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Application of the Trail Making Test in the assessment of cognitive flexibility in patients with speech disorders after ischaemic cerebral stroke

Zastosowanie Testu Łączenia Punktów do oceny elastyczności poznawczej u chorych z zaburzeniami mowy po udarze mózgu

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Abstract

The main aim of this study was to evaluate the level of cognitive flexibility in patients with speech disorders after ischaemic cerebral stroke. The study was conducted in a group of 43 patients (18 women and 25 men) who had experienced cerebral ischaemic stroke. The patients under study were divided into groups based on the type of speech disorders, i.e.: aphasia, lack of speech disorders and dysarthria. A Mini-Mental State Examination (MMSE) and a Clock Drawing Test (CDT) were applied for the general evaluation of the efficiency of cognitive functions. Cognitive flexibility – a component of executive functions, was evaluated with the use of a Trail Making Test (TMT). The results obtained prove that patients with aphasia show the lowest level of cognitive flexibility. Disorders of executive functions can be related to the dysfunction of the prefrontal cortex which has been damaged as a result of ischaemic cerebral stroke. Presumably, there are common functional neuroanatomical circuits for both language skills and components of executive functions. In the case of damage to the structures that are of key importance for both skills, language and executive dysfunctions can therefore occur in parallel. The presence of executive dysfunctions in patients with aphasia can additionally impede the functioning of the patient, and also negatively influence the process of rehabilitation the aim of which is to improve the efficiency of communication.

Key words: aphasia, executive functions, cognitive flexibility, stroke, dysarthria

Streszczenie

Nadrzędnym celem pracy było określenie poziomu elastyczności poznawczej za pomocą Testu Łączenia Punktów (*Trail Making Test*, TMT) u chorych z zaburzeniami mowy po udarze mózgu. Badaniem objęto 43 chorych (18 kobiet oraz 25 mężczyzn) z niedokrwiennym udarem mózgu. Badanych przydzielono do trzech grup w zależności od rodzaju zaburzenia mowy: chorych z afazją, brakiem afazji i dyzartrią. Do oceny ogólnej sprawności funkcji poznawczych zastosowano Krótką Skalę Oceny Stanu Psychicznego (*Mini-Mental State Examination*, MMSE) oraz Test Rysowania Zegara (*Clock Drawing Test*, CDT). Elastyczność poznawcza była badana przy użyciu Testu Łączenia Punktów. Uzyskane wyniki wykazały, że chorzy z afazją wykazują najniższy poziom elastyczności poznawczej. Zaburzenia elastyczności poznawczej mogą być związane z dysfunkcją kory przedczołowej, która uległa uszkodzeniu w wyniku niedokrwiennego udaru mózgu. Przypuszczalnie dla umiejętności językowych i komponentów funkcji wykonawczych istnieją wspólne neuroanatomiczne obwody funkcjonalne. Stąd w przypadku uszkodzenia kluczowych dla obu zdolności struktur dysfunkcje językowe i wykonawcze mogą występować równolegle. Współwystępowanie deficytów poznawczych u chorych z afazją może dodatkowo utrudniać funkcjonowanie chorego, a także mieć negatywny wpływ na proces rehabilitacji sprawności porozumiewania się.

Słowa kluczowe: afazja, funkcje wykonawcze, elastyczność poznawcza, udar mózgu, dyzartria

INTRODUCTION

A Trail Making Test (TMT) derives from Halstead-Reitan Neuropsychological Battery. TMT is used for the measurement of the skills of visual and spatial search, operative memory and executive functions in the scope of prolonged concentration and smooth alternating attention between two tasks performed simultaneously (cognitive flexibility). Cognitive flexibility is one of the components of executive functions, next to initiating and planning activities (Friedman and Miyake, 2000). Executive functions are involved in situations in which automatic behaviour in response to an external impulse is replaced by a planned behaviour and by one that is related to the extinction or delay of a reaction (Norman and Shallice, 2000). In the literature on the subject, there is no consensus as to the issue of identifying neuronal structures responsible for cognitive processes related to executive functions (Jodzio, 2008). Executive skills require activity and coordination between scattered areas of the brain, which is indispensable in order to achieve such a wide scope of mental activities (Rajtar *et al.*, 2014). Executive functions are mainly associated with the neuronal activity within the frontal lobes, and specifically within the dorsolateral prefrontal cortex (Alvarez and Emory, 2006; Stuss and Alexander, 2000; Zakzanis *et al.*, 2005). However, more and more researchers stress the interaction of numerous brain structures in regulating executive functions, both those localised in the frontal lobes and the subcortical structures (Niendam *et al.*, 2012). Recent empirical data indicate that one of the most frequent causes of executive dysfunctions is cerebral stroke involving the areas of the frontal lobes of the brain and subcortical structures which project into this cortex (Jodzio *et al.*, 2012). The frequency of occurrence of executive function disorders in patients after stroke ranges from 10 to 63%, depending on the scope of methods applied (Grau-Oliveres *et al.*, 2007; Nys *et al.*, 2005; Pohjasvaara *et al.*, 2002; Su *et al.*, 2007; Zinn *et al.*, 2007). Moreover, attention has to be drawn to the fact that in the recent years, researchers are more and more interested in the issues of the coexistence of non-linguistic cognitive and behavioural dysfunctions in patients with speech disorders after ischaemic cerebral stroke (Seniów *et al.*, 2009). In neuropsychology, it has been pointed out for a long time that damage to the prefrontal areas results in the disintegration of complex cognitive (executive as well as linguistic), volitional, motivational and emotional functions. In the case of a blood supply pathology within the forebrain, the coexistence of focal cognitive disorders and acquired speech disorders, such as aphasia and dysarthria, is quite frequent. Despite varied aetiopathogeneses, cerebral stroke is the most frequent cause of aphasia which is believed to affect over a half of patients after stroke (Pąchalska, 2011). The frequency of occurrence of post-cerebral aphasia is estimated at 21–38% (Ryglewicz and Milewska, 2004). The prevalence of various types of aphasia as a consequence of the first cerebral stroke is as

follows: total aphasia – 32%, amnesic aphasia – 25%, Wernicke’s aphasia – 16%, Broca’s aphasia – 12%, transcortical sensory aphasia – 7%, conduction aphasia – 5% and transcortical motor aphasia – 2% (Pedersen *et al.*, 2004). In aphasia, depending on the location of damage, changes consist in the loss or impairment of creating and/or understanding spoken and written language. Recent theoretical considerations and study results suggest that the deterioration of executive functions is a frequent neuropsychological deficit in patients with aphasia (Purdy, 2002). What is more, the studies involving healthy individuals confirm that the efficiency of executive functions is correlated with the speed of naming objects (Shao *et al.*, 2012), verbal fluency (Constantinidou *et al.*, 2012) and the ability to make sentences (Engelhardt *et al.*, 2013).

Other speech disorders, namely dysarthrias, are also frequently related to the damage within the subcortical structures of the brain. Dysarthria is defined as impaired ability to produce articulated speech sounds as a result of the disruption of neural mechanisms for creating and modulating: volume, shape and resonance of voice. Patients with dysarthria, in contrast to patients with aphasia, understand speech and have no difficulty in formulating speech, although pronunciation itself is impaired.

In the literature on the subject there are very few studies on executive functions in patients with dysarthria. Researchers such as Sterling *et al.* (2010), having assessed executive functions in patients with dysarthria, pointed out that the deterioration of their results was exclusively related to the slower work pace which resulted from the general slowness of movement in this group of patients. In the light of the above findings, attention was drawn to the non-homogeneous nature of the symptoms of executive dysfunctions and an attempt was made to separate the key component – cognitive flexibility. The purpose of the study was to compare cognitive flexibility in patients with speech disorders (aphasia and dysarthria) after cerebral stroke, which are the consequences of ischaemic lesions located in various brain regions.

MATERIAL AND METHOD

The study included 43 patients (18 women and 25 men) with diagnosed ischaemic cerebral stroke, hospitalised at the Department of Neurology and Cerebral Strokes with a Subdivision for Cerebral Strokes in Ludwik Rydygier Specialist Hospital in Krakow. The study included demographic data, such as: sex, age and level of education, as well as clinical data taking into account the ischaemic lesion location, type of speech disorder and the time that has passed since the occurrence of the vascular accident. The inclusion criterion was ischaemic cerebral stroke. The exclusion criteria were: poor nonverbal communication skills, coexistence of other diseases and disorders that can affect the variables studied, i.e. consciousness disturbances, psychosis, dementia diagnosed before stroke, alcoholic disease,

post-traumatic cognitive deficits, post-stroke movement (e.g. paresis handedness) or visual percepton deficits (e.g. amblyopia, alexia, agnosia) making it impossible to carry out neuropsychological tests.

In a cross-sectional study, a group of patients was examined at one point in time to compare the level of cognitive function efficiency in patients with various speech disorders. The study was carried out over a period of 12 months. Patients were recruited for the study according to the order of admission to hospital. Patients with a clinical diagnosis of ischaemic stroke and who met the criteria were included in the study. The presence and location of a defect was confirmed in computed tomography (CT) recommended by a radiologist. Patients were divided into three groups according to the type of speech disorder: a) patients with aphasia, b) patients without disorders of speech, and c) patients with dysarthria. An experienced clinical neuropsychologist, neurologist and a speech therapist confirmed the diagnosis of a speech disorder. This study included patients with non-fluent forms of aphasia: motor (Broca's) aphasia and transcortical motor aphasia, which are usually the consequences of damage to the frontal lobe. The research was carried out as part of research project Demeter, with the approval of the Ethics Committee at the local Chamber of Krakow – No. 12/KBL/2010 of 26 January 2011.

For the assessment of the general efficiency of cognitive functions, the following were applied: a Mini-Mental State Examination (MMSE) and Clock Drawing Test. A Trail Making Test (TMT) was used to assess psychomotor skills (part A) as well as working memory and cognitive flexibility (part B). TMT consists of two parts assessed separately (A and B). In part A, there are 25 circles numbered from 1 to 25 in a white sheet of paper while in part B there are 25 circles marked with numbers from 1 to 13 and with letters from A to L. In part A, the task of the subject is to connect the dots with a solid line in numerical order as fast as possible. In part B, the subject has to, as fast as possible, connect with a solid line the digits with the subsequent letters of the alphabet in the following alternating order: 1 – A – 2 – B – 3 – C – 4 – D etc. In the assessment of the test results, the time (in seconds) needed to complete the task and the number of mistakes made (Reitan, 1955) are assessed. A result of part B is a sensitive indicator of a dysfunction within cognitive flexibility – a component of executive functions (Kortte *et al.*, 2002; Lee *et al.*, 2014; Salthouse, 2011). Furthermore, some authors suggest that the B/A ratio should be taken into account in order to reflect the efficiency of executive functions more precisely. In their opinions, the psychomotor component, measured in part A of the TMT, is then eliminated (O'Rourke *et al.*, 2011). Therefore, the longer the time needed to complete part B in comparison to that in part A (and, at the same time, the higher the B/A ratio), the worse the result of cognitive flexibility testing. The study included the score of components A and B, the B/A ratio and the number of mistakes in Part B. Moreover, the execution time

(expressed in seconds) for each part, A and B, was also taken into account.

Statistical analysis

The calculations in this study were made with the use of a STATISTICA v 9.0 PL package. The comparisons between the groups were made using a single-factor analysis of variance, as more than two groups were compared. In order to establish statistically significant differences between the groups, multiple comparisons of the average results were made according to Tukey method. The variables at a nominal scale were described by the multiplicity and the corresponding percentage. All statistical hypotheses were verified at the significance level of $\alpha = 0.05$.

In order to select the type of measurement, an analysis of the variables under study was carried out, which proved that the hypothesis of normal distribution has to be partly rejected. Due to the fact that the variance analysis is “resistant” to the breaking of the assumption concerning normal distribution and that in the study, small groups were compared in terms of variables, which in theory have the normal distribution, and that the assumption concerning homogeneity of variance was met, parametric tests were applied for all the variables compared.

Descriptive statistics

The group under study consisted of persons aged 42 to 87, with average age $M = 66$. The study included more men (58%) than women (42%). The most numerous group consisted of persons with secondary education (40%) and vocational education (30%). The average time of examination was 3.5 days after stroke (from 1 to 7 days). In almost a half of the cases, stroke affected the left hemisphere. Aphasia was noted in 42% of the persons examined and dysarthria – in 26%. In every third person no speech disorders occurred. Motor aphasia (Broca's aphasia) was diagnosed in 61% of the patients, and transcortical motor aphasia – in 39% of the patients. Frontal lobe damage was noted in 42% of the persons examined, subcortical structure damage – in 33% of the patients, and in every fourth person the damage to the cortex of the posterior part of the cerebral hemispheres was found. A radiologist confirmed the location of the damage in a CT scan, while a neurologist and a clinical psychologist confirmed speech disorders. The clinical and demographic data are compiled in Tab. 1.

RESULTS

According to the data presented in Tab. 2, it appears that the groups with different types of speech disorders did not differ in respect of age and a day after stroke. Similarly, no differences were found between the examined persons with various speech disorders with respect to cognitive efficiency measured with the use of screening methods of assessment

(MMSE, Clock Drawing Test) (Tab. 3). In the analysed subgroups of patients, no differences were observed in the average time of completing the Trail Making Test, both in part A and B, and in the number of mistakes made. The only differences observed between the examined persons with different types of speech disorders concerned part B to part A ratio in the Trail Making Test (Tab. 4). The ratio of the

average time in part B to the average time in part A was different in the groups with different speech disorder types ($p < 0.001$). Multiple comparisons with the use of Tukey method proved that the persons with aphasia demonstrated a lower level of flexibility in comparison to the persons without aphasia ($p = 0.003$) and in comparison to the persons with dysarthria ($p = 0.002$).

Variable	Category	Group with aphasia (n = 18)		Group with no aphasia (n = 14)		Group with dysarthria (n = 11)	
		N (%)	M (SD) gap	N (%)	M (SD) gap	N (%)	M (SD) gap
Age			65.9 (10) 48–86		66.6 (13) 44–87		63.6 (10) 42–79
Education level	Higher	2 (11.1)		2 (14.3)		-	
	Vocational	6 (33.3)		3 (21.4)		4 (36.4)	
	Secondary	8 (44.4)		6 (42.8)		3 (27.3)	
	Primary	1 (5.5)		2 (14.3)		1 (9.1)	
	Technical	1 (5.5)		1 (7.1)		3 (27.3)	
Number of days after stroke			4.2 (2) 1–7		3.2 (2) 1–7		3.1 (2) 1–7
Hemisphere	Left	14 (77.8)		1 (7.1)		6 (54.5)	
	Right	-		11 (78.6)		4 (36.4)	
	Bi-hemispheric	4 (22.2)		2 (14.3)		1 (9.1)	
Location of the damage	KP	11 (61.1)		4 (28.6)		4 (36.4)	
	KT	4 (22.2)		4 (28.6)		2 (18.2)	
	SP	3 (16.7)		6 (42.8)		5 (45.4)	

Source: author's own material based on the test results obtained.

N – multiplicity, % – percentage of the whole, M – average, SD – standard deviation.

KP – persons with the damage to the frontal cerebral lobes; KT – persons with the damage to the cortex of the posterior parts of the cerebral hemispheres; SP – persons with the damage to the subcortical structures of the brain.

Tab. 1. Characteristics of the group under study divided into subgroups based on the type of speech disorders

Test	Aphasia (n = 18)	No aphasia (n = 11)	Dysarthria (n = 14)	F(2,40)	Effect strength (η^2)	p
Age	65.9 (9.63)	66.4 (12.65)	63.64 (10.14)	0.25	0.01	0.776
Day	3.6 (1.97)	4.27 (2.19)	3.21 (1.31)	1.89	0.09	0.165

Source: author's own material based on the test results obtained.

Tab. 2. Comparison of the group divided into subgroups according to the type of speech disorders with respect to age and a day after stroke

Test	Aphasia (n = 18)	No aphasia (n = 14)	Dysarthria (n = 11)	F(2,40)	Effect Strength (η^2)	p
MMSE	23.78 (5.05)	26.57 (3.98)	24.82 (5.55)	1.30	0.06	0.283
Clock Test	7.83 (1.92)	8.79 (1.63)	7.09 (2.51)	2.27	0.10	0.116

Source: author's own material based on the test results obtained.

MMSE – Mini-Mental State Examination; Clock Test – Clock Drawing Test.

Tab. 3. Level of efficiency of cognitive functions in patients after cerebral stroke divided into subgroups according to the type of speech disorders

Test	Aphasia (n = 18)	No aphasia (n = 14)	Dysarthria (n = 11)	F(2.40)	Effect strength (η^2)	p
TMT (A)	75.39 (27.9)	70.57 (34.3)	101.2 (49.8)	2.46	0.11	0.098
TMT (B)	313.7 (130.6)	219.7 (140.0)	276.5 (144.6)	1.85	0.08	0.171
TMT (B/A)	4.29 (1.47)	2.91 (0.82)	2.70 (0.54)	9.52	0.32	<0.001
TMT-number of mistakes	4.89 (4.57)	4.64 (5.77)	5.00 (4.63)	0.02	0.00	0.983

Source: author's own material based on the test results obtained.
TMT – Trail Making Test; TMT A – average time of completion (s); TMT B – average time of completion (s); B/A ratio of average time (s) from part A to part B of the TMT.

Tab. 4. Level of the efficiency of executive functions in patients after cerebral stroke divided into subgroups according to the type of speech disorders

DISCUSSION

The purpose of this study was to compare the skill of cognitive flexibility as a component of executive functions in patients with speech disorders after cerebral stroke. The verification of the significance of the differences between the groups in the test assessing the level of cognitive flexibility proved that the persons with aphasia found it more difficult to solve part B compared to part A of the Trail Making Test (TMT). Motor aphasia and transcortical motor aphasia are most frequently the consequences of the damage to the lower areas of the left frontal part of the brain. This allows one to presume that the noticeable relation between cognitive flexibility dysfunctions and the occurrence of motor aphasia disorders results from the functional and anatomical interdependence of the two types of disorders. The most significant result of the tests was that the patients with aphasia demonstrated a significantly lower level of flexibility, i.e. the ability to switch from one task or mental state to another carried out or occurring simultaneously. The relation between the disorders in the scope of cognitive flexibility and aphasia was already noted by Purdy (2002). She pointed out that patients with aphasia performed tasks involving cognitive flexibility less efficiently. Such conclusions were drawn after taking into account the precision and effectiveness of performance rather than the pace of work. However, the author did not undertake to characterise the group under study either in respect of the type of aphasia or the location of brain damage. The TMT selected in this study is currently a frequently used method for the assessment of the efficiency of cognitive flexibility in persons after cerebral stroke. It is believed that part A of this test is to a larger extent used for the assessment of psychomotor skills while part B is used for the assessment of working memory and the skill of alternating attention between tasks being performed, i.e. cognitive flexibility. Due to the fact that executive functions to a large extent depend on the activity of the frontal lobes, part B of the test is more sensitive in detecting damage just within these lobes. Studies with the

application of functional neuroimaging in healthy adults proved that performing part B of the TMT is related to the greater activity of the frontal lobe within the left dorsolateral prefrontal cortex compared to part A of this test (Zakzanis *et al.*, 2005). Similarly, patients with focal cerebral damage located in the frontal lobes perform part B with significantly worse results in comparison to part A. What is more, it was proven that significantly worse performance of the test is observed in patients with dorsolateral prefrontal cortex damage in comparison to patients with damage to the orbitomedial prefrontal cortex (Stuss *et al.*, 2001). As some authors argue, the ratio of the time needed to complete part B to the time needed to finish part A (B/A) enables one to assess the efficiency of cognitive functions more precisely, as the disruptive influence of the psychomotor component measured in part A of the test is eliminated (O'Rourke *et al.*, 2011). This dependence was also observed in this study when comparing the average time in both tests and the ratio of part B to part A in the groups examined. The patients with dysarthria spent more time performing both part B and part A of the test, and therefore no significant differences were observed after taking into account the part B to part A ratio. Poorer results in both parts can be related to a slower pace of work resulting from general psychomotor impairment in patients with dysarthria. Sterling *et al.* (2010) drew similar conclusions after comparing the results obtained in a wide range of neuropsychological tests in patients with dysarthria and in the control group. The authors observed that poorer results in executive tests (inter alia, in both parts of the TMT) are found when the time of completion, which is longer in the group of patients with general motor retardation, is taken into consideration in the assessment. Dysarthria generally occurs as a result of damage to the motor area of the cortex, pyramidal and extrapyramidal tracts, medulla oblongata or cerebellum, and not as a result of damage to the lower parts of the frontal cortex, as in the case of patients with aphasia. Therefore, psychomotor retardation can result from damage to the subcortical structures and cortical-subcortical tracts. This observation

can be useful in diagnosing executive dysfunctions in patients with a pathology within the subcortical structures of the brain.

Beside cognitive flexibility, another key component of executive functions is the control of extinction. The loss of inhibition is manifested in the form of unsuppressed and disorganised reactions. The lack of flexible suppression of impulsive reactions makes reactions and the course of mental processes rigid, causing perseveration in behaviour. Behavioural symptoms, such as hyperactivity, increased susceptibility to distraction, impulsiveness, perseveration and stereotypic reactions, were presented by Godefroy (2003). The inhibition assessment is also performed with the use of the TMT, the performance of which requires efficiency of various cognitive modalities. That is why this test is a very sensitive tool for detecting mental rigidity mentioned above. If the problem with inhibition causes difficulties in suppressing reactions, and hence retardation and tendencies to perseveration, the deficits in cognitive flexibility can impede accepting, maintaining and changing the mental attitude in the course of performing equivalent tasks. Other studies also indicate the relation between inhibition and linguistic functions. Deficits in storing semantic information in short-term memory can be related to a disorder in inhibition. It is believed that the weakening of the ability to extinct insignificant utterances impede the search for and selection of appropriate responses, which results in the deterioration of speech fluency (Martin and Allen, 2008). Almaghyuli *et al.* (2012) also stress the role of executive functions in the processes of controlling semantic processing. They observed that patients with aphasia show deficits in suppressing false associations, that is why their performance in a task consisting in providing synonyms of words that are more common is poorer than doing so with words that occur more rarely. The authors explain this phenomenon claiming that executive functions are to a greater degree involved in choosing synonyms for the words that occur more frequently, which is related to the selective concentration of attention on those aspects of processing that are significant for a given task or context. In other words, executive functions are related to the adjustment of the processes of semantic information processing by means of selective reception of semantically significant elements and discarding the insignificant ones. There are numerous reports concerning the co-occurrence of disorders in attention processes that are components of executive functions in patients with aphasia. The findings confirm that persons with aphasia are characterised by worse results in attention and working memory (Christensen and Wright, 2010; Helm-Estabrooks, 2002; Murray, 2012; Starowicz and Prochowicz, 2005).

The last issue to be discussed is the results of the remaining tests included in the analysis. For the initial assessment of the efficiency of cognitive functions, quick-and-easy screening tools were applied, namely: a Mini-Mental State Examination (MMSE) and Clock Drawing Test. In this study,

the average results of both tests, conducted in patients after stroke, did not differ in a significant way between the groups with different speech disorders.

In the light of the studies carried out and the conclusions formulated by other authors, executive dysfunctions characterised by specific symptoms of behavioural disorganisation are undoubtedly a frequently occurring neuropsychological deficit in persons after cerebral stroke. The clinical manifestation of focal cognitive behavioural syndromes in the acute phase of the illness after focal, non-progressive brain damage, primarily depends on the location of the damage. Despite the fact that there is no consensus as to the manner of defining “executive” functions, which are frequently incorrectly defined as “frontal” functions, cognitive dysfunctions are most frequently the consequences of damaging the frontal lobes (Stuss and Alexander, 2000). Patients with motor aphasia and transcortical motor aphasia find it difficult to perform tasks involving cognitive flexibility. These actions are undoubtedly connected with speech generation processes. In the light of the above considerations, effective communication depends on the integrity of executive functions. Despite numerous clinical data as well as the results obtained in this study concerning the co-occurrence of executive dysfunctions and aphasia, there are still no explicit conclusions that would explain anatomical and functional correlates of these disorders. It is possible that future studies, combining the paradigm of linguistic communication and cognitive neuropsychology, will broaden the knowledge of the cerebral mechanisms of the most complicated cognitive functions in human beings.

Conflict of interest

The authors do not report any financial or personal links with other persons or organizations, which might affect negatively the content of this publication or claim authorship rights to this publication.

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