CASE STUDY

ACTA Vol. 19, No. 1, 2021, 11-22
NEUROPSYCHOLOGICA

Received: 18.04.2020
Accepted: 23.11.2020

A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

ERPs AS AN INDEX OF IMPAIRED COGNITIVE CONTROL IN AN ISCHEMIC BRAIN STROKE APHASIC PATIENT

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SUMMARY

Background: Stroke is a sudden-onset neurological deficit resulting from focal vascular lesions. This is either due to a clot-induced obstruction of a vessel (ischemic stroke) or a rupture of a vessel causing haemorrhage (hemorrhagic stroke). The appropriate diagnosis of brain stroke aphasic patients is a major public health problem one so important for effective rehabilitation. Here an important role is played by the diagnosis of impaired cognitive processes. The aim of the research was to find the index of impaired cognitive control with the use of ERPs in a patient following an ischemic stroke with aphasia.

Case study: A male patient, aged 69, after an ischemic brain stroke experienced 4 months previously with resulting naming problem, was admitted to the Reintegrative and Teaching Center of the Polish Neuropsychological Society. In the neuropsychological evaluation three neuropsychological tests were employed: (a) the Boston Naming Test-Polish version, to evaluate the naming and word finding problem; (b) the nonverbal Bell test to ascertain a selective, visuospatial and strategic attentional evaluation; (c) the Digit Memory test to evaluate working memory capabilities; (d) ERPs as a neurophysiological index of impaired cognitive control. Significant changes were observed in testing. All cognitive functions including naming, nonverbal, visuospatial and strategic attention, along with the digit memory deviate substantially from the norm. The patient obtained a lower score, compared to the norm ($p < 0.05$). *Boston Naming Test* (patient = 21< Mean-Norm = 57.29; SD= 0.52). *Bell test* (patient = 23 < Mean-Norm = 31.29; SD= 2.52). *Digit Memory Test scores: Forward digit span* (patient = 3 < Mean-Norm = 7.65, SD = 0.49). *Backward digit span* (patient = 2 <Mean-Norm = 6.51, SD = 0.7). Significant changes were observed also in neurophysiological testing: behavioral parameters (except RT) deviate substantially from the reference. EEG spectra show clear abnormalities on the left side within the left Rolandic fissure. The deviations include excessive mu-rhythm and beta activity, which means that this area is inhibited.

Conclusions: The ERPs show no difference between GO and NOGO conditions in the patient in comparison to the norm from HBI database indicating poor cognitive control. ERPs could be treated as an index of impaired cognitive control in the ischemic stroke aphasic patient.

Key words: ERPs, attention, working memory, naming problem, cognitive control

INTRODUCTION

Stroke is a major public health problem, both in terms of the number of people affected, which is constantly increasing in view of population aging, and through its medical, social and economic consequences (Fery-Lemonnier, 2009). Poland, like most developing countries, is seeing its stroke burden increase (Pąchalska 2011). The aging of the population suggests an increase in cases for the years to come (knowing that strokes affect young people too). Strokes are two to three times less frequent in women than in men between 50 and 65 years. This difference then decreases to cancel itself out after 85 years of age (Kolb & Whishaw 2007). Like other countries in the world, Poland is seriously threatened by cardiovascular diseases, something constituting an epidemiological issue. Among these are brain strokes, something which currently constitutes a real health problem in Poland, for reasons such as the frequency of vascular risk factors (Trystuła 2017, 2018).

The definition of an ischemic brain stroke is limited to focal ischemia and does not include global ischemia (see also: Trystuła 2017; 2018). There are several reasons for limiting the definition of an ischemic stroke to focal ischemia alone. First, there are significant differences in the pathology and mechanisms of ischemia between focal and global ischemia. Focal ischemia occurs within the perfusion territory of an artery that is stenosed or occluded, and cell death is localized to this region (Pąchalska 2011). In focal cerebral ischemia, cell death is maximal in the ischemic focus and may extend to the penumbra, with all cellular elements including both neurons and supportive cells affected (Kolb & Whishaw 2007). In contrast, global ischemia results from decreased cerebral perfusion as a result of decreased blood pressure (e.g., cardiac arrest or in shock) or severely increased intracranial pressure (e.g., severe head trauma). In global ischemia, selective neuronal loss appears to occur in vulnerable areas of the cerebral neocortex, hippocampus, thalamus, basal ganglia and cerebellum (Bartoli, Di Brita, Crocamo, et al. 2018) and is not isolated to particular vascular distributions. Furthermore, applying the definition of prolonged cell death attributable to global ischemia in the central nervous system would include sources of injury such as anoxia caused by airway or lung diseases and some metabolic injuries, which are quite distinctly nonvascular in origin. In addition, survivors of global ischemia (e.g., patients resuscitated after cardiac arrest) will always have reperfusion of the ischemic cerebral tissue. This results in a larger role for injury because of the pathological effects of reperfusion in global ischemia than is the case in focal ischemia (Asplund 1996; Anderson & Whitfield 2013; Sacco, Kasner, Briderick et al. 2013). The proper diagnosis of subsequent disturbances in stroke patients are important for any effective rehabilitation; with this constituting a major public health problem (Ch'Ng, French, Mclean 2008). An important role is played by the diagnosis of these impaired processes, including language processes. For disturbed and impaired cognitive control is a cause of a patient's social dependence (Pąchalska, Kaczmarek & Bednarek 2020; Pąchalska, Kaczmarek & Kropotov 2020).

The aim of the research was to find the index of impaired cognitive control here employing ERPs in a patient following an ischemic brain stroke with aphasia.

CASE STUDY

A male patient, aged 69, was admitted to the Reintegrative and Teaching Center of the Polish Neuropsychological Society following an ischemic brain stroke experienced 4 months earlier, with resulting naming problems. In the neuropsychological evaluation three neuropsychological tests were used: (a) the Boston Naming Test- Polish version; (b) the nonverbal Bell Test allowing for a selective, visuospatial and strategic attentional evaluation; (c) the Digit Memory Test to evaluate the working memory capabilities of stroke patients.

Boston Naming Test – Polish version

The *Boston Naming Test – Polish version* presents the patient with six A4-format sheets, each comprising 6 categories of objects, in total 60 drawings of objects (see: Fig. 1). It allows for an evaluation of the naming and word finding problem. The patient has to name as many objects as possible. At the end of the test, the score (the number of named objects) is noted (Pąchalska 2011).

Bell Test, its different strategies and omissions

The Bell Test was used in this study to evaluate the visuo-attentional abilities. It also allows to distinguish between groups with, and without, neurological deficits and lesions of the right or left hemisphere. The test consists of presenting the subject with an A4-format sheet containing 112 drawings of objects (saw,

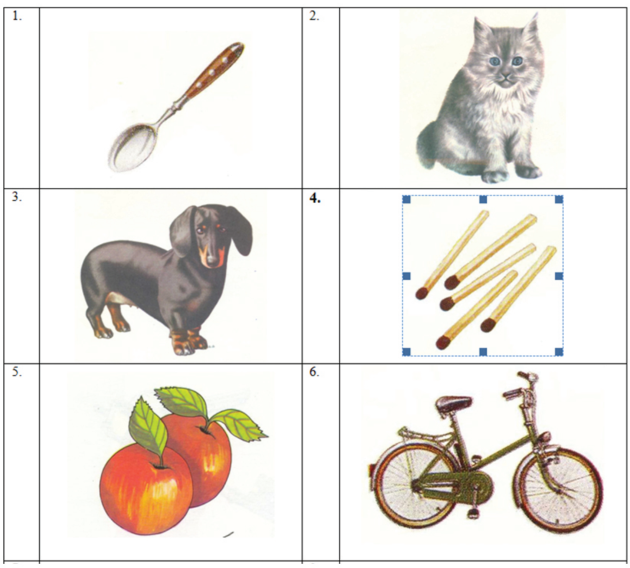

Fig. 1. Samples of objects from the Boston Naming Test – Polish version
Source: Pąchalska 2011

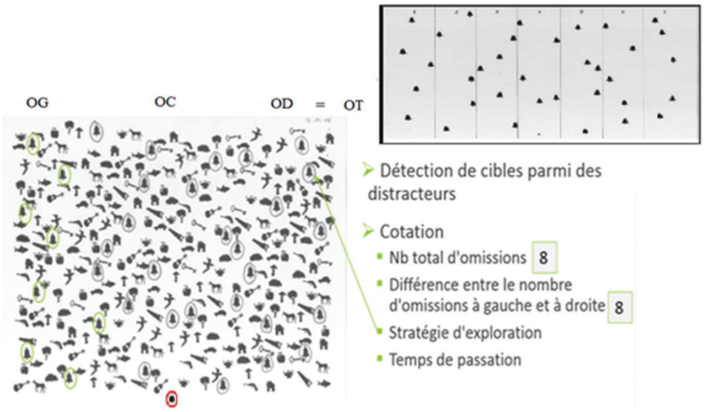

Fig. 2. Example of the Bell Test and the different types of omission
Source: Mènon, Ahami, Latifi et al. 2019

apple, horse, car, cloud ... including 35 bells). The patient has to, for 2 minutes, strike out or circle as many bells as possible. At the end of the test, the score (the number of crossed out bells) is noted (Mènon, Hal El Fadl, Ahami et al. 2015). The A4 sheet with the number of bells omitted is subdivided into seven columns, three are on the right hand side of the page representing the right omission, one is in the middle position indicating the central omission while the last three are to the left which correspond to the left omission. There are four types of omissions highlighted: right omission (RO), left omission (LO), central omission (CO) and total omission (TO) (Ferber and Karnath 2001, Mènon, Hal El Fadl, Ahami et al. 2015; Mènon, El Fadl, N'Go et al. 2016). Therefore, a patient is considered moderately negligent if they are unable to surround the bells in the left-most column. An omission found in the more medially located columns will be interpreted as a sign of greater neglect of the left space (Gauthier, Dehaut & Joanette 1989) (Fig. 2).

Different strategies

The strategy used in the neuropsychological examination, included after Mènon, Hal El Fadl, Ahami et al. (2015), the 9 different types of strategies envisaged during the passing of the Bell Test (A, B, C, D, E, F, G, H and I); which allowed us to identify the correlation envisaged in the 9 types of strategies (A, B, C, D, E, F, G, H and I) of the Bell Test to distinguish whether the subject is right-handed or left-handed.

1. ***Strategy A:*** The subject starts striking out the bells from the top of the A4 sheet, starting from the right towards the left.
2. ***Strategy B***: The bell is crossed out from left to right while starting from the top.
3. ***Strategy C:*** The subject must arrange to start to strike out the bell at the bottom of the A4 sheet while moving from the right to the left side.
4. ***Strategy D***: The circling of the bells is done from the bottom of the A4 sheet and from left to right.

5. ***Strategy E***: The patient or participant starts to strike out the bell from the right top to the bottom of the A4 sheet,
6. ***Strategy F:*** The patient starts from the right of the top of the sheet in the format towards the left side.
7. ***Strategy G***: This is done from the bottom right to the top of the A4 sheet,
8. ***Strategy H:*** The patient undertakes the circling of bells from the left direction while starting from the bottom up.
9. ***Strategy I***: The patient undertakes the circling of bells in a disorganized strategy. This will enable us to find important elements concerning the type of strategy identified at the level of the neuro-injured patient.

Digit Memory Test

The Digit Memory Test is a subtest from the Wechsler Memory Scale III, WMS-III, andis used to evaluate working verbal memory abilities (Wechsler, 1997). The maximum number of digits that the subject is able to repeat in the order in which they have been said is called the forward digit span. When the number of digits that the subject has to repeat is in the reverse order to that which was stated this is called the backward digit span, which allows for an estimation of working memory capacities (Wechsler, 1991; Pąchalska & Lipowska 2006) (Table 1).

RESULTS OF THE NEUROPSYCHOLOGICAL TESTING

In all the neuropsychological tests we observed significant changes in the cognitive functions such as naming, nonverbal and visuospatial and strategic attention, along with the digit memory deviate from the reference substantially.

Table. 1. Example of a digit test

No.	**Figures in direct order Test 1/Answer**	**Score**	**Trial 2 / Answer**	**Score**	**Total score 0, 1 or 2**
1	2-9		4-6		
2	3-8-6		6-1-2		
3	3-4-1-7		6-1-5-8		
4	8-4-2-3-9		5-2-1-8-6		
5	3-8-9-1-7-4		7-9-6-4-8-3		
6	5-1-7-4-2-3-8		9-8-5-2-1-6-3		
7	1-6-4-5-9-7-6-3		2-9-7-6-3-1-5-4		
8	5-3-8-7-1-2-4-6-9		4-2-6-9-1-7-8-3-5		
No.	**Count in reverse order Test 1 / Answer**	**score**	**Trial 2/ Answer**	**Score**	**Total score 0, 1 or 2**
	Example 8-2		Example 5-6		
1	2-5		6-3		
2	5-7-4		2-5-9		
3	7-2-9-6		8-4-9-3		
4	4-1-3-5-7		9-7-8-5-2		
5	1-6-5-2-9-8		3-6-7-1-9-4		
6	8-5-9-2-3-4-2		4-5-7-9-2-8-1		
7	6-9-1-6-3-2-5-8		3-1-7-9-5-4-8-2		

Source: Pąchalska and Lipowska 2006

Boston Naming Test – Polish version

The results of the *Boston Naming Test – Polish version* show that the difference is significant in the patient compared to the control group (p <0.05). The results of the *Boston Naming Test* showed that the test scores were significantly lower in the patient when compared to the control group (patient = 21< Mean-Norm = 59.29; SD= 0.52).

Bell Test

The average number of bells crossed out or circled by the patient was significantly lower (p <0.05) than in the control group (Table 2).

Digit Memory Test scores

The results of the Digit Memory Test (Tab. 3) shows that the difference is significant in the forward digit span and backward digit span trials in the patient compared to the control group (p <0.05).

Forward digit span from the ***Digit Memory Test***

The forward digits span from the Digit Memory Test showed that the test scores were significantly higher in the control group when compared to the patient (patient = 3 < Mean-Norm = 7.65, SD = 0.49).

Backward digit span from the ***Digit Memory Test***

The backward digits span from the Digit Memory Test showed that the test scores were significantly higher in the control group when compared to the patient (patient = 2 <Mean-Norm = 6.51, SD = 0.7).

Neurophysiological testing

The patient was assessed using the Human Brain Index (HBI) methodology (Kropotov 2009; 2016;Kropotov, Pachalska, Mueller 2014; Pąchalska, Kaczmarek & Kropotov 2014) which consisted of recording 19-channel EEG in resting state conditions, during the cued GO/NOGO task and comparing the parameters of EEG spectra and Event-Related Potentials (ERPs) with the normative and patient databases of the Human Brain Index (HBI).

Behavioral performance of the patient in comparison to healthy controls from the Human Brain Index (HBI) is presented in Table 4.

Table 2. Scores from the bells circled by the patient and control group

Patient	**Mean**	**6**	**3**	**3**	**11**	**23**
Control group	Mean	2.38	1.44	1	4.82	30.18
	SD	1.16	0.96	0.85	2.97	2.52
Total number						10

Table 3. Scores from the Digit Memory Test of the patient and control group

Tested persons		Forward digit span	Backward digit span
Patient	Mean	3	2
Control group	Mean	7.65	6.51
	SD	0.49	0.7
	Total number	10	

Table 4. Behavioral performance of the patient in comparison to healthy controls from the Human Brain Index (HBI)

Group name	Total	Averaged	Error	Omission	Comission	Artefact	RT1	RT2	var(RT1)	var(RT2)
a-a GO [D]	64	39	0.00%	p=0.000	p=0.823	0	p=0.666	0	p=0.000	0.0
a-p NoGO [D]	61	51	0.00%	0.00%	p=0.000	0	0	0	0.0	0.0
p-p [D]	65	65	0.00%	0.00%	p=0.744	0	0	0	0.0	0.0
p-h [D]	65	64	0.00%	0.00%	p=0.000	0	0	0	0.0	0.0
+ [D]	125	125	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
- [D]	130	130	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
a-p NoGO - a-a GO [D]	0	90	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
p-h - p-p [D]	0	129	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
- - + [D]	0	255	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
a-a GO [1]	64	39	0.00%	39.06%	0.00%	0	347	0	19.9	0.0
a-p NoGO [1]	61	51	0.00%	0.00%	16.39%	0	0	0	0.0	0.0
p-p [1]	65	65	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
p-h [1]	65	64	0.00%	0.00%	1.54%	0	0	0	0.0	0.0
+ [1]	125	125	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
- [1]	130	130	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
a-p NoGO - a-a GO [1]	0	90	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
p-h - p-p [1]	0	129	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
- - + [1]	0	255	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
a-a GO [2]	64	39	0.00%	4.74%	0.08%	0	396	0	7.6	0.0
a-p NoGO [2]	61	51	0.00%	0.00%	1.68%	0	0	0	0.0	0.0
p-p [2]	65	65	0.00%	0.00%	0.30%	0	0	0	0.0	0.0
p-h [2]	65	64	0.00%	0.00%	0.11%	0	0	0	0.0	0.0
+ [2]	125	125	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
- [2]	130	130	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
a-p NoGO - a-a GO [2]	0	90	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
p-h - p-p [2]	0	129	0.00%	0.00%	0.00%	0	0	0	0.0	0.0
- - + [2]	0	255	0.00%	0.00%	0.00%	0	0	0	0.0	0.0

Patient deviation in EEG spectra in eyes closed conditions in comparison to the norm from the reference is presented in Fig.3. It was found, that all behavioral parameters (except RT) in the patient deviate substantially from the reference. EEG spectra show clear abnormalities on the left side within the left Rolandic fissure. The deviations include excessive mu-rhythm and beta activity, which means that this area is inhibited.

The ERPs show no difference between GO and NOGO conditions in the patient indicating poor cognitive control in comparison to the norm from the reference (Fig. 4).

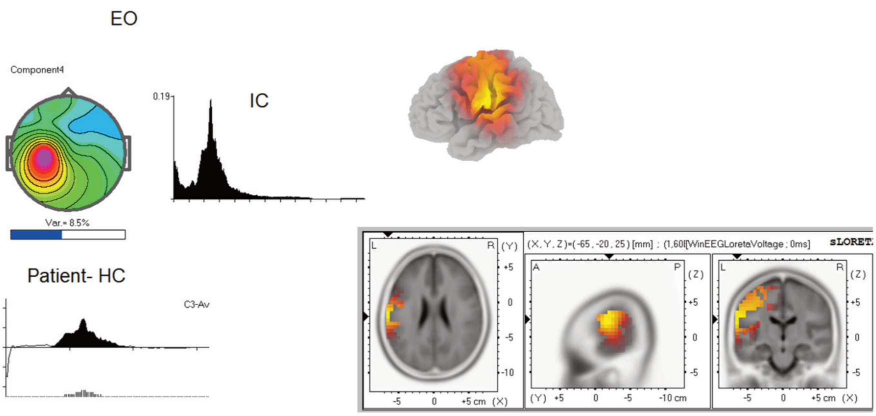

Fig. 3. Patient deviation in EEG spectra in eyes closed conditions in comparison to the norm from the reference. On the bottom to the left: The difference subject minus healthy controls at C3. On the top. Independent component extracted in eyes closed conditions. A) Topography; B) Spectra, C) sLoreta image
Source: own research

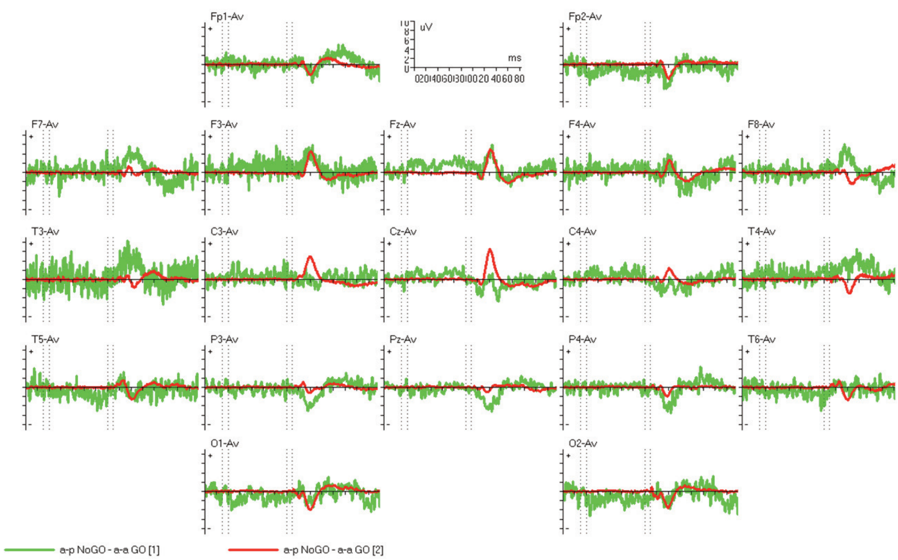

Fig. 4. The difference NOGO minus Go in the patient and in the norm from the reference. Red = reference, Green = Subject
Source: own research

DISCUSSION

Our study has shown that all cognitive functions such as naming, nonverbal, visuospatial and strategic attention, along with the digit memory obtained by the patient deviate substantially from the reference. The results of the *Boston Naming Test – Polish version* shows that the difference is lower in the patient compared to the control group. Also nonverbal (the number of bells circled), visuospatial and strategic attention, along with the digit memory (forward digit span and backward digit span trials) is lower in the patient compared to the control group. Also the ERPs, which show no difference between GO and NOGO conditions indicate poor cognitive control in the patient in comparison to the norm from the HBI database.

How to explain the obtained research results?

A stroke leads to a destabilization of neural networks and in turn causes a poor cognitive control. These mainly include attention disorders and working memory disorders. For a better understanding of the brain work underlying cognitive control, we will present a synchronic model of memory (Fig. 5) elaborated according to the principles of process neuropsychology and developed by Pachalska, Kaczmarek and Kropotov (2014). Synchronicity is defined, based on process theory (i.e., Microgenetic Theory) and evolutionary-genetic theory (Brown 2015, as the appearance in parallel lines of two (or several) phenomena, event, or mental states that have, for the observer, a common meaning, though they are not linked causally.

The synchronic model of memory is derived from the holographic model of the universe, which reflects the synchronicity of reality. The spatial arrangement of the model enables it to present, on the *x* and *y* axes, the relation between the general structure of the attention and memory systems in terms of the number, content, and complexity of the items being processed, and the time needed to process them. It is assumed, as in Pribram's concept [1984], that thanks to the change of the angle at which bursts radiating from two lasers affect a photographic image, it is possible to keep many different images on the same surface. The synchronic pattern of the model (the dotted line) in turn reflects the holographic interference of waves, corresponding to what goes on in the brain: the pulsing of mental states and changes in neuronal connections (including new connections arising in brain tissue).

In this model, consciousness and self-awareness have been represented by a separate circle, since these are prerequisites for the normal course of cognitive processes (including memory) and emotional processes. The outer (yellow) spiral refers to the fractal concept of consciousness and self-awareness in relation to the mind, and to the synchronic image of reality formed by the self in relation to the world and the universe (see: Fig. 5)

The tunnels through which the small spheres swim represent the various kinds of working and long-term memory, thanks to which the conscious self forms its own synchronic reality in the relation between the self, the world, and the

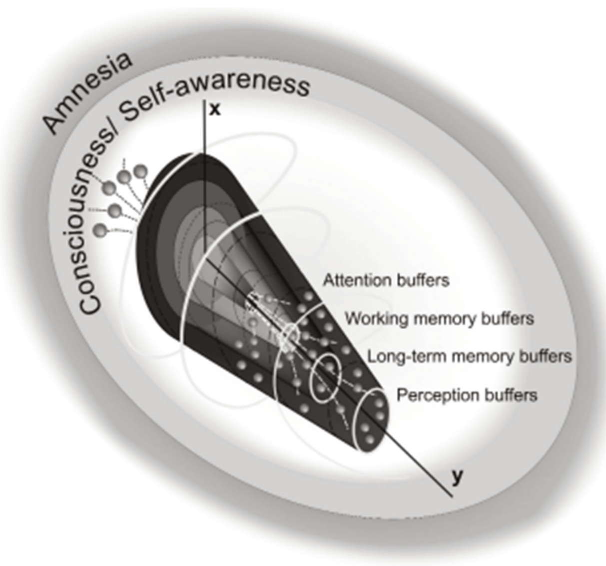

Fig. 5. The synchronic model of memory.
From: Pąchalska, Kaczmarek & Kropotov [2014], with permission.

universe [Pąchalska, Kaczmarek & Kropotov 2014]. Thanks to plasticity and new connections in the brain, there appears a kind of dependency between events, in which every causal connection is possible. The large yellow circles are buffers:
1. attention;
2. working memory;
3. long-term memory;
4. perception.

According to data recently obtained from neurophysiological research, the attention system buffers the transmission of data to the working memory system. The attention system processes the smallest number of elements in the shortest time (seconds, even milliseconds). When the number of elements being processed and/or the processing time exceeds a certain threshold, there is a gradual transition from the attention system (a few stimuli, a few milliseconds) to the working memory system (a dozen or more stimuli, several milliseconds, seconds, or minutes), depending on the capacity of the working memory buffer.

The transition from working memory to long-term memory takes place in a similar fashion. The boundary for transition is difficult to establish precisely, and in reality it is probably rather blurred. In the human brain there is a constant process, lasting from milliseconds to whole years, when information is committed to memory, stored, recalled, and forgotten (see also: Brown 2015, Pąchalska 2019).

The longest duration of storage is naturally provided by long-term memory, which is why we have placed it near the base of the model. Memory (both retrospective and prospective) is closely associated with the creation of a model of the world, thanks to the perception buffer placed at the very base of the model. Without a properly functioning memory system, there is no properly functioning perception system, or other cognitive processes. It is also essential to note that in the process of perception, the feeling that an object exists and that it belongs to a primitive functional category precedes the awareness of its particular perceptual features. On the edges of the model of memory, outside the circle of consciousness and self-consciousness, is unawareness and amnesia. It requires a major commitment of brain resources to recover information from this domain.

The presented model provides a better understanding of the cognitive disorders (naming, nonverbal, visuospatial and strategic attention, along with the digit memory disorders) that occur after a stroke, and the poor cognitive control confirmed in our patient.

“Time is the brain” (Brainin, Teuschl, Kalra et al. 2007). 2007), therefore fast and effective clinical diagnosis with the use of neuromarkers, and subsequently the effective rehabilitation of stroke patients is the goal of modern medicine. In order to improve the diagnosis and treatment of patients following an ischemic stroke, it is important to employ new neurotechnologies.

CONCLUSIONS

The ERPs show no difference between GO and NOGO conditions in the patient in comparison to the norm from the HBI database, herein indicating poor cognitive control. ERPs could be treated as an index of impaired cognitive control in an ischemic stroke aphasic patient**.**

Acknowledgements

Our appreciation goes to the entire neuropsychology team at the Reintegrative and Teaching Center of the Polish Neuropsychological Society we acquired the methods in the field of neuroscience relating to stroke patients, and especially to Prof. Maria Pąchalsa and Prof. Juri D. Kropotov for help in the interpretation of the tests results.

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