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The tools of cognitive creativity assessment

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Abstract. Background. The purpose of the study was to assess the occurrence of disorders in the field of cognitive creativity in patients with minimal manifestations of leukoencephalopathy. **Materials and methods.** The study was carried out in the Expert Health Center in 2021–2022. We have examined 43 patients aged 45–60 years who had hyperintense foci in the white matter of the brain on magnetic resonance imaging, meeting Fazekas 1 criteria, and preserved cognitive abilities according to the MMSE and MoCA (≥ 25 and ≥ 26 points, respectively). As a control, 20 people of the same age with Fazekas 0 were examined, including 9 people employed in the creative professions. Additionally, all participants were examined using the Divergent Association Task (DAT). Statistical processing of the obtained results was performed by methods of dispersion and correlation analysis using Statistica 14.1 software (TIBCO, USA). **Results.** The average age of patients in the main group was 53.1 ± 0.3 years, while in the controls, it was 52.6 ± 0.5 years. In patients with signs of minimal microangiopathy of cerebral vessels, the MMSE score was on average 26.4 ± 0.2 points, and MoCA — 27.0 ± 0.3 points, while in the control group, 27.8 ± 0.2 and 28.1 ± 0.3 points, respectively ($p < 0.05$). In the main group, the DAT was on average 59.0 ± 1.3 %, while in the controls, it was 81.9 ± 1.1 % ($Z = 3.8$; $p = 0.0001$). The highest indicators of DAT were found in workers of creative specialties — 85.0 ± 0.9 % ($Z = 2.7$; $p = 0.008$). **Conclusions.** There was demonstrated that 95.0 % of patients with minimal manifestations of leukoencephalopathy caused by microangiopathy had a decrease in creative abilities (DAT 59.0 ± 1.3 vs. 81.9 ± 1.1 %; $Z = 3.8$; $p = 0.0001$). The coefficient of internal agreement of the DAT test α_k was 0.7 with a reproducibility of 85.7 %, which allows recommending the method for use in clinical practice. The method of assessing associative tasks on divergent thinking has a higher sensitivity (97.7 %) than traditional methods of evaluating cognitive abilities at subclinical stages of chronic cerebral blood flow disorders.

Keywords: cognitive creativity; divergent thinking; microangiopathy; diagnosis; semantics

Introduction

One of the evolutionary advantages of a person is creativity, a level of creative giftedness that ensures adaptation to environmental conditions by generating new useful ideas [1–3]. Creativity is an important characteristic of personality and is closely correlated with intellectual abilities in general. In recent years, in the practice of neuropsychologists and neurologists, the term “cognitive creativity” has been used as a characteristic of cognitive processes aimed at solving complex, non-standard problems [4, 5].

Cognitive creativity can be considered the key to success in modern society. It is individuals with a high level of cognitive creativity who determine the ways of technology development, influence art, science, economy, and solving everyday problems [1, 4, 5]. At one time, J.P. Guilford proposed a multifactorial model of the structure of intelligence [6], in which creative thinking encompassed convergent and divergent thinking. As convergent thinking, the author understood the ability to converge with prevailing ways of thinking in order to find a single, correct and ready-made



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solution to a problem that other people could use. Instead, divergent thinking represents a spontaneous and free form of thought and exemplifies the ability to find many new solutions to an open problem. Currently, divergent thinking itself is recognized as one of the main indicators of a person's creative potential [6, 7].

Other concepts of the functioning of cognitive creativity have been proposed [8–10]. Thus, the Geneplore model describes the creative process as a cyclic movement between the generative and research phases [8]. The generative phase plays a decisive role in behavior, it is aimed at creating ideas of an inventive nature, which differ in varying degrees of creative potential and originality [8, 11]. This stage requires the involvement of available cognitive resources, including memory recovery, mental synthesis, mental transformation, and categorical reduction [1, 2, 11]. In the research phase, the individual uses cognitive and metacognitive processes, such as the search for attributes, conceptual interpretation, formulation of conclusions and hypothesis testing, which in general lead to the verification and practical interpretation of a creative idea for the final realization of a creative result [8, 12].

Innovativeness and originality of thinking are difficult to assess with conventional clinical tools [13–15]. Available psychometric methods are subjective in nature. In general, the quantitative expression of attributes for evaluating creative inventions (elegance, aesthetics, originality, compliance with the challenges of time) seems impossible — most researchers rely on descriptive qualitative characteristics [13].

Creativity can be measured by testing and non-testing methods. Testing methods include creative tests for problem perception, attitude and thinking [13, 14]. Among the available creativity tests, two versions of Torrance test of creative thinking are most often used — figurative and verbal (TTCT-F and TTCT-V) [15]. According to K. Kim (2017), TTCT-F is a more complete, reliable, and valid indicator of creativity than TTCT-V [16], but most researchers consider it necessary to use both tests in clinical practice [15, 17, 18].

Thinking style is a key factor that determines the ability to be creative [1, 2, 19, 20]. At the same time, it is the main characteristic of how a person expresses thoughts, receives, organizes, and uses information [1, 19]. People of creative professions can develop a certain independence from the external context when a person consciously chooses decisions that do not fit into the paradigm of aesthetic or socially approved “norm” [20].

Cognitive creativity is one of the ways to achieve success and noticeable progress in professional, personal, and social life. But what neurochemical mechanisms underlie the ability to be creative? How do creative urges form sustainable motivation for creativity? How does a person's emotional state change during the creative process? What is the reward for successfully solving a complex, non-standard problem? How does the creative mind work?

Today, it is known that cognitive creativity is influenced by the functioning of the dopaminergic, noradrenergic, and serotonergic systems [21–23]. However, our understanding of exactly how the neuromodulatory effects of the main

neurotransmitters are realized in the creative process is meager and incomplete. All that is known about cognitive creativity at the neurochemical level is the results of animal studies [21]. The best-known model consists of three levels of increasing cognitive complexity: novelty, observational learning, and innovative behavior. The first one includes as a cognitive ability to recognize novelty, which associated with hippocampal function and active novelty seeking that is linked to the mesolimbic dopaminergic system. The second level refers to learning through observation the complexity of which can vary from imitation to the cultural transmission of creative behavior. Observational learning may depend on the cerebellum and prefrontal cortex. The third level is represented by innovative behavior, which is associated with the specific recognition of a specific object characterized by novelty. This innovative behavior may depend on the prefrontal cortex [21].

It should be noted that both nigrostriatal and mesocortical dopaminergic pathways influence creative urges and creative cognition, which are essentially executive functions [22, 23]. Dopaminergic influences on cognitive creativity are realized through the so-called dual process model, which consists of resistance and cognitive flexibility. Executive provision of creativity involves the mechanisms of shifting, inhibition and activation of working memory and requires an optimal balance between deliberate (controlled) and spontaneous processing of information. On the other hand, there is a link between reward (i.e., promise, learning, and intrinsic interest) and creativity through action-effect binding. The moderating influence of thinking (cooperation and competition) and cognitive resources on creative drives (i.e., mood, motivation, and emotions) is also important [22].

A meta-analysis of 45 functional magnetic resonance imaging (fMRI) studies conducted by Boccia et al. (2015) showed that creativity relies on multicomponent neural networks and in different cognitive domains (musical, verbal, and visual-spatial) depends on the interaction of structures localized in different areas and networks of the brain. Using overall activation likelihood estimation analysis, these authors found creativity-related clusters of activations in all four cortical lobes studied, while maximal activation of individual activation likelihood estimation expressed different neural networks in each creative cognitive area [24].

In clinical practice, we often come across situations when, formally, there are no significant deviations from the population norm according to traditional cognitive assessment scales, but the patient complains of changes in thinking, lack of creative urges, impoverished emotions, deterioration of the ability to be creative in general. These patients do not always have signs of a depressive state — all the listed complaints relate directly to the creative component of existence. This situation is most typical for people in creative professions, but similar complaints can occur to any person. The question remains open — whether it is possible to use changes in a person's cognitive creativity for diagnostic purposes to identify early manifestations of cognitive deficits, in-

cluding in patients with chronic cerebrovascular pathology. The most popular TTCT in the world has not been validated in Ukraine, and its standard version requires a long time to perform. In addition, training in the use of TTCT is paid [15]. In this regard, the search for cognitive creativity assessment tools suitable for use in clinical practice continues. One of these tools is Divergent Association Task (DAT) — assessment of associative tasks on divergent thinking [25].

The purpose of the study was to assess disorders in the field of cognitive creativity in patients with minimal manifestations of leukoencephalopathy.

Materials and methods

The study was carried out in the Expert Health Center (Odesa, Ukraine) in 2021–2022. We have examined 43 patients aged 45–60 years who had hyperintense foci in the white matter of the brain on MRI, meeting Fazekas 1 criteria [26], and preserved cognitive abilities according to the Mini-Mental State Examination (MMSE) and Montreal Cognitive Assessment (MoCA) (≥ 25 and ≥ 26 points, respectively) [27, 28]. As a control, 20 persons of the same age with Fazekas 0 were examined, including 9 people employed in creative professions. Participation in the study was voluntary, all participants signed an informed consent before the examination.

MRI scans were performed on a Siemens Magnetom Avanto high-field tomograph (Germany) [26]. Assessment of cognitive functions was performed with the help of MMSE tests (2nd edition) and MoCA 8.1 [27, 28].

Additionally, all participants were examined using the DAT. The base code for evaluating test results is available from <https://github.com/jayolson/divergent-association-task> [29]. The test methodology is as follows. The interviewee was asked to write down 10 words in Ukrainian or Russian that are as different as possible from each other in terms of meaning. Only nouns can be used, proper names and special vocabulary (technical terms, etc.) cannot be used. The choice of words should be independent, in particular, it is not recommended to simply name objects that are in front of the interviewee's eyes. Up to 4 minutes were given to complete the task [18].

DAT average score is 78, with most people scoring between 74 and 82. The score is calculated based on the average semantic distance between each of the words. These

distances are calculated by measuring how often words are used together in similar contexts.

The first seven valid words out of ten are used for the calculation. Using a subset of words allows for some redundancy; you can include up to three invalid words (such as misspelled words or words that are too technical) and still get the overall score. The overall score is given in percentiles (Fig. 1).

Cronbach's α coefficient [30] was used to assess internal agreement. The reproducibility of the scale was determined by repeated testing with comparison of results. The period between attempts was 3–5 days.

Statistical processing of the obtained results was carried out by the methods of dispersion and correlation analysis using Statistica 14.1 software (TIBCO, USA) [31].

Results

The average age of the subjects from the main group was 53.1 ± 0.3 years, the control group — 52.6 ± 0.5 years. All subjects of the main group had mild leukoaraiosis (Fazekas 1). The Fazekas scale divides the white matter into periventricular and deep white matter, and each area is graded depending on the size and confluence of the lesions [26]:

— changes in periventricular white matter: 0 = absent, 1 = “caps” or thin lining similar in shape to a pencil, 2 = smooth “halo”, 3 = irregular periventricular signal extending into the deep white matter;

— changes in the deep white matter: 0 = absent, 1 = point foci, 2 = beginning of fusion of individual foci, 3 = large fusion zones.

The etiology of changes in the periventricular and deep white matter of the brain is different. In the latter case, the cause is chronic ischemia due to a damage to small vessels. However, with a predominance of periventricular foci, there is a combination of demyelination, granular ependymitis and subependymal gliosis, with ischemia of small vessels.

In all examined subjects, the indicators on the MMSE and MoCA scales did not differ from the population average (Table 1). Thus, among those with signs of minimal microangiopathy of cerebral vessels, the MMSE score was on average 26.4 ± 0.2 points, and the MoCA score was 27.0 ± 0.3 points. On the other hand, in the controls, the MMSE score averaged 27.8 ± 0.2 points, and the MoCA was 28.1 ± 0.3 points ($p < 0.05$). This indicates that the standard scales for cognitive function assessment retain

Radio							
Squid	101						
Snow	84	84					
Kidney	93	82	86				
Lemon	97	66	76	72			
Bullet	87	83	79	84	88		
Aircraft	75	94	82	97	98	78	
	Radio	Squid	Snow	Kidney	Lemon	Bullet	Aircraft

Figure 1. DAT assessment (result 85.02 %, control group)

Table 1. Results of the assessment of cognitive abilities in the examined persons

Group	MMSE				MoCA			
	M	m	min	max	M	m	min	max
Main	26.4*	0.2	25	28	27.0*	0.3	26	29
Control	27.8	0.2	26	30	28.1	0.3	26	30

Note: * — differences between groups are statistically significant ($p < 0.05$).

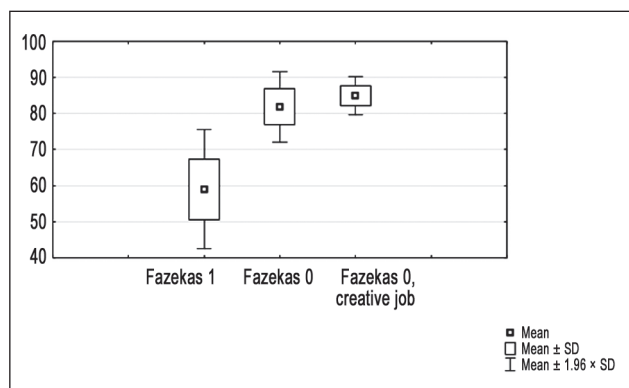


Figure 2. Assessment of cognitive creativity by DAT (box and whisker plot)

their value as a diagnostic tool and can be used for screening purposes to identify people with a tendency to decline in cognitive abilities.

When assessing the level of cognitive abilities according to the DAT, significant differences were found (Fig. 2). Thus, in patients with manifestations of microangiopathy, the indicator of divergent creativity was on average $59.0 \pm 1.3 \%$, while among those without changes in the white matter of the brain, this value was $81.9 \pm 1.1 \%$ ($Z = 3.8$; $p = 0.0001$).

The highest indicators of DAT were determined among employees of creative specialties (designers, artists, scientists, creative directors) — $85.0 \pm 0.9 \%$ ($Z = 2.7$; $p = 0.008$).

The internal agreement of the DAT test α_k was equal to 0.7 with a reproducibility of 85.7 %, which allows recommending the method for use in clinical practice. When comparing the results of the MMSE, MoCA and DAT tests, no significant correlations were found, which can be explained by the absence of cognitive creativity assessment blocks in the MMSE and MoCA. On the other hand, the sensitivity of DAT to changes in cognitive creativity turned out to be higher (97.7 %) than that of standard scales. Even in patients with manifestations of leukoencephalopathy, the values on the MMSE and MoCA scales, showing a tendency to decrease, remained within the reference values, while DAT decreased below the lower limit of normal in 95.0 % of cases in Fazekas 1.

Discussion

Development of tools to assess cognitive creativity remains a challenging task. In fact, since the classic works of J. Guilford and E. Torrance, the methods of creativity assessment include mainly tests of diver-

gent thinking and other non-standard problem-solving skills.

In recent years, significant progress has been made in automated assessment of divergent thinking tests using a semantic approach. In particular, they include DAT — assessment of associative tasks on divergent thinking and similar methods, which use semantic networks to develop indicators of originality [25]. Along with relatively simple methods, with online data interpretation resources open to the user, more complex scalable systems for computerized automated testing (SparcIt Creativity Index Testing system) are used [33].

Some researchers use a socio-personal approach to measuring creativity. In these studies, personality traits, such as independence of judgment, self-confidence, attraction to complexity, aesthetic orientation, and risk-taking, are used as measures of creativity [14, 34].

An alternative is to use questionnaire method when the interviewee actually reports on his creative activity. This method uses quantitative characteristics like the number of publications, patents, or works performed. Although it was originally developed for people with creative specialties, today it is also available for self-assessment of creative activity common in everyday life of an average person. In this case, less prominent creative acts, such as writing an essay or creating one's own recipes, are to be taken into account [35].

Some authors suggest evaluating creativity with the help of IQ tests. Indeed, these parameters are closely correlated with each other, but as experience shows, this correlation is unstable. In order to objectify the assessment of cognitive creativity, it is proposed to use functional diagnostic methods (EEG with evoked potentials, fMRI) simultaneously with tasks of innovative orientation [5, 14, 15].

However, in clinical settings, according to our experience, preference should be given to relatively simple tests with a minimum time to perform. These requirements are satisfied by DAT, which allows you to get an idea of the state of cognitive creativity in 2–4 minutes. The test has high sensitivity and reproducibility, which allows it to be used dynamically to control the effectiveness of treatment and rehabilitation measures.

The weaknesses of this study are the small sample size and the impossibility of using highly informative methods (fMRI) to assess the functions of the centers of higher nervous activity. Furthermore, divergent thinking reflects only one of many aspects of cognitive creativity. The use of Russian and Ukrainian for testing also reduces the accuracy of the DAT, which uses semantic and lexical differences of the English language.

Conclusions

1. In 95.0 % of patients with minimal manifestations of leukoencephalopathy caused by microangiopathy, there is a decrease in creative abilities (DAT 59.0 ± 1.3 vs. 81.9 ± 1.1 %; $Z = 3.8$; $p = 0.0001$).

2. The coefficient of internal agreement of the DAT test was equal to 0.7 with a reproducibility of 85.7 %, which allows recommending the method for use in clinical practice.

3. The method of assessing associative tasks on divergent thinking has a higher sensitivity (97.7 %) than traditional methods of evaluating cognitive abilities at subclinical stages of chronic cerebral blood flow disorders.

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Резюме. Актуальність. Метою дослідження була оцінка наявності порушень у сфері когнітивної креативності при мінімальних проявах лейкоенцефалопатії. **Матеріали та методи.** Дослідження виконане на базі МЦ «Експерт Хелс» упродовж 2021–2022 років. Обстежено 43 пацієнти віком 45–60 років з мінімальними проявами церебральної мікроангіопатії (Fazekas I згідно з даними магнітно-резонансної томографії) та збереженими когнітивними здібностями (≥ 25 та ≥ 26 балів за шкалами MMSE та MoCA відповідно). У контрольну групу ввійшли 20 осіб того ж віку з Fazekas 0, у тому числі 9 осіб, які мають творчу професію. У всіх учасників проведена оцінка дивергентного мислення методом DAT. Статистична обробка результатів виконана за допомогою дисперсійного та кореляційного аналізу з використанням програмного забезпечення Statistica 14.1 (TIBCO, США). **Результати.** Середній вік пацієнтів основної групи становив $53,1 \pm 0,3$ року, контрольної — $52,6 \pm 0,5$ року. У хворих з ознаками мінімальної мікроангіопатії церебральних судин оцінка за MMSE становила

в середньому $26,4 \pm 0,2$ бала, а за MoCA — $27,0 \pm 0,3$ бала, тоді як у контрольній групі — відповідно $27,8 \pm 0,2$ та $28,1 \pm 0,3$ бала ($p < 0,05$). В основній групі показник DAT дорівнював у середньому $59,0 \pm 1,3$ %, в контролі — $81,9 \pm 1,1$ % ($Z = 3,8$; $p = 0,0001$). Найвищі показники DAT були визначені у працівників творчих спеціальностей — $85,0 \pm 0,9$ % ($Z = 2,7$; $p = 0,008$). **Висновки.** У 95,0 % пацієнтів із мінімальними проявами лейкоенцефалопатії, обумовленої мікроангіопатією, має місце зниження креативних здібностей (DAT $59,0 \pm 1,3$ проти $81,9 \pm 1,1$ %; $Z = 3,8$; $p = 0,0001$). Коефіцієнт внутрішньої згоди тесту DAT як становив 0,7 при відтворюваності 85,7 %, що дозволяє рекомендувати його для застосування в клінічній практиці. Метод оцінки асоціативних завдань з дивергентного мислення має більш високу чутливість (97,7 %), ніж традиційні методи оцінки когнітивних здібностей на субклінічних стадіях хронічного порушення мозкового кровотоку.

Ключові слова: когнітивна креативність; дивергентне мислення; мікроангіопатія; діагностика; семантика