless the person made attempts to complete all of them which was analogical with respondents ID 08, 09, 14. Noteworthy is respondent ID03 with a higher education degree. The person did not complete

Table 3 Writing test individual responses

PATIENTS ID – ATTEMPT	ABILITY TO WRITE A DICTATION OF SOUNDS	ABILITY TO WRITE A DICTATION OF SYLLABLES	COPYING WORDS	LABELLING PICTURES	ORTHOGRAPHIC TASK	FILLING SOUNDS IN WORDS	FILLING IN SENTENCES
01	P	N	N	N	N	T	N
02	T	T	T	T	T	T	T
03	N	N	N	N	P	N	N
04	T	T	T	T	T	T	P
05	T	P	N	N	T	T	N
06	P	N	P	P	T	N	P
07	T	P	T	T	T	T	T
08	T	N	N	N	T	N	N
09	T	N	T	N	T	N	N
10	N	N	T	N	T	T	N
11	N	N	N	N	N	N	N
12	P	N	T	N	N	N	N
13	T	P	T	P	T	T	T
14	N	N	N	N	T	N	N

T – correct response, N – incorrect response, P – attempt the task concerning mistakes recognition and had difficulties in performing the orthographic task. During several attempts increased anxiety and muscle tension was observed as well as stronger determination to complete the task correctly.

The analysis of the results combined with observation during tests show a certain analogy. People ID 03, 05, 06 in copying words and labelling pictures and people ID 03, 06 in filling sounds in words, resigned from performing the task themselves. They made two attempts, still, without completing them personally indicated moving to the next task. It required a conscious and deliberate move on the screen as the respondents had to find the instruction that closed a particular task.

Clinical observation also revealed that the participants did not have any disturbances of attention. It was particularly visible with regards to focusing and maintain attention i.e. focusing long enough to finish a given task. An efficient "attention system" is a necessary condition for performing the majority of tests and neuropsychological rehabilitation. The notion of attention, similarly to other cognitive processes, is often investigated in relation with consciousness as the process of focusing on a stimulus is based on realising its existence. In case of the participants of this research the ability to concentrate and maintain attention did not decrease with time. Moreover, a great deal of motivation to complete the tasks was observed. The assessment of motivation was done on the basis of physiological observation (e. g. muscle tension), concentration of vision and attentiveness of attentional processes during problem solving. The respondents aimed to achieve the goal which may imply their consciousness was preserved.

DISCUSSION

The results of the preliminary research show that language abilities are maintained and allow an appraisal with the use of the specially prepared test. We confirm that it is possible to carry out a diagnosis of cognitive functions using eye-gaze of people with quadriplegia and anarthria. The observation of the ability to focus or the motivation to complete the tasks showed that the participants preserved consciousness. Cognitive processes require certain intentionality of reaction to stimuli, therefore, no deep distortion of the examined functions was revealed by the respondents.

It is not confirmed that the distortions of language processes influence more the one channel or the modality of communication. Therefore, analogical symptoms occurring in speech are also going to appear in writing. The participants almost fully maintained the ability to read and, to a great extent, the ability to write. 92% of the respondents correctly completed tasks related to reading and 78% succeeded in the orthographic task.

The final assumption is that it proved ineffective to use only the quantitative analysis when diagnosing people with reduced consciousness. A qualitative analysis ought to be additionally conducted. The results, despite the small number of participants, provoke deliberation about the diagnosis of patients so easily attributed with vegetative state. The time which is especially important in rehabilitation is frequently wasted, while, it could be devoted to improving the quality of life and giving chances of full consciousness regain. Since the preservation of the reading ability is acknowledged we may enable these people to exercise cognitive functions and, hence, maintain synaptic connections in their brains. Since we know that they are able to write, we can provide them with a virtual keyboard being a means of expressing their needs, emotions or communicating with the society.

The results indicate that the diagnosis of people who did not regain full consciousness after severe brain injury ought to be improved. Providing that research is conducted in a bigger group a valid and effective research tool may be created. Apart from the consciousness appraisal scales, neuroimaging and electroencephalography it is worthwhile to introduce neuropsychological tests which use the diagnostic potential of the preserved eye-gaze of patients.

A considerable limitation is the impossibility to form a homogenous research group. On the other hand the present qualitative analysis of such diversified results did not reveal any relationships between the time since the trauma occurred, the type of injury and the results obtained in the tests estimating the maintenance of reading and writing. It confirms that people with MCS and LIS preserved full or partial reading and, in some cases, writing ability.

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REFFERENCES

American Congress of Rehabilitation Medicine (1995). Recommendations for use of uniform nomenclature pertinent to patients with severe alterations of consciousness. *Archives of Physical Medicine and Rehabilitation*, 76, s. 205-209. downloaded from: http://www.coma.ulg.ac.be/index.html (12.12.2013).

Bauer, G., Gerstenbrand, F., Rumpl, E. (1979). Varieties of the locked-in syndrome. *Journal of Neurology, 221*, s. 77-91. downloaded from: http://www.coma.ulg.ac.be/index.html (12.12.2013).

Ciociola, P., Bellaspriga, L., Tresoldi, L. (2013). *A teraz idę na Maksa*. Wydawnictwo: Jedność.

Dalakaki, X., Mantzouranis, G., (2012). Reflections on coma: Man deprived of his consciousness. *The International Journal of Psychoanalysis*, 93, s. 1137-1152.

Damasio, A.R. (2000). *Tajemnica świadomości*, Poznań: Dom Wydawniczy REBIS.

Demertzi, A., Laureys, S., Boly, M., (2009). Coma, Persistent Vegetative States, and Diminished Consciousness. *Encyclopedia of Consciousness, 1*, s. 147 - 156.

Fenton, A., Alpert, S., (2008). Extending Our View on Using BCIs for Locked-in Syndrome. *Neuroethics, 1*, s. 119-132.

Gałkowski, T., Jastrzębowska, G. (1999). *LOGOPEDIA Pytania i odpowiedzi*, Wydawnictwo Uniwersytetu Opolskiego.

Jodzio, K, Nyka, W.M. (ed.). (2008). *Neuropsychologia medyczna. Wybrane zagadnienia*, Wydawnictwo ARCHE.

Jonkisz, J. (2009). Świadomość i subiektywność we współczesnej filozofii umysłu razem czy osobno?. *Analiza i Egzystencja, 9*, s. 121-139. Kaiser J. (2007).*Obecność mózgu w świadomości*, Wydawnictwo Uniwersytetu Jagiellońskiego.

Kądzielowa, D. (2003). Neuropsychologiczna charakterystyka afazji i metody jej diagnozowania. in: Bolejko A. (ed.). (2003). *Diagnoza i terapia osób z afazją. Holistyczne podejście do chorego* (pp. 32-45). Białystok: Bolejko Antoni.

Kowalczyk, M. (1995). *Świadomość w funkcjonowaniu umysłu człowieka*, Uniwersytet im. Adama Mickiewicza w Poznaniu.

Konorski, J. (1969). *Integracyjna działalność mózgu*, Warszawa: PWN.

Krasowicz-Kupis, G. (2001). *Język, czytanie i dysleksja*. Lublin: AWH ANTONI DUDEK.

Kunka, B., Czyżewski, A., Kwiatkowska, A. (2013). Awareness evaluation of patients in vegetative state based on eye-gaze tracking. *International Journal on Artificial Intelligence Tools, 2*, s. 1-10.

Lieby, A. (2013). *Ocaliła mnie łza*. Warszawa: Świat Książki.

Łuria, A.R. (1976). *Problemy neuropsychologii i neurolingwistyki*. Warszawa: PWN.

Łuria, A.R. (1976). *Podstawy neuropsychologii*. Warszawa: PZWL.

Łuria, A.R. (1976). *Świat utracony i odzyskany. Historia pewnego zranienia*. Warszawa: PWN.

Milner, A.D., Goodale, M.A. (2008). *Mózg wzrokowy w działaniu*, Warszawa: Wydawnictwo Naukowe PWN.

Monti, M., Laureys, S., Owen, A.M. (2010). The vegetative state. *BMJ*, 341.

Monti, M., Coleman, M.R., Owen, A.M., (2009). Neuroimaging the Vegetative State. *Annals of the New York Academy of Sciences, 1157*, s. 81-89.

Monti. M., Vanhaudenhuyse, A., Coleman, M., Boly, M., Pickard, J., Tshibanda, L., Owen, A., Laureys, S. (2010). Willful modulation of brain activity in disorders of consciousness. *The New England Journal of Medicine, 362*, s. 579-589.

Norkowski, J.M. (2013). *Człowiek umiera tylko raz.* Thaurus.

O`Shea, M. (2012). *Mózg*, Sopot: Gdańskie Wydawnictwo Psychologiczne.

Pąchalska, M. (2007). *Neuropsychologia kliniczna. Urazy mózgu*, PWN.

Posner, J.B., Saper, C.B., Schiff, N.D., Plum, F. (2007). The diagnosis of stupor and coma. 4th ed. 2007: *Oxford University Press*. downloaded from: http://www.coma.ulg.ac.be/index.html (12.12.2013).

Prusiński, A. (1998). *Neurologia praktyczna*. Warszawa: PZWL.

Rayner, K. (1998). Eye Movements in Reading and Information Processing: 20 Years of Research. *Psychological Bulletin. 3*, s. 372-422.

Rostowski, J., (2012). *Rozwój mózgu człowieka w cyklu życia. Aspekty bioneuropsychologiczne.* Warszawa: Difin.

Sternberg, R.J. (1996). *Cognitive Psychologi*. Yale University, Harcourt Brace College Publishers.

Talar, J. (2002). *Urazy pnia mózgu*. Katedra i Klinika Rehabilitacji Akademii Medycznej im. L.Rydygiera Bydgoszcz.

The Multi-Society Task Force on PVS (1994). Medical aspects of the persistent vegetative state (1). *The New England Journal of Medicine*, 330, 1499-1508. downloaded from: http://www.coma.ulg.ac.be/index.html (12.12.2013).

Vetulani, J. (2010). *Mózg: fascynacje, problemy, tajemnice*, Kraków: Wydawnictwo Domini.

Websites:

http://www.coma.ulg.ac.be/ (12.12.2013)