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D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

EYE TRACKER AS A TOOL SUPPORTING DIFFERENTIAL DIAGNOSIS IN THE STATES OF DISORDES OF CONSCIOUSNESS (DOC)

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SUMMARY

Background:

One of the key parameters in the evaluation of disorders of consciousness (DOC) is visual behavior. In the past, visual potential testing or PET scanning was mainly used to assess these parameters. Recently, Eye Tracker (ET) technology for assessing visual functions has emerged; however, there are only a few publications devoted to the use of this technology in assessing people with disorders of consciousness (DOC). The purpose of this study was to evaluate the feasibility of using ET in the diagnosis of visual functioning in DOC patients.

Material/ Methods:

The study group consisted of 25 patients (8 women and 17 men) awakened from prolonged post-traumatic coma in the Care and Treatment Facility of the "Light" Foundation in Toruń. The coma occurred as a result of severe brain damage: brain injury, stroke or sudden cardiac arrest. The mean age was 39.83 (SD 11.88) for the entire group, 38.85 (SD 9.99) for women, and 40.23 (SD 12.84) for men. All of these patients were in various states of disorders of consciousness (DOC), which was examined using the Coma Recovery Scale-Revised (CRS-R) (Giaciano et al., 2004). Appropriate inclusion and exclusion criteria were applied based on examinations by an internal medical physician and an ophthalmologist. Important exclusion criteria from the study were infection, elevated temperature, visual impairment and patient agitation. The visual functioning of the patients was measured with the use of the Eye Tracker Tobii X-120 device.

Results:

A significant difference in visual functioning was demonstrated primarily in the areas of (1) reaction time to first fixation, where the Minimal Consciousness State minus (MCS-) group showed a significantly longer reaction time compared to the Minimal Consciousness State plus (MCS+) and the Emergency of Minimal Consciousness State (EMCS) groups; (2) fixation duration, where the MCS- group showed a longer time compared to patients in the MCS+ and EMCS groups; (3) the number of fixation points on the screen, where the MCS- group showed a significantly lower number of fixation points compared to the MCS+ and EMCS groups.

Conclusions:

Eye Tracker Tobii X-120 can serve as a valuable tool to aid in the neuropsychological diagnosis of individuals experiencing states of reduced consciousness. Indicators that most differentiate between the different levels of impaired consciousness include the time to the first fixation, the number of fixation points on the screen and the total number of fixations.

Key words: eye tracker, differential diagnosis, reduced consciousness

INTRODUCTION

The return of visual functions appears to be correlated with the state of awakening from post-traumatic coma (Pąchalska, Kaczmarek & Kropotov 2021; Pąchalska 2022) and this aspect is the subject of our research interest. In standard clinical assessment, visual behaviors are a point of evaluation for many tools assessing the level of Disorders of Consciousness (DOC). Nevertheless, all available utilized tools are burdened with a fairly large dose of the examiner's assessment subjectivity, as they utilize observation. So far, published studies on visual behaviors in coma pertain to differential studies of the vegetative state, minimal consciousness state, and locked-in syndrome. In the described studies, visual potential tests and PET studies are used (Kwan-Chun Ting et al., 2014). To date, only a few studies have been published using Eye Tracker, and these studies concerned the differences between particular types of consciousness disorders; most of them involved small groups or case studies (Trojano et al., 2013).

Eye trackers are used in diagnostic tests as systems for recording and analyzing patients' behavior leading, among others, to supporting the process of treatment and the health assessment of the patient's condition. The use of a motion analysis system and properly targeted software in eye trackers can be used to detect human reactions to specific external stimuli and indicate brain activity as well as to study the cognitive functions of individual elements in various states of consciousness (Fan et al., 2015, Kopsky et al., 2013, Tuszyńska-Bogucka et al., 2020).

When considering the issue of consciousness in the context of individuals with disorders in this area, two components are typically distinguished: wakefulness (quantitative awareness) and awareness (qualitative awareness) – associated with cognitive processes (Pąchalska, 2007, Pąchalska et al., 2014). It is known that with imprecise diagnosis, as many as about 1/3 of patients diagnosed with a vegetative state may actually represent a minimal conscious state.

A precise assessment of consciousness and awareness is of paramount importance in patients following severe craniocerebral injuries. Recently, there has been a substantial development in various technologies that facilitate the diagnostic process and subsequent rehabilitation of these individuals. However, as of now, these tools are either too costly for everyday use or too time-consuming. Currently, we lack an effective and objective “measure” of consciousness in severely injured patients. One of the predictors, through which we can infer consciousness, is visual behavior. The screening test determines the depth of the coma and logical contact, primarily based on eye contact, before a verbal reaction appears.

Previous research on visual behaviors using eye-tracking technologies has focused on the differential diagnosis between the vegetative state and the minimally conscious state (Trojano et al., 2013, Ting et al., 2014). In practice, the measure of awakening from a coma is establishing logical contact with the patient. Thanks, in part, to such research, an increasing amount of data is emerging about the misdiagnoses of individuals classified as being in a vegetative state,

defined as a state in which a person does not establish logical contact with the environment and does not respond to most external stimuli.

The number of studies utilizing eye-tracking technology in clinical practice is relatively small to date. A challenge in evaluating eye contact in screening examinations based on traditional observation is the interference of disrupted attention processes, memory, and other perceptual processes such as auditory, gustatory, and olfactory, overlaying the visual processes. It was found that the attention focus time initially is very short, lasting even less than a second. An additional difficulty is the visual disturbances that may occur after brain injury. The most common occurrences include, for example, unilateral neglect, cortical blindness, anisocoria, optic neuropathies, saccadic movement disorders, and accommodation disorders. Motor disturbances also present challenges (Pąchalska 2007).

The aim of the study was to try to answer the questions:

1. What are the characteristics of selected Eye tracker (ET) indicators in relation to the level of awareness: UWS, MSC-, MSC+ oraz EMCS?
2. Can ET be a tool supporting the diagnosis of the level of conscious functioning of patients in a state of reduced consciousness?
3. What difficulties arise in examining patients with states of reduced consciousness?

MATERIAL AND METHODS

Characteristic of the patients

The study included 25 patients (8 women and 17 men) awakened from prolonged post-traumatic coma in the Care and Treatment Facility of the "Light" Foundation in Toruń. The coma occurred as a result of severe brain damage: brain injury, stroke or sudden cardiac arrest. The mean age was 39.83 (SD 11.88) for the entire group, 38.85 (SD 9.99) for women, and 40.23 (SD 12.84) for men. All of these patients were in various states of disorders of consciousness (DOC), which was examined using the Coma Recovery Scale-Revised (CRS-R) (Giaciano, et al. 2004). Appropriate inclusion and exclusion criteria were applied based on examinations by an internal medical physician and an ophthalmologist. Important exclusion criteria from the study were infection, elevated temperature, visual impairment and patient agitation.

Characteristics of the methods used

Coma Recovery Scale-Revised (CRS-r) [Giaciano, et al. 2004]] is a well-known and commonly used standardized assessment measure of consciousness state. It was designed to capture subtle changes in the neurobehavioral status of DOC patients. It comprises 6 subscales assessing auditory, visual, motor, oromotor, communication, and arousal processes organized in 29 hierarchically

ordered items. The reliability of the CRS-r in monitoring conscious awareness evolution has been widely demonstrated. This scale strongly correlates with clinical outcome at discharge. Also, its scores proved to have excellent concurrent validity with other well-known neurobehavioral scales, such as the Glasgow Outcome Scale and the Disability Rating Scale.

The Eye Tracker Tobii X-120. The device is a strip connected to the screen. The measurement frequency is 120 Hz. The analysis of visual behavior was performed using Tobi Studio version 3.4.8. This analysis in our study highlights selected indicators of visual behavior:

- **Gaze sample:** this metric measures the number of samples detected by the device.
- **Time to first fixation** (in seconds): this metric measures how long it takes before a test participant fixates on an active area of interest (AOI) or AOI group for the first time. The time measurement starts when the media containing the AOI is first displayed. For AOI groups, the time measurement starts when any of the media containing an AOI member of the group is first displayed. The AOIs do not have to be active for the time measurement to start. Time measurement stops when the participant fixates on the AOI if the AOI is active. For AOI groups, the time measurement stops when the participant fixates on any of the active AOIs belonging to the group;
- **Fixation Duration**– seconds - This metric was previously called Fixation Length in older versions of Tobii Studio and measures the duration of each individual fixation within an AOI (or within all AOIs belonging to an AOI group). The N value used to calculate the descriptive statistics, such as mean and standard deviation, is based on the number of fixations (read the N value description below for more details). If during the recording, the participant returns to the same media element, the new fixations on the media will also be included in the calculations of the metric. If, at the end of the recording, the participant has not fixated on the AOI, the Fixation Duration value will not be computed and that recording will thus not be included in the descriptive statistics calculations (e.g. when computing averages for participant groups);
- **Number of fixation points** on the screen (count): this metric measures the number of times the participant fixates on an AOI or an AOI group. If during the recording the participant leaves and returns to the same media element, then the new fixations on the media will be included in the calculations of the metric. If at the end of the recording the participant has not fixated on the AOI, the Fixation Count value will not be computed and the recording will not be included in the descriptive statistics calculations (e.g. when computing N).
- **Total number of fixations** (count): this metric measures the number of visits within an active AOI (or AOI group). A visit is defined as the time interval between the first fixation on the active AOI and the end of the last fixation within the same active AOI where there have been no fixations outside the AOI. For AOI groups, a visit is defined as the time interval between the first fixation on any active AOI belonging to the group and the end of the last fixation within

any active AOI within the AOI group, where there have been no fixations outside the active AOIs of the AOI group.

- **Percentage of fixation on the screen** (in %). This metric measures the number of recordings in which participants have fixated at least once within an AOI or AOI group and expresses it as a fraction of the total number of recordings. It is calculated by dividing the total number of recordings in which participants have fixated within the AOI by the total number of recordings in the test.

Procedure of the experiment

The examinations were usually conducted in the morning during patient optimal functioning. All patients were assessed using the CRS-R scale. On this basis, distinguished were patients with the Unresponsive Weakness State (UWS), Minimal Consciousness State minus (MCS-), Minimal Consciousness State plus (MCS+) and the Emergency of Minimal Consciousness State (EMCS). Subsequently, patients were examined using the Eye Tracker Tobii X-120. Each patient sat comfortably with back and head support in bed in front of a 19-inch screen, at a distance of approximately 50 cm. The device was calibrated on a single-point basis for each patient. The patient was shown a 3-minute film "Funny Animals" under a common license on the screen. Reactions were recorded with the device used in the experiment.

Statistical analysis

Statistical analyses were performed using Statistica 13.1. software developed by StatSoft Poland. Between group comparison involved ANOVA analyses of the Kruskal-Wallis Test .

RESULTS

Characteristics of visual behavior measured with an ET

The results of the CRS-R made it possible to distinguish 4 groups: 4 patients were included in the Unresponsive Weakfulness State (UWS) group, 7 in the Minimal Consciousness State minus (MCS-) group, 9 in the Minimal Consciousness State plus (MCS+) group, and 5 in the Emergency of Minimal Consciousness State (EMCS) group. The average results of ETparameter analysis in all the study groups are shown in Table 1.

In the group of individuals with UWS, the device could not be calibrated for 2 patients, and the ET did not detect visual activity. For the next two individuals, the analysis detected visual activity in only 3% of the recording. Therefore, for further analysis, individuals from the MSC, MSC+, and EMCS groups were selected.

Particularly important was the discovery that in the UWS group in two patients the ET could not be calibrated so that eye movement could not be tracked, making it impossible to detect any visual activity. In another two patients, although

Table 1. Average results of ETparameter analysis in all study groups

	UWS (n=4)			MCS- (n=7)			MCS+(n=9)			EMCS (n=5)		
	Mean	SD	Me	Mean	SD	Me	Mean	SD	Me	Mean	SD	Me
Gaze sample	3	3.56	2	16.57	7.76	16,00	38.67	18.92	37.00	29,00	3,46	31,00
Time to first fixation	1.21	0.95	1,26	22.36	15.38	27.34	1.54	1.48	0.89	2.05	2.97	,051
Fixation duration	0.08	0.06	0.09	0.44	0.31	0.67	0.12	0.09	0.09	0.28	0.36	0,13
Number of fixation points on the screen	2.75	3.40	2.00	17.47	31.41	5.00	103.33	115.41	86.00	105.00	18.09	112,00
Total number of fixations	15.00	23.10	5.50	47.71	27.46	49.00	204.56	184.82	106.00	156.20	49.88	159,00
Percentage of fixation on the screen	13.57	18.86	7.14	24.58	29.55	14.28	60.48	29.04	56.25	71.66	19.48	59,24

it was possible to calibrate the eye tracker, the analysis was ineffective and allowed detection of only 3% of visual activity. This is a very important finding, as it allows us to conclude that in the future, patients with UWS should be excluded from testing with the Eye Tracker Tobii X-120. Therefore, for further analysis, we selected patients from the MSC-, MSC+ and EMCS groups in whom it was possible to both calibrate the device and detect any visual activity.

The analysis of the results showed that in the MSC- group, the computer detected an average of 16.57% (SD=7.76) of visual activity. Notably, two individuals scored below 10%.

The MCS+ group obtained an average of 38.67% (SD=18.92) of visual activity, while a slightly lower value, as an average of 29.00% (SD=3.46) of visual activity, was obtained in the EMCS group.

The Kruskal-Wallis test in all the study groups is show in Table 2. Significant differences were found between patients in MCS- and MCS+ states of consciousness in terms of the percentage of gaze sample. No significant differences were found between the gaze sample levels of the EMCS group and the MCS- and MCS+ groups, although a comparison of the averages shows that the patients in the EMCS group have a higher mean and lower SD than those in the MCS- group, and conversely, there was a lower mean in terms of gaze sample in individuals in the EMCS condition than in the MCS+ group, but these groups showed greater intergroup differences. This may be rooted in erroneous classification of the patients based on the CRS-R examination, since some of these patients exhibited better cooperation with the ET than did other patients. The analysis revealed that the gaze sample parameter (number of samples detected by the eye tracker) differentiated the MCS- and MCS+ groups. The analysis of the parameter of gaze sample (number of samples detected by the eye tracker) differentiated between the MCS- and MCS+ groups.

Table 2. Kruskal-Wallis test in all study groups

	H (2, N= 21)		MSC-		MSC+		EMCS	
			z	p	z	p	z	p
Gaze sample	H =8,057072 p =,0178	MSC- MSC+ EMCS	- 2.74 1.94	- 0.02 0.16	2.74 - 0.44	0.02 - 1.00	1.94 0.44 -	0.16 1.00, -
Time to first fixation	H=8,929128 p=,0115	MSC- MSC+ EMCS	- 2.68 2.45	- 0.02 0.04	2.68 - 0.15	0.02 - 1.00	2.45 0.15 -	0.04 1.00 -
Fixation duration	H=4,823 p=,0897	MSC- MSC+ EMCS	- 2.17^ 0.84	- 0.09 1.00	2.17^ - 1.09	0.09 - 0.83	0.84 1.09 -	1.00 0.83 -
Number of fixation points on the screen	H=11,502 P=,0032	MSC- MSC+ EMCS	- 2.44 3.24	- 0.045 0.003	2.44 - 1.19	0.045 - 0.693	3.24 1.19 -	0.003 0.693 -
Total number of fixations	H=9,9007 p=,0071	MSC- MSC+ EMCS	- 2.62 2.79	- 0.026 0.016	2.62 - 0.55	0.026 - 1.000	2.79 0.55 -	0.016 1.000 -
Percentage of fixation on the screen	H=7,518 p=,0233	MSC- MSC+ EMCS	- 0.25^ 2.46	- 0.073 0.041	0.25 - 0.55	0.073 - 1.000	2.46 0.55 -	0.041 1.000 -

At the same time, the analysis of parameters of fixation showed that in MCS- patients, the parameter time to first fixation was significantly longer, when compared to those in the MCS+ and EMCS groups. These patients needed an average of 22.36 seconds, while those with MCS+ fixated their gaze after about 2 seconds. In contrast, the fixation duration parameter did not differentiate the examined groups, although a comparison of the results of the mean fixation duration showed that this was longer in the patients from the MCS- group. This means that patients with a lower level of consciousness (MCS-) showed longer time of gaze fixation; however, the measurements varied among individual patients. For the other parameters analyzed: the number of the fixation points on the screen and the total number of fixations, the MCS- group also showed a significantly lower recorded number of points than did the MCS+ and EMCS groups.

DISCUSSION

The study of eye movements by direct observation was conducted as early as 1800 . Wolf & Ueda (2021) report that an early form of eye-tracker was built by Edmund Huey in 1908, and that the first non-invasive eye-tracker was constructed by experimental educational psychology pioneer Guy Thomas Buswell, known for his groundbreaking research on recording and analyzing eye movements (Buswell, 1935). Buswell's results indicate that observers often focused on the same spatial locations in an image, but not necessarily in the same temporal order. Moreover, viewers' eyes tended to focus on foreground elements (e.g., faces and people) rather than on background elements (e.g., clouds or foliage). In 1945, Brandt published a general analysis of the eye movement patterns of participants who watched ads. Like Buswell, Brandt concluded that there

were noticeable individual differences in eye movements, but that overall the behaviors were similar enough to formulate “psychological laws” (Franchak, Kretch, and Soska 2010).

Work on the relationship between eye movements and the sequence of thought processes was first undertaken by Alexander Romanovich Luria and co-authors (1966). The authors used Ilya Repin’s painting *They Did Not Expect Him* (see Fig. 1) in their study, recording eye movements while viewing this picture.

Our gaze falls on Repin’s canvas. The work depicts the unexpected return of an exiled member of the revolutionary movement to his family in Siberia. A room, seven figures, an open door, furniture, paintings, a piano, sunlight streaming in. The exile returns home. An emotional space opens up before us, related to the epic of arrests, deportations, transports, cathartic labor, exhausting wanderings, illnesses and deaths, and grievous absences; experiences well known from Russian and Polish history, as recorded in memoirs, literature, songs, painting (Fig. 1 A). Our attention is drawn to the appearance of the deportee: his clothes (a peasant’s coat and old shoes, hat in hand), short-cut hair, face, eyes expressing joy mixed with disbelief and guilt evoke our first reactions: what did he go through, how much did he suffer? What was the fate of this man? (Fig. 1 B). In the foreground, the artist depicts the deportee’s mother, dressed in mourning home clothes and a headpiece, who, at the sight of her son, stands up from her chair and has stopped in a gesture of disbelief, gazing at his figure (Fig. 1 C). A similar facial expression can be seen in the young wife of the returnee, sitting in an armchair at the piano in the depth of the painting (Fig. 1 D). Two young children, sitting behind a table, look at their father with amazement (girl) and joy (boy). The artist has captured the moment when the family does not yet believe in the man’s happy return, before everyone starts to greet him with Joy (Fig. 1 E). Registered eye movements while looking at the entire painting by Ilya Repin “The Unexpected Guest” (Fig. 1 F).

The authors found that eye movements are closely related to thought and cognitive processes when viewing this image. What’s more, it also has some socio-cultural background, as some people view cultural artifacts (jewelry, clothing), indicating that the study of visual attention is related to thought processes.

This research was greatly extended by Russian psychologist Alfred Lukyanovich Yarus (1967), who believed that viewers’ eyes are directed to those areas of the stimulus that are “useful or relevant” in the perception process. The author conducted further studies of eye movement using the same image of Ilya Repin’s “The Unexpected Guest” (see Fig. 1a). They provided key findings on the significant effect of the experimental task on the viewer’s eye movements. Yarus (1967: 190), based on his own research, states that:

(...) Eye movement reflects the human thought processes; so the observer’s thought may be followed to some extent from records of eye movement (the thought accompanying the examination of the particular object). It is easy to determine from these records which elements attract the observer’s eye (and, consequently, his thought), in what order, and how often.”

Although historically Eye tracking (ET) has been used primarily in psychophysics or developmental cognition research, there is also promising scope for using ET in movement disorders and measuring cognitive processes in neurodegeneration. Studies in subsequent years have shown that ET can be a powerful tool for the neuropsychological assessment of cognitive function (Noton and



Fig. 1. Ilya Repin's picture analysis entitled: They Did Not Expect Him, (Russian org. Не ждали) 1884-1888. Oil on canvas. 160.5 × 167.5 cm. The Tretyakov Gallery in Moscow, Aurora Art Publishers, Leningrad 1979.

Fot. Janna Glozman, with permission

Stark, 1971; Walker Smith et al., 1977; Hayhoe and Ballard, 2005; Unema et al., 2005; Castelhana et al., 2009; Greene et al., 2012; Martinez-Conde and Macknik, 2015; Boisvert and Bruce, 2016; Smith et al., 2018).

In the first and second decades of the 21st century, there have been tremendous developments in neuroimaging methods and technologies, including techniques using ET to assess visual behavior. Bueno, Sato, Hornberger (2019) emphasize that oculographic (ET) testing is becoming increasingly popular due to rapid methodological and technological advances, as well as the development of relatively inexpensive and portable eye trackers. However, this technique is mainly offered for the diagnosis and training of children (Chawarska, Macari, and Shic 2013) and adults (Wolf & Ueda 2021) with a variety of brain dysfunctions and cognitive impairments, including communication

Relatively recently, ET has been introduced for the functional diagnosis of patients with consciousness disorders following severe brain injury (traumatic brain injury, stroke, cardiac arrest) (Rasmus 2023) and for the neurotherapy of these patients (Lech, Kucewicz, Czyzewski 2019). ET can be an effective diagnostic and therapeutic method, however, there are few works that address this topic. In addition, the works published to date on the use of eye trackers present the results of studies in the form of qualitative analyses of heat maps or images showing eye tracking (cf. also Johansson et al., 2021). This publication fills this gap by demonstrating the potential of the Eye Tracker Tobii X-120 as an effective diagnostic tool for assessing visual function in people with disorders of consciousness, with a focus on MCS-, MCS+ and EMCS patients.

In answering the first research question posed in our paper: what are the characteristics of selected the Eye Tracker Tobii X-120 indicators in 4 groups in relation to the level of consciousness: UWS, MSC-, MCS+ and EMCS, on the basis of our study we have shown that in the UWS group, the device was basically unable to detect visual activity. This is because there was no conscious, intentional directing of the eyes to the screen. In the analyses of the other groups, the most prominent differences were in three parameters: time to first fixation, number of fixation points on the screen and total number of fixations. Analyses of the differences primarily showed that those in the MCS- condition had significantly fewer fixation points on the screen and a significantly longer time to first fixation. Similar results were obtained by Trojano et al. (2013), and Candelieri et al. (2011).

In answering the second question: can the ET be a tool to help diagnose the level of conscious functioning of people in a state of reduced consciousness – the study has shown that the Eye Tracker Tobii X-120 can be a useful tool in differentiating MCS- and MCS+ states, but for differentiating MCS+ and EMCS states, a more sensitive procedure would need to be prepared, for example, with a test for selecting pictures, captions or executing commands with the eyes. It was very important to discover in our study that the calibration of this ET for UWS patients turned out to be impossible, and therefore these patients should be excluded from such studies, so it is necessary to technically modify the Eye Tracker

Tobii X-120 for these patients. We should agree with Trojano et al. (2013), and Candelieri et al. (2011) that the condition of patients awakened from coma is variable and fluctuates throughout the day (cf. also Brown 2015). Also, studies by Rasmus (2023) have shown that people in states of reduced consciousness show significant functional variability over time.

The results we obtained can be useful not only for diagnostic purposes, but can also provide direction for improving the daily functioning of patients awakened from coma (Liu et al., 2021; Rasmus 2023). By understanding that a person in a state of reduced consciousness needs more time for a visual stimulus to reach consciousness, as well as more time to direct gaze to the indicated visual stimulus, we can use this information in the communication process. As an example, the need to adjust the exposure time of a stimulus or to wait for a response by directing one's gaze to communication boards (see also Pąchalska 2007; Rasmus 2023). This may also have relevance in clinical practice, especially in the process of shaping therapeutic and communication strategies. This is because they can provide a basis for tailoring therapeutic stimuli to the unique needs of patients in states of limited consciousness. This includes modifying the duration and presentation of visual stimuli during therapy sessions or communication interactions. This ensures better communication with the patient, who has adequate time to process and respond to the information presented. This has positive implications for the design of eye tracker-based assistive devices and software communication strategies, ensuring that they are tailored to the patient's specific visual and cognitive abilities. Moreover, recognizing the specific challenges and capabilities of individuals in different states of consciousness (e.g., MCS-, MCS+, EMCS) can facilitate more personalized and effective interventions.

It is worth noting that the examination of visual function should be preceded by an assessment of the patients' specific functioning. It is necessary to conduct an ophthalmic or optometric examination and a physical examination to rule out infection, elevated fever, excessive agitation of the patient. It should be remembered that people in states of reduced consciousness show significant functional variability over time, so it is worth ensuring that the examination is conducted at a time when the person is functioning optimally.

How can the obtained research results be explained?

Microgenetic theory best explains these findings, especially the idea of mental state developing from unconsciousness to consciousness (Brown 2015). As shown by the latest clinical and neurophysiological research allowing for modification of microgenetic theory, the mental state developing from the unconscious to consciousness pulsates during individual intellectual operations, including visual behavior (Pąchalska, Kaczmarek and Kropotov 2014; Pąchalska 2019). The path of development of the mental state follows the serial order, which means that this state occurs:

1. *in the space of brain structures*, where it can develop from covert processes to the level of the threshold of consciousness (ascending mental state) and disappear (disappearance of the mental state) or exceed this threshold (de-

velopment of the mental state) and rise even higher to the appearance of full consciousness and conscious cognition (the culmination of the mental state);
 2. *in time*, in the form of pulsating individual mental states, which ensures the renewal of these states. This allows a person to become more aware of reality. The time it takes to become aware of this may last, for a relatively short time in healthy people with a properly functioning brain, while in brain-damaged patients it may slow or accelerate (as for example, in patients awakened from a prolonged coma), which in each case will lead to disorders of consciousness as well as cognitive and emotional processes due to the destabilization of neural networks (see also: Feinberg 2005).

The above described approach to the essence of the mental state makes it possible to understand the phenomenon of developing (T1) and renewing (T2) this state in time (cf. Fig. 2) and the birth of the minimal working self.

In working memory, images are reproduced in subsequent mental states in serial order, i.e., in relation to their resemblance to the coming state, and thus to the possibility of renewing the mental state. In the current state of mind, there are images closer to the perception that takes place, i.e., images from the working memory buffer that have almost reached the character of renewed perception. The brain-mind state in T1 is replaced by the overlapping state T2 before T1 ends in time, i.e., before the next phase occurs. This explains the reoccurrence of the early phases of the development of the mental state in T1, related to the condition of the body (body and brain), individuality of the person, i.e., Self, character, disposition, capacity of working memory buffers, long-term memory resources and experience, and the durability of basic beliefs, values, and personality. Later phases disappear when the whole process of realizing reality is completed to make room for new perceptions. The activity of earlier phases of the mental state in the process of the overlapping of individual phases explains the sense of self continuity in time.

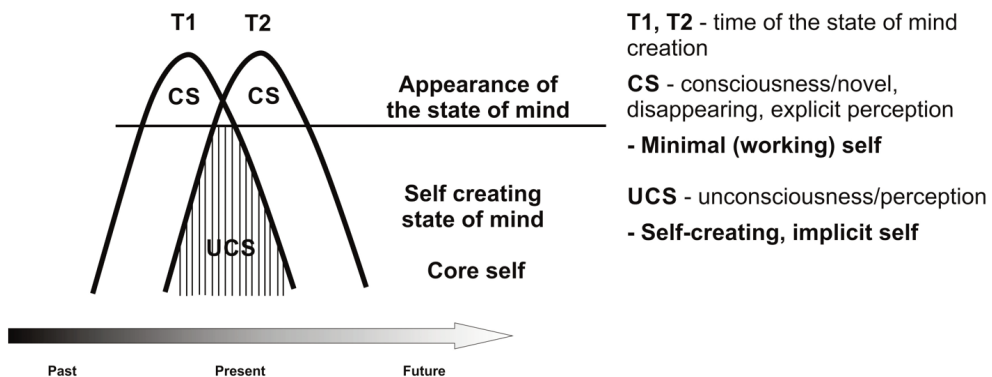


Fig. 2. Developing (T1) and renewing (T2) mental state in time: the birth of the minimal (working) self
 Source: Pąchalska, MacQueen and Brown (2012a), modified

It should be emphasized that the early stages of mental state development are components that incorporate later states that are more susceptible to environmental influences. At the same time, the repetition of earlier phases is closely connected with the feeling of existing reality (Pąchalska, MacQueen and Brown 2012b). This means that in the process of creating consciousness, one state of mind is replaced by another in a split second, which makes the apparent change replace the previous states of mind by successive states. This overlap of individual states creates a sense of continuity, while their mutual substitution creates a sense of change. It is worth emphasizing that the process of becoming aware of reality may vary depending on the needs, attitude, emotional state, and cognitive processes of a person, as well as the criterion features of objects with which a given person interacts, as well as environmental conditions. Mental states do not constitute a cumulative whole created as a result of separate processes occurring on three levels of microgeny (drives and needs, emotional and cognitive processes), but recreate the course of object (perception) formation in the mind (cf. Pąchalska, Kaczmarek, Kropotov 2014). And it is the process of creating an object representation that organizes the process of self-formation in microgenesis.

In patients awakening from a prolonged coma, the mental state on which consciousness depends may not reach or exceed the threshold of consciousness within a certain period of time, creating different levels of consciousness: from minimal, to partial and full consciousness. Since about 80% of information is transmitted through the visual channel (Pąchalska, Kaczmarek & Kropotov 2014), conducting tests with the help of the described technology enables objective evaluation of visual behavior and reaction time, thus helping to assess the level of consciousness of these patients. In conclusion, the integration of eye-tracking technology, particularly the insights gained regarding visual behavior and response times, can be a valuable addition to the tool kit of clinicians and caregivers working with individuals in states of reduced consciousness. It provides a window into the cognitive and perceptual experiences of these individuals, offering a means to enhance their engagement, communication, and overall quality of life by aligning interventions with their specific capabilities and needs.

LIMITATIONS

It should be noted that the study had:

1. hardware limitations and related difficulties in calibrating the Eye Tracker Tobii X 120 to the needs of patients with DOC conditions, especially UVS. This is because these patients are incapable of consciously directing their eyes to the screen, which meant that the signal often faded and it was necessary to restart the test.
2. limitations in maintaining the sitting position of the patient under study, due to a drooping head and excessive tension, or flaccidity due to the bone and muscle disorders that occur in patients awakened from prolonged coma, reports on patients after brain injury.

3. the small number of patients studied in particular states of consciousness, especially patients with EMCS . However, it is worth noting that the carefully selected inclusion and restriction criteria used have a positive impact on the reliability of the study.

CONCLUSIONS

The Tobii X-120 Eye Tracker can serve as a valuable tool to aid in the neuropsychological diagnosis of patients with disorders of consciousness. Indicators that most differentiate between different levels of the disorders of consciousness include the time to first fixation, the number of fixation points on the screen and the total number of fixations. In order to effectively use the TOBI X120 Eye Tracker in future studies of patients with disorders of consciousness, especially patients with UWS, it is necessary to modify the device by mounting the strip and screen on a movable arm.

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