Adv Psychiatry Neurol 2018; 27 (2): 135-145
DOI: https://doi.org/10.5114/ppn.2018.77032

ADVANCES IN PSYCHIATRY & NEUROLOGY
POSTĘPY Psychiatrii i Neurologii

EXECUTIVE DYSFUNCTION AFTER STROKE – POSSIBILITIES AND LIMITATIONS OF DIAGNOSIS

ZABURZENIA FUNKCJI WYKONAWCZYCH PO UDARZE MÓZGU – MOŻLIWOŚCI I OGRANICZENIA DIAGNOZY

Correspondence to/
Adres do korespondencji:

Ernest Tyburski
Zakład Psychologii Klinicznej
i Psychoprofilaktyki
Instytut Psychologii
Uniwersytet Szczeciński
ul. Krakowska 69
71-004 Szczecin, Polska
tel. +48 91 444 32 40
e-mail: ernest.tyburski@usz.edu.pl

Submitted/Otrzymano: 31.05.2017
Accepted/Przyjęto do druku: 26.06.2018

Ernest Tyburski[1], Monika Mak[2], Jacek Kurpisz[2], Agnieszka Samochowiec[1], Andrzej Potemkowski[1]

[1]Department of Clinical Psychology, Institute of Psychology, University of Szczecin, Szczecin, Poland
[2]Independent Clinical Psychology Unit, Department of Psychiatry, Pomeranian Medical University, Szczecin, Poland

[1]Zakład Psychologii Klinicznej i Psychoprofilaktyki, Instytut Psychologii, Uniwersytet Szczeciński, Szczecin, Polska
[2]Samodzielna Pracownia Psychologii Klinicznej, Katedra i Klinika Psychiatrii, Pomorski Uniwersytet Medyczny, Szczecin, Polska

Abstract

Purpose: A variety of neuropsychological symptoms, including executive dysfunction, are common consequences of a stroke. However, as demonstrated in literature reviews, there are still several unclear issues in this area. This article, therefore, provides description of specific components of executive dysfunction in stroke patients together with principles of their diagnosis.

Views: Cerebral stroke is one of the most common causes of disability, with a devastating impact on the daily functioning of patients. Some of its common consequences are cognitive and behavioural disorders. Comorbid symptoms include premorbid personality changes and emotional disorders. A relatively new diagnostic category of post-stroke symptoms is the dysexecutive syndrome. It involves a variety of symptoms, such as ineffective performance, perseveration, rigidity of thought or impaired planning and predicting the consequences of one's actions. The dysexecutive syndrome is not a homogenous syndrome, and many researchers postulate its division into subunits, depending on the predominant symptoms.

Conclusions: Executive dysfunction after stroke is an important clinical and social problem. Impaired performance of complex tasks or deficits within planning or reasoning have a marked effect on patients' social and professional functioning. The theoretical notion of dysexecutive syndrome may allow to better understand the scope and nature of patients' problems and implementation of more effective forms of neuropsychological rehabilitation.

Key words: stroke, neuropsychological diagnosis, executive dysfunctions, dysexecutive syndrome, emotional disorders.

Streszczenie

Cel: Konsekwencjami udaru mózgu mogą być różnorodne zaburzenia neuropsychologiczne, w tym deficyty wykonawcze. Jak pokazuje przegląd badań nadal jednak istnieje kilka nie do końca rozstrzygniętych kwestii w tym zakresie. W związku z tym w artykule przedstawiona została charakterystyka poszczególnych podzespołów dysfunkcji wykonawczych oraz zasad ich diagnozy.

Poglądy: Udar mózgu jest jedną z najczęstszych przyczyn niepełnosprawności utrudniającej codzienne funkcjonowanie chorych. Dość powszechnymi jego następstwami są zaburzenia poznawcze i behawioralne. Wraz z deficytami poznawczymi mogą współwystępować zmiany osobowości przedchorobowej i zaburzenia emocjonalne. Stosunkowo nową kategorią diagnostyczną objawów poudarowych jest zespół dysfunkcji wykonawczej. Charakteryzuje się on występowaniem różnorodnych objawów, takich jak nieskuteczne działanie, pomimo posiadanej wiedzy o jakimś zadaniu, persewerowanie, sztywność myślenia, trudności w planowaniu i przewidywaniu konsekwencji własnych działań. Opisywany syndrom nie stanowi jednolitego zespołu objawów, a wielu badaczy postuluje rozróżnienie poszczególnych podzespołów z dominującymi objawami.

Wnioski: Dysfunkcje wykonawcze pojawiające się po udarze mózgu stanowią ważny problem kliniczny i społeczny. Problemy pacjentów w postaci niemożności realizacji złożonych zadań czy trudności w zakresie planowania i przewidywania konsekwencji własnych działań mają negatywny wpływ na ich funkcjonowanie społeczne i zawodowe. Konstrukt teoretyczny syndromu dysfunkcji wykonawczej może być przydatny dla lepszego zrozumienia problemów pacjentów oraz opracowania bardziej skutecznych form rehabilitacji neuropsychologicznej.

Słowa kluczowe: udar, diagnoza neuropsychologiczna, zaburzenia funkcji wykonawczych, zespół dysfunkcji wykonawczej, zaburzenia emocjonalne.

INTRODUCTION

Some of the quite common consequences of cerebral stroke are cognitive disorders, which may include deficits within perception, attention, memory, language and the ability to handle complex tasks [1, 2]. Along with cognitive disturbances, there are reports of premorbid personality changes involving a loss of interests and plans, a change within values or self-esteem or general inability to fulfil social roles [3]. There may also appear certain affective disturbances, i.e. emotional lability, increased anxiety, irritability or impulsivity, inappropriate affect or depressive states [4]. The aforementioned disorders may stem from organic brain damage or constitute a psychological response to the disability [5].

Stroke is characterised by fast and focal development of neurologic symptoms reflecting a loss of brain function due to a sudden loss of blood circulation or an intracranial haemorrhage [6]. Most strokes are ischaemic, constituting approximately 80% of all cases, and about 15% are haemorrhagic [7]. Stroke is one of the most common causes of disability, including disability resulting from neuropsychological disorders. Approximately 70% of stroke patients require third party care [8]. In this patient group, it is of major importance to make an immediate and accurate diagnosis of the disability and implement effective therapeutic methods. Complex neuropsychological consequences of a stroke call for such an individualised approach, involving planned and intentional interventions of both the caregivers and professionals, and thus improving the quality and effects of patients' return to functional autonomy. With regard to the diagnostic process, it is especially important to discuss the executive dysfunction in patients with post-stroke symptoms as well as possibilities and limitations of their diagnosis.

CHARACTERISTICS OF EXECUTIVE FUNCTIONS

The notion of executive functions has become one of the fundamental concepts in modern neuroscience [9]. Based on clinical observations and scientific research, it has been concluded that the frontal lobes are particularly involved in the regulation of complex human behaviours [10]. Theoretical background of executive functions is associated with research conducted by Luria [11]. In his model of the human brain, he distinguishes three functional systems: (a) a unit for arousal and attention (limbic and reticular activation system); (b) a unit for receiving, analysing and storing information (posterior neocortex); and (c) a unit for planning, organising and regulating behaviour and cognition (frontal lobes). This concept defines regulation as the ability to alter an operation during the performance of a particular task, which often occurs with the participation of language processes [12]. Control, in turn, is understood as the ability to compare the effects of an action to the original intent. Solving a problem requires an analysis of initial conditions, development of a specific plan (strategy), implementation of relevant operations and, finally, a comparison of the result to the input data [13]. Clinical neuropsychology promotes Lezak's approach [14], according to which executive functions form a system that allows successful completion of a purposeful action. These functions comprise four processes: (a) volition; (b) planning; (c) purposive action; and (d) effective performance. Proper performance of each of them depends on the completion of the previous one. Currently, executive functions are understood as mental abilities responsible for, among others, the following: (1) anticipation and focus of attention; (2) self-monitoring and impulse control; (3) initiation of activity; (4) working memory; (5) mental flexibility and the ability to make use of feedback; (6) planning and organisation; and (7) the choice of effective problem-solving strategies [15]. They also form a central executive system that allocates cognitive resources, monitors, controls and inhibits other cognitive processes and behavioural responses, thus contributing to a better adaptation to the environment [16]. They enable modification of initiated actions and customisation of responses, depending on the changing situational context [9]. Cognitive and behavioural control are believed to be particularly significant executive domains [17, 18]. Complex nature of executive function was also demonstrated in research on healthy individuals, involving factor analyses of various measures of executive performance. For example, based on the factor analysis

of 19 neuropsychological tests in 200 healthy people, Testa, Bennett and Ponsford [19] distinguished 6 relatively independent factors: prospective working memory, set-shifting and interference management, task analysis, response inhibition, strategy generation and regulation, self-monitoring and set-maintenance. In turn, Miyake *et al*. [20] distinguish three main executive domains (shifting, updating, and inhibition), suggesting their relative independence but also certain common characteristics.

A part of stroke patients experience typical executive dysfunction symptoms, such as ineffective performance despite sufficient knowledge about a task [21]. Some other symptoms of executive deficits include: hypersensitivity to external stimuli, perseverations, rigidity of thought, difficulty in planning and anticipating consequences of actions, adynamia or disinhibition. Some patients constantly make mistakes carrying out particular tasks, even when they detect and verbalise the principle behind it. Such difficulties are a manifestation of the dissociation between thinking and action [22]. The prevalence of executive dysfunction after stroke ranges from 18.5% to 39%, depending on definitions and instruments used for its evaluation [23, 24]. Executive dysfunction after stroke is often associated with the location of the damage.

EXECUTIVE DYSFUNCTION AND LOCATION OF STROKE

To date, there have been a number of reports on various specific executive symptoms resulting from lesions to different brain areas in stroke patients [22]. Assessment of such disorders is no easy task, considering the complexity of cerebral vascularisation and disassociation in severity of different deficits. Depending on lesion location, i.e. whether stroke was located in the frontal (anterior vascularisation), rear (posterior vascularisation) or subcortical portions of the brain (various blood vessels), patients were normally divided into frontal – non-frontal – subcortical groups and thus compared in their performance of neuropsychological tests [25]. Studies regarding executive dysfunction, depending on location of pathology in the brain, were selected from PubMed, PsychINFO and Google Scholar databases. As shown in Table 1, their results are inconsistent.

Some studies demonstrate larger executive dysfunction, involving impairment in critical thinking and planning [26, 27], verbal working memory and verbal mental flexibility [27, 30], cognitive and motor inhibition [28, 30] and non-verbal mental flexibility [30], in patients with stroke located in the frontal rather than the rear areas of the brain. Other reports, however, do not confirm such findings, indicating no difference between the groups in terms of cognitive inhibition, verbal and non-verbal mental flexibility, critical thinking, verbal working memory and planning [27, 29, 31, 32, 34]. In addition, Pohjasvaara *et al*. [35] and Zinn *et al*. [36] reported greater executive dysfunction, manifested in basic and complex activities of daily living, in patients with stroke located in the frontal areas of the brain.

Research analyses also indicate that patients with lesions located in the frontal lobes compared to those with pathology in the subcortical structures struggle with similar executive difficulties within e.g. cognitive and motor inhibition [28], critical thinking, verbal and non-verbal mental flexibility [30, 34].

In turn, patients with pathology in the rear areas of the brain compared with patients with lesions located in subcortical structures are characterised by smaller deficits in executive functioning [28, 30].

Furthermore, there is evidence of executive dysfunction in patients with stroke located in the basal ganglia, in terms of verbal working memory and critical thinking [37] and in the insula in terms of non-verbal mental flexibility [38].

Relevant data was also provided by Vataja *et al*. [39], who demonstrated that stroke patients with executive deficits compared to those without them (with scores below 1.5 SD compared to the controls in SCWT, TMT, WCST) were characterised by brain lesions located in different brain areas: frontal, rear and subcortical. In addition, certain executive dysfunctions in various processes, i.e. cognitive inhibition, visual set shifting, non-verbal mental flexibility, were demonstrated in patients with stroke only in the subcortical brain structures [40–42].

THE DYSEXECUTIVE SYNDROME AND THE FRONTAL LOBE SYNDROME

Various executive function deficits and their characteristics are currently a subject that is widely discussed in neuropsychology. Many researchers and practitioners highlight the complicated nature of executive dysfunction and postulate the need to establish a typology of its different subunits [43]. Among the first ones to introduce the concept of the dysexecutive syndrome to the world literature were Baddeley and Wilson [44]. In their scientific and clinical activity, they wanted to change and replace the diagnostic unit known as the frontal lobe syndrome [45], especially since the previous approach assuming frontal lobe pathology to be a necessary and sufficient condition to trigger executive dysfunction proved to be outdated in light of later research. The last three decades have provided empirical evidence that malfunctioning brain structures outside of the frontal lobes may induce various executive symptoms, and, on the other hand, that frontal lobe damage does not always lead to such dysfunction [46]. In addition, many patients with different neurological and mental health problems

Table 1. Assessment tools for executive dysfunction, evaluated in patients after stroke

Authors	Participants	Measured duration after stroke	Measurement	Results
Glosser and Goodglass (26)	22Front/19Non-front/49Cont[a,b,c]	< 1 month	SGT, TOH	Front vs. Non-front patients had low scores in SGT and TOH Front and Non-front patients vs. Cont participants had low scores in SGT and TOH
Leskelä *et al.* (27)	62Front/188Non-front/39Cont[a,b,c]	< 3 months	DS, SCWT, TMT, WCST, VFT	Front vs. Non-front patients had low scores in DS (backward) and VFT (semantic and phonemic) but similar in SCWT, TMT and WCST Front and Non-front patients vs. Cont participants had low scores in all tests
Jodzio *et al.* (28)	10Front/12Non-front/21Sub/25Cont[b,c]	< 1 month	GNG, SCWT	Front vs. Non-front patients had low scores in GNG and SCWT Front vs. Sub patients had similar scores in GNG and SCWT Sub vs. Non-frontal had low scores in GNG and SCWT Front and Sub patients vs. Cont participants had low scores in GNG and SCWT Non-front patients vs. Cont participants had similar scores in GNG and SCWT
Tamez *et al.* (29)	52Front/175Non-front[a,b,c] (DS) 45Front/122Non-front[a,b,c] (TMT)	< 72 hours	DS, TMT	Front vs. Non-front patients had similar scores in DS Front vs. Non-front patients had similar scores in TMT
Jodzio *et al.* (30)	10Front/12Non-front/21Sub[a,b,c]	< 1 month	GNG, SCWT, TMT, WCST, VFT	Front vs. Non-front patients had low scores in SCWT, TMT, VFT Front vs. Sub patients had similar scores in all tests Front, Non-front and Sub patients vs. Cont participants had low scores in all tests
Roussel *et al.* (31)	17Front/12Non-front/29Cont[a,c,d]	< 1 month	DS, MCST, SCWT, TMT, TOL, VFT	Front vs. Non-front patients had similar scores in all tests Front patients vs. Cont participants had lower scores in all tests (DS forward) Non-front patients vs. Cont participants had lower scores in MCST and VFT
Andrews *et al.* (32)	14Front/30Non-front/41Cont[a,b,c]	> 1 month	VFT	Front vs. Non-front patients had similar scores in VFT Front and Non-front patients vs. Cont participants had lower scores in VFT
Andrews *et al.* (33)	14Front/29Non-front/40Cont[a,b,c]	> 1 month	TOL	Front vs. Non-front patients had low scores in TOL Front patients vs. Cont participants had lower scores in TOL Non-front patients vs. Cont participants had similar scores in TOL
Jankowska *et al.* (34)	19Front/13Non-front/13Sub[a,b,c]	1–12 months	TMT, WCST, VFT	Front vs. Non-front vs. Sub patients had similar scores in all tests

Cont – control participants; DS – Digit Span from Wechsler Adults Intelligence Scale; Front – frontal lesion patients; GNG – Go No Go Task; MCST – Modified Card Sorting Test; Non-front – non-frontal lesion patients; SCWT – Stroop Colour Word Test; SGT – Sequence Generation Test; Sub – subcortical lesion patients; TMT – Trail Making Test; TOL – Tower of London; VFT – Verbal Fluency Test; WCST – Wisconsin Card Sorting Test
[a]Healthy controls matched for gender, [b]Age, [c]Education, [d]Premorbid IQ

exhibit considerable variation in terms of symptoms known as the dysexecutive syndrome [47]. Presented below are descriptions of both syndromes to indicate some of the most important differences between them.

Frontal lobe syndrome is a psychiatric diagnostic unit characterised by a number of changes within personality and emotional function [48]. A classic example of a patient with the frontal lobe syndrome is the case of Phineas Gage, who manifested all sorts of behavioural and emotional changes [49]. From the neurological point of view, a patient with the frontal lobe syndrome is a patient with symptoms in the form of jocular attitude or aboulia, lack of criticism and concurrent neurological symptoms [49, 50]. There are three main types of frontal lobe syndromes, depending on the location of the damage. The first one is the orbitofrontal syndrome, characterised by impulsive behaviour, disinhibition, lack of insight, irritability and emotional lability. The second one is the medial frontal syndrome, marked by apathy, loss of interest, lack of motivation, initiative or drive and self-negligence. The third one is the frontal convexity syndrome, which includes impairment within memory, abstract thinking and mental set changes, lack of problem-solving strategies, and depression [51].

In contrast, dysexecutive syndrome involves a wide variety of different executive disturbances due not only to lesions to the frontal areas but also other brain regions, such as parietal lobes, anterior cingulate cortex, subcortical structures (e.g. the thalamus or striatum) and the cerebellum [52]. Therefore, it seems incorrect to use the term "frontal lobe syndrome," as current state of knowledge concerning other brain areas suggests that their damage may result in a similar clinical picture.

SELECTED COMPONENTS OF THE DYSEXECUTIVE SYNDROME

The dysexecutive syndrome has been suggested to include a variety of symptoms, which often dissociate, with some processes being impaired, and others remaining intact [53]. The syndrome is thus of a heterogeneous nature. Depending on the theoretical concept, there are several classifications of executive dysfunction. Presented below are four selected models of dysexecutive syndromes.

One of the more interesting models, proposed by Godefroy and Stuss involves distinguishing of two subunits [54]: the behavioural dysexecutive syndrome and the cognitive dysexecutive syndrome. The former includes the following: (a) limited activity (apathy and aspontaneity) or general agitation (disinhibition and impulsivity); (b) stereotyped behaviour and perseverations; (c) excessive environmental dependency (e.g. utilisation behaviour – performance of motor activity associated with the correct function of the object despite the absence of explicit instructions). Other reported symptoms are difficulties in social behaviour, anosognosia or inappropriate sexual behaviour. In turn, the cognitive type includes as follows: (a) problems within initiation and inhibition of actions and reduced focus of attention; (b) difficulty in maintaining and shifting of mental sets; (c) planning and problem-solving deficits; and (d) impaired information generation. Associated deficits may be problems within working memory and the ability to rapidly refresh information, impaired learning strategies and deficits within the so-called social intelligence (the ability to predict human behaviour based on the analysis of their thoughts, beliefs and intentions).

A similar model, involving a distinction into two subunits, was developed by Jodzio [55]. The first subunit includes a dominant planning disorder and includes the following: (a) difficulty within the choice of purposeful actions; (b) planning deficits; (c) mental set perseverations; (d) mental set rigidity; (e) obsessiveness and rigidity of thought; and (f) adynamia. The other one is characterised by dominant control deficits and involves as follows: (a) difficulty in action initiation; (b) control deficits; (c) perseverations; (d) mental set instability; (e) compulsivity and impulsivity of actions; and (f) disinhibition.

Table 2. Description of selected classifications of the dysexecutive syndrome

Authors	Syndrome type	Main features
Ardila (56)	A. Dysexecutive syndrome with dominant meta-cognitive disorder	Planning and temporal organisation deficits
	B. Dysexecutive syndrome with dominant motivational/ emotional disorder	Control deficits and personality change
Baune *et al.* (57)	Depression-executive dysfunction syndrome	Disturbances in sequencing, organising, planning, abstracting, reduced interest in activities, and psychomotor retardation and vegetative symptoms
Godefroy and Stuss (53)	A. Dysexecutive syndrome with dominant conduct disorder	Control deficits
	B. Dysexecutive syndrome with dominant cognitive disorder	Planning deficits
Jodzio (55)	A. Dysexecutive syndrome with dominant planning disorder	Planning and thinking deficits
	B. Dysexecutive syndrome with dominant control disorder	Control and executive deficits

Table 3. Description of standard neuropsychological tests used to measurement executive functions

Test	Description	Components	Limits
Wisconsin Card Sorting Test (WCST) (65)	Test consists of two identical packs of cards (each pack contains 64 cards) and four reference cards; using the feedback provided by the examiner, the subject is trying to lay the card according to the shape, colour and number; manual or computer version	Switching, perseveration, problem solving	Time-consuming, difficult to complete, motor (non-paresis patients), low level of ecological validity
Stroop Colour Word Test (SCWT) (66)	Test consists usually of three tasks: part 1 speed reading of names of colours printed in black; part 2 speed naming of colours presented in the form of rectangles; part 3 speed naming of colour words printed in ink of different colour; manual or computer version	Cognitive inhibition, working memory, verbal attention	Verbal (non-aphasic patients), low level of ecological validity
Trail Making Test (TMT) (67)	Part A consists in connecting 25 circles containing numbers from 1 to 25, arranged irregularly; in part B, the subject is to alternate between irregularly arranged circles containing numbers from 1 to 13 and letters from A to L, connecting them with a continuous line; paper-pencil test	Non-verbal cognitive flexibility, non-verbal attention	Motor (non-paresis patients), low level of ecological validity
Verbal Fluency Test (VFT) (68)	Consists of a letter (phonemic) task or a category (semantic) task; in the category task, the participants are to provide as many words from each category as they can, and in the letter test, as many words starting with the given letter of the alphabet as they can in 1 min	Verbal flexibility, word production, verbal attention	Verbal (non-aphasic patients), low level of ecological validity
Tower of London (TOL) (69)	The participants receive a wooden tower with three pins (large, medium or small) and three balls (red, green or blue), starting from a fixed position must move the balls, one at a time, matching stimulus showed in a card (12 problems), with the minimum moves required (from 2 to 5); if participant cannot do it or perform with more moves than the minimum required, such person is asked to try it again; manual or computer version	Planning, visual attention	Motor (non-paresis patients), low level of ecological validity
Go No Go Task (GNG) (68)	Requires the subjects to perform conflicting motor responses, manual or computer version	Motor inhibition, visual attention	Motor (non-paresis patients), low level of ecological validity

According to Jodzio, those symptoms do not form a complete list of all executive deficits. Manifestations of the disorder can be observed on a continuum from the cognitive (mental) to the behavioural symptoms (action).

The third classification is one by Ardila [56]. He distinguishes the metacognitive and the motivational/emotional executive dysfunction syndromes. The former manifests itself through the following: (a) inability to create task performance strategies; (b) difficulties in complex problem solving; (c) difficulties in consequence anticipation; (d) perseverations and (e) deficits within temporal organisation. The latter one entails: (a) deficits within cognitive and emotional control; (b) difficulty within basic impulse inhibition; (c) inappropriate social behaviour; (d) disregard of important events and inability to respond to social cues; and (e) personality changes.

Due to depression being a common comorbidity of executive deficits in stroke patients suffering damage to frontostriatal and limbic pathways, Baune *et al.* [57] proposed the so-called depression-executive dysfunction syndrome. Their model is characterised by disturbances in sequencing, organising, planning, abstracting, reduced interest in activities, and psychomotor retardation but less pronounced vegetative symptoms than those reported in depressed elderly patients without significant executive dysfunction [4].

Both clinical observations and research findings [58] support the aforementioned classification systems. All four of them take into account cognitive and behavioural aspects of executive function. The last two consider also emotional deficits. A summary of the described dysexecutive syndromes is presented in Table 2. All presented models comprise similar theoretical approaches to particular aspects of executive dysfunction observed in stroke patients.

DIAGNOSTICS OF EXECUTIVE DYSFUNCTION

Diagnosis of executive function disorders is a complex process that may be a challenge both in the theoretical and technical contexts [58]. Diagnostic difficulties may arise not only because of the different etiopathogenetic circumstances and complex clinical characteristics of executive dysfunction, but also because of the need to take into account the age of patients. It has been empirically confirmed that the natural aging process leads to the shrinking of neurons, especially within the frontal lobes, which translates into weaker performance in tests measuring executive functions [59–61]. The profile of cognitive deficits in post-stroke patients depends on the location of vascu-

Table 4. Description of ecological neuropsychological tests used to measurement executive functions

Test	Description	Components
Six Elements Test (SET) (71)	Consists of two sets of arithmetic problems, two dictation tasks and two sets of pictures that have to be named, i.e. six subtasks in total; the subject is to attempt to do at least some of all six sections within 10 min according to the rules; however, they are not allowed to do the two parts of the same task consecutively	Strategy application, performance monitoring, planning
Multiple Errands Test (MET) (72)	Measures executive function on everyday functioning through a number of real-world tasks (e.g. purchasing specific items, collecting and writing down specific information, arriving at a stated location); the participant is observed performing the test and the number and type of errors (e.g. rule breaks, omissions) are recorded	Strategy allocation, planning
Executive Function Performance Test (EFPT) (73)	Measures the execution of four basic tasks that are essential for self-maintenance and independent living: simple cooking, telephone use, medication management, and bill payment	Multitasking, planning, activities of daily living

Table 5. Description of computer-based cognitive programs used to training of executive dysfunctions

Test	Description
Cogmed (24)	Includes both audio (verbal) and visual (visuospatial) working memory tasks, which always require a motor response; task difficulty is adapted to the performance of the trainee, and positive feedback is given immediately; program that can either be done at the rehabilitation centre or at home
AixTent (24)	Consists of separate training modules that can be combined (focus on phasic alertness, vigilance, selective attention, or divided attention); responses can be given with two response keys that can also be operated with only one hand; all tasks were designed to be game-like, and task difficulty is automatically adapted to the performance of the participant; feedback is given during and at the end of a training session
RehaCom (24)	Consists of several graphical games that adapt to the performance of the participant and use a variety of stimuli such as playing cards; the training focuses on several cognitive domains (selective attention, working memory, executive functions e.g. buying items from a shopping list while purchases must fit within a certain budget)

lar lesions and they may manifest themselves in the form of cortical, subcortical, or mixed symptoms [62].

Description of the deficit profile in the dysexecutive syndrome requires a wider perspective, extending beyond the classification of symptoms into the cortical and subcortical ones. In addition, executive disorders do not often constitute an isolated symptom (although they may dominate the clinical picture), but rather co-occur with other cognitive deficits (impaired attention, memory, language, and visual-spatial functions).

Studies on post-stroke patients often report their scores in the Mini-Mental State Examination (MMSE), but this test is insensitive to executive dysfunction and does not capture more subtle cognitive deficits [63]. Due to this very fact, a better tool facilitating the process of screening for executive dysfunction in stroke patients is the Birmingham Cognitive Screen (BCoS) [64]. This battery assesses five cognitive domains: (a) attention and executive function; (b) language; (c) memory; (d) number skills; and (e) praxis.

The most common standard tests used to measure executive functions are the following: the Wisconsin Card Sorting Test, the Tower of London, the Stroop Colour Word Test, the Trail Making Test, and Verbal Fluency Test, or the Go No Go Task [2, 22]. A short description of those tools is presented in Table 3. Quantitative results obtained from the use of those methods can, however, provide a false clinical picture, because their design often deviates from the real life problems patients may not be able to cope with [70]. Therefore, there is now a tendency to create tools resembling everyday life challenges, i.e. ones of greater ecological accuracy. Among these, the most popular ones are: the Six Elements Test, the Multiple Errands Test, and the Executive Function Performance Test. Their descriptions can be found in Table 4. They are based on tasks measuring different types of executive function, including planning, thinking and acting strategies, and do not often require general knowledge but rather spontaneity and thinking flexibility [74]. Research tools based on virtual reality are also a new diagnostic method. Development of virtual methods was based on a different methodological approach than paper-pen or computer assisted tests, one of the fundamental concepts associated with the use of virtual reality in neuropsychology is immersion, i.e. the ability of computer-generated environment to elicit a feeling of presence in virtual reality [75, 76]. The tool that is most commonly used in working with patients is the so-called head-mounted display (HMD), which allows the projection of three-dimensional (3D) graphics. Through tracking head movement, the tool allows its users to naturally interact with electronic environment [77]. This means that they can navigate, see from different perspectives, and

manipulate its contents [78]. Virtual tests are currently used in experimental studies to evaluate neuropsychological deficits including executive dysfunction in patients after stroke, but they may soon become useful in clinical practice [79–81].

In the literature, different rules appear to facilitate the selection of a specific diagnostic approach, such as: (a) time requirements, i.e. using as many methods to collect as much data on the executive functions within a specified time; (b) the test selection factors, understood as ways of administration, cost, accuracy or range of clinical applications; (c) the use of diagnostic hypotheses formulated on the basis of the collected qualitative and quantitative data from the medical history, the results of previous assessments, observation and interview; and (d) theoretical foundations of the research procedures, i.e. selection of methods in accordance with the chosen theoretical approach [82].

Either a functional or ecological approach to neuropsychological diagnostics of executive dysfunction in stroke patients seems a more accurate choice than functional localisation or differential diagnosis [55]. This is due to limitations of localisation diagnosis, according to which a function is linked to a specific area of the brain. To that end, tools designed to measure executive performance are not limited to investigating only the functions of the frontal lobes [83]. On the other hand, due to the heterogeneous nature of executive functions, and the fact that various degrees of executive dysfunction are observed in patients with different medical conditions, it seems insufficient to use methods of differential diagnosis, the aim of which would be to describe a single set of symptoms. Functional diagnosis has the greatest potential to fully describe the functioning of human mental processes, both the impaired and the preserved ones. Functional psychological assessment is therefore a more accurate approach, as it enables implementation of more effective therapy or neuropsychological rehabilitation.

Apart from quantitative data, proper diagnostics of executive dysfunction requires also qualitative description of patients' performance and errors. Some practitioners and researchers suggest that the best way to draw conclusions concerning executive function is to create a general patient profile based on all test scores as well as interview and observation data [84]. In stroke patients, who often have limited mobility, the administration of standard psychometric methods can be much more difficult or even impossible. Therefore, it is often suggested to apply simple clinical/experimental techniques based on the Lurian [83] approach (e.g. simple finger opposition task, Fist-Edge-Palm Test, and the Reciprocal Motor Programme Test) to obtain qualitative data on mental function disorders. In addition, good diagnosis of executive dysfunction involves more general questions concerning future plans or their implementation [55].

INTERVENTIONS FOR EXECUTIVE DYSFUNCTION AFTER STROKE

Even though early spontaneous improvement within certain neuropsychological domains (especially up to six months) after stroke may occur in a substantial proportion of patients [85], executive deficits are known to persist over time [86]. Those lead to functional dependency [35], limit patients' ability to return to work [87] and affect their social functioning [88]. Executive functions are, therefore, of great concern to clinicians and researchers involved in cognitive rehabilitation following a stroke. In line with the latest guidelines, neuropsychological rehabilitation should be based on research using standardised therapeutic methods, the application of which is aimed at functional improvement in significant life domains [89]. Different therapeutic approaches are suggested [90]. Some are oriented toward targeted remediation of specific executive processes, e.g. through computer-based training (Cogmed QM, AixTent or RehaCom) [91–93]. Others focus on teaching patients to use their residual skills more efficiently or to compensate for their difficulties through the use of various strategies, such as cognitive strategies to improve problem solving. External compensatory mechanisms, such as electronic paging systems or environmental modifications are also used in an attempt to improve accomplishment of daily activities. Two recent systematic reviews demonstrated that stroke patients may possibly benefit from specific executive function training and learn compensatory strategies to reduce the consequences of executive impairment. Poulin *et al.* [24] describe 10 studies confirming effectiveness of remedial and compensatory interventions in executive deficit reduction. In turn, upon analysis of 20 papers, van de Ven *et al.* [94], concluded that most reported good effects of computer-based cognitive training on functional improvement in stroke patients. Unluckily, most studies suffered certain methodological limitations (e.g. lack of an active control group or no adjustment for multiple testing), thus hampering differentiation of training effects and spontaneous recovery, retest effects and placebo effects.

CONCLUSIONS

Post-stroke executive dysfunctions are an important clinical and social problem. The loss of skills to perform complex tasks or impairment of planning and anticipating might adversely affect the social and professional functioning of patients and their quality of life. In the diagnostics of executive dysfunction, it is important to use a variety of neuropsychological methods, especially those of confirmed ecological validity, to properly recognise the underlying causes of the observed deficits and recommend effective forms of therapy.

Conflict of interest/Konflikt interesu

Absent./Nie występuje.

Financial support/Finansowanie

This paper was supported by a grant from the Faculty of Humanities, University of Szczecin no. 504-3000-240-764/2012./ Praca finansowana z grantu Wydziału Humanistycznego Uniwersytetu w Szczecinie nr 504-3000-240-764/2012.

References/Piśmiennictwo

1. Edwards JD, Jacova C, Sepehry AA, Pratt B, Benavente OR. A quantitative systematic review of domain-specific cognitive impairment in lacunar stroke. Neurology 2013; 80: 315-322.
2. Rostamian S, Mahinrad S, Stijnen T, Sabayan B, de Craen AJ. Cognitive impairment and risk of stroke: a systematic review and meta-analysis of prospective cohort studies. Stroke 2014; 45: 1342-1348.
3. Aben I, Denollet J, Lousberg R, Verhey F, Wojciechowski F, Honig A. Personality and vulnerability to depression in stroke patients: a 1-year prospective follow-up study. Stroke 2002; 33: 2391-2395.
4. Sibolt G, Curtze S, Melkas S, Pohjasvaara T, Kaste M, Karhunen PJ, et al. Post-stroke depression and depression-executive dysfunction syndrome are associated with recurrence of ischaemic stroke. Cerebrovasc Dis 2013; 36: 336-343.
5. Cumming TB, Marshall RS, Lazar RM. Stroke, cognitive deficits, and rehabilitation: still an incomplete picture. Int J Stroke 2013; 8: 38-45.
6. Donnan GA, Fisher M, Macleod M, Davis SM. Stroke. Lancet 2008; 371: 1612-1623.
7. Feigin VL, Forouzanfar MH, Krishnamurthi R, Mensah GA, Connor M, Bennett DA, et al. Global and regional burden of stroke during 1990-2010: findings from the Global Burden of Disease Study 2010. Lancet 2014; 383: 245-254.
8. Pinedo S, Erazo P, Tejada P, Lizarraga N, Aycart J, Miranda M, et al. Rehabilitation efficiency and destination on discharge after stroke. Eur J Phys Rehabil Med 2014; 50: 323-333.
9. Jurado MB, Rosselli M. The elusive nature of executive functions: a review of our current understanding. Neuropsychol Rev 2007; 17: 213-233.
10. Alvarez JA, Emory E. Executive function and the frontal lobes: a meta-analytic review. Neuropsychol Rev 2006; 16: 17-42.
11. Luria AR. Higher cortical functions in man. New York: Consultants Bureau; 1980.
12. Luria AR. The Working Brain. New York: Basic Books; 1973.
13. Tupper DE. Introduction: neuropsychological assessment après Luria. Neuropsychol Rev 1999; 9: 57-61.
14. Lezak MD. Neuropsychological assessment. Third Edition. New York: Oxford University Press; 1995.
15. Anderson V, Jacobs R, Anderson PJ. Executive functions and the frontal lobes: A lifespan perspective. New York: Psychology Press; 2011.
16. Gioia GA, Isquith PK, Guy SC, Kenworthy L. Test review behavior rating inventory of executive function. Child Neuropsychol 2000; 6: 235-238.
17. Barkley RA. ADHD and the nature of self-control. New York: Guilford Press; 1997.
18. Nigg JT. On inhibition/disinhibition in developmental psychopathology: views from cognitive and personality psychology and a working inhibition taxonomy. Psychol Bull 2000; 126: 220-246.
19. Testa R, Bennett P, Ponsford J. Factor analysis of nineteen executive function tests in a healthy adult population. Arch Clin Neuropsychol 2012; 27: 213-224.
20. Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD. The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. Cogn Psychol 2000; 41: 49-100.
21. Jodzio K, Biechowska D, Gąsecki D. Symptomatic and neuroanatomical characteristic of dysexecutive syndrome after stroke. Stud Psychol 2008; 46: 19-34.
22. Conti J, Sterr A, Brucki SM, Conforto AB. Diversity of approaches in assessment of executive functions in stroke: limited evidence? eNeurologicalSci 2015; 1: 12-20.
23. Leśniak M, Bak T, Czepiel W, Seniów J, Członkowska A. Frequency and prognostic value of cognitive disorders in stroke patients. Dement Geriatr Cogn Disord 2008; 26: 356-363.
24. Poulin V, Korner-Bitensky N, Dawson DR, Bherer L. Efficacy of executive function interventions after stroke: a systematic review. Top Stroke Rehabil 2012; 19: 158-171.
25. Sun JH, Tan L, Yu JT. Post-stroke cognitive impairment: epidemiology, mechanisms and management. Ann Transl Med 2014; 2: 1-16.
26. Glosser G, Goodglass H. Disorders in executive control functions among aphasic and other brain-damaged patients. J Clin Exp Neuropsychol 1990; 12: 485-501.
27. Leskelä M, Hietanen M, Kalska H, Ylikoski R, Pohjasvaara T, Mäntylä R, et al. Executive functions and speed of mental processing in elderly patients with frontal or nonfrontal ischemic stroke. Eur J Neurol 1999; 6: 653-661.
28. Jodzio K, Biechowska D, Szurowska E, Gąsecki D. Neuropsychologiczna ocena zaburzeń kontroli wybranych funkcji poznawczych i motorycznych po udarze mózgu. Post Psychiatr Neurol 2011; 20: 251-257.

29. Tamez E, Myerson J, Morris L, White DA, Baum C, Connor LT. Assessing executive abilities following acute stroke with the trail making test and digit span. Behav Neurol 2011; 24: 1771-1785.
30. Jodzio K, Biechowska D, Szurowska E, Gąsecki D. Profilowa analiza dysfunkcji wykonawczych w diagnostyce neuropsychologicznej osób po udarze mózgu. Rocz Psychol 2012; 15: 83-100.
31. Roussel M, Dujardin K, Henon H, Godefroy O. Is the frontal dysexecutive syndrome due to a working memory deficit? Evidence from patients with stroke. Brain 2012; 135: 2192-2201.
32. Andrews G, Halford GS, Shum D, Maujean A, Chappell M, Birney D. Relational processing following stroke. Brain Cogn 2013; 81: 44-51.
33. Andrews G, Halford GS, Chappell M, Maujean A, Shum DH. Planning following stroke: A relational complexity approach using the Tower of London. Front Hum Neurosci 2014; 8: e1032.
34. Jankowska AM, Klimkiewicz R, Kubsik A, Klimkiewicz P, Śmigielski J, Woldańska-Okońska M. Location of the ischemic focus in rehabilitated stroke patients with impairment of executive functions. Adv Clin Exp Med 2017; 26: 767-776.
35. Pohjasvaara T, Leskelä M, Vataja R, Kalska H, Ylikoski R, Hietanen M, et al. Post-stroke depression, executive dysfunction and functional outcome. Eur J Neurol 2002; 9: 269-275.
36. Zinn S, Bosworth HB, Hoenig HM, Swartzwelder HS. Executive function deficits in acute stroke. Arch Phys Med Rehabil 2007; 88: 173-180.
37. Su CY, Chen HM, Kwan AL, Lin YH, Guo NW. Neuropsychological impairment after hemorrhagic stroke in basal ganglia. Arch Clin Neuropsychol 2007; 22: 465-474.
38. Varjačić A, Mantini D, Levenstein J, Slavkova ED, Demeyere N, Gillebert CR. The role of left insula in executive set-switching: Lesion evidence from an acute stroke cohort. Cortex 2017; S0010-9452(17)30390-8.
39. Vataja R, Pohjasvaara T, Mäntylä R, Ylikoski R, Leppävuori A, Leskelä M, et al. MRI correlates of executive dysfunction in patients with ischaemic stroke. Eur J Neurol 2003; 10: 625-631.
40. Wolfe N, Babikian MD. Frontal systems impairment following. Arch Neurol 190; 47: 129-132.
41. Ghika-Schmid F, Bogousslavsky J. The acute behavioral syndrome of anterior thalamic infarction: a prospective study of 12 cases. Ann Neurol 2000; 48: 220-227.
42. Jokinen H, Kalska H, Ylikoski R, Madureira S, Verdelho A, Van Der Flier WM, et al. Longitudinal cognitive decline in subcortical ischemic vascular disease – the LADIS Study. Cerebrovasc Dis 2009; 27: 384-391.
43. Chan RC, Manly T. The application of "dysexecutive syndrome" measures across cultures: performance and checklist assessment in neurologically healthy and traumatically brain-injured Hong Kong Chinese volunteers. J Int Neuropsychol Soc 2002; 8: 771-780.
44. Baddeley A, Wilson B. Frontal amnesia and the dysexecutive syndrome. Brain Cogn 1988; 7: 212-230.
45. Mesulam M. Frontal cortex and behavior. Ann Neurol 1986; 19: 320-325.
46. Andrés P. Frontal cortex as the central executive of working memory: time to revise our view. Cortex 2003; 39: 871-895.
47. Daffner KR, Searl MM. The dysexecutive syndromes. Handb Clin Neurol 2008; 88: 249-267.
48. Cummings JL, Mega MS. Neuropsychiatry. Wrocław: Elsevier Urban & Partner; 2005.
49. Damasio AR. Błąd Kartezjusza. Emocje, rozum i ludzki mózg. Poznań: Dom Wydawniczy Rebis; 1999.
50. Walsh K, Darby D. Neuropsychologia kliniczna Walsha. Gdańsk: Wydawnictwo GWP; 2008.
51. Cummings JL, Miller BL. Conceptual and clinical aspects of the frontal lobes. In: Miller BL, Cummings JL (eds.). The human frontal lobes: Functions and disorders. New York: The Guilford Press; 2007, p. 12-21.
52. Stuss DT. Functions of the frontal lobes: relation to executive functions. J Int Neuropsychol Soc 2011; 17: 759-765.
53. Godefroy O. Frontal syndrome and disorders of executive functions. J Neurol 2003; 250: 1-6.
54. Godefroy O, Stuss DT. Dysexecutive syndromes. In: Godefroy O (ed.). The Behavioral and cognitive neurology of stroke. New York: Cambridge University Press; 2007, p. 379-406.
55. Jodzio K. Neuropsychologia intencjonalnego działania. Koncepcje funkcji wykonawczych. Warszawa: Wydawnictwo Naukowe Scholar; 2008.
56. Ardila A. On the evolutionary origins of executive functions. Brain Cogn 2008; 68: 92-99.
57. Baune BT, Stuart M, Gilmour A, Wersching H, Heindel W, Arolt V, et al. The relationship between subtypes of depression and cardiovascular disease: a systematic review of biological models. Transl Psychiatry 2012; 2: e92.
58. Stuss DT, Knight RT. Principles of frontal lobe function. Oxford: Oxford University Press; 2013.
59. Buckner RL. Memory and executive function in aging and AD: multiple factors that cause decline and reserve factors that compensate. Neuron 2004; 44: 195-208.
60. Craik FI. Brain-behavior relations across the lifespan: A commentary. Neurosci Biobehav Rev 2006; 30: 885-892.
61. Zimmerman ME, Brickman AM, Paul RH, Grieve SM, Tate DF, Gunstad J, et al. The relationship between frontal gray matter volume and cognition varies across the healthy adult lifespan. Am J Geriatr Psychiatry 2006; 14: 823-833.
62. Jodzio K, Biechowska D. Wisconsin Card Sorting Test as a measure of executive function impairments in stroke patients. Appl Neuropsychol 2010; 17: 267-277.
63. Pendlebury ST, Rothwell PM. Prevalence, incidence, and factors associated with pre-stroke and post-stroke dementia: a systematic review and meta-analysis. Lancet Neurol 2009; 8: 1006-1018.
64. Bickerton WL, Riddoch MJ, Samson D, Balani AB, Mistry B, Humphreys GW. Systematic assessment of apraxia and functional predictions from the Birmingham Cognitive Screen. J Neurol Neurosurg Psychiatry 2012; 83: 513-521.

65. Heaton RK, Chelune GJ, Talley JL, Kay GG, Curtiss G. Wisconsin card sort test manual: Revised and expanded. Odessa: Psychological Assessment Resources; 1993.
66. Stroop JR. Studies of interference in serial verbal reactions. J Exp Psych 1935; 18: 643-662.
67. Reitan RM. Validity of the Trail Making Test as an indicator of organic brain damage. Percept Mot Skills 1958; 8: 271-276.
68. Strauss E, Sherman E, Spreen O. A compendium of neuropsychological tests: Administration, norms, and commentary. Oxford: Oxford University Press; 2006.
69. Shallice T. Specific impairments of planning. Phil Trans R Soc Lond B 1982; 298: 199–209.
70. Burgess PW. Strategy application disorder: the role of the frontal lobes in human multitasking. Psychol Res 2000; 63: 279-288.
71. Burgess PW, Alderman N, Evans JJ, Wilson BA, Emslie H, Shallice T. Modified Six Element Test. In: Wilson BA, Alderman N, Burgess PW, Emslie H, Evans JJ (eds.). Behavioural assessment of the dysexecutive syndrome. Bury St. Edmunds: Thames Valley Test Company, p. 18-19.
72. Shallice TI, Burgess PW. Deficits in strategy application following frontal lobe damage in man. Brain 1991; 114: 727-741.
73. Baum CM, Morrison T, Hahn M, Edwards DF. Test manual: Executive Function Performance Test. St. Louis: Washington University; 2003.
74. Burgess PW, Alderman N, Forbes C, Costello A, Coates LM, Dawson DR, et al. The case for the development and use of "ecologically valid" measures of executive function in experimental and clinical neuropsychology. J Int Neuropsychol Soc 2006; 12: 194-209.
75. Bohil CJ, Alicea B, Biocca FA. Virtual reality in neuroscience research and therapy. Clin Neuropsychol 2011; 12: 752-762.
76. Parsons TD. Neuropsychological assessment using virtual environments: Enhanced assessment technology for improved ecological validity. In: Brahnam S, Jain LC (eds.). Advanced computational intelligence paradigms in healthcare 6. Virtual reality in psychotherapy, rehabilitation, and assessment. Berlin: Springer; 2011, p. 271-289.
77. Schultheis MT, Himelstein J, Rizzo AA. Virtual reality and neuropsychology: upgrading the current tools. J Head Trauma Rehabil 2002; 17: 378-394.
78. Lalonde G, Henry M, Drouin-Germain A, Nolin P, Beauchamp MH. Assessment of executive function in adolescence: A comparison of traditional and virtual reality tools. J Neurosci Methods 2013; 219: 76-82.
79. Buxbaum LJ, Dawson AM, Linsley D. Reliability and validity of the Virtual Reality Lateralized Attention Test in assessing hemispatial neglect in right-hemisphere stroke. Neuropsychology 2012; 26: 430-441.
80. Kang YJ, Ku J, Han K, Kim SI, Yu TW, Lee JH, et al. Development and clinical trial of virtual reality-based cognitive assessment in people with stroke: preliminary study. Cyberpsychol Behav 2008; 11: 329-339.
81. Neguț A, Matu SA, Sava FA, David D. Virtual reality measures in neuropsychological assessment: a meta-analytic review. Clin Neuropsychol 2016; 30: 165-184.
82. Burgess PW. Assessment of executive function. In: Halligan PW, Kischka U, Marshall C (eds.). Handbook of clinical neuropsychology. New York: Oxford University Press; 2010, p. 349-371.
83. Chan RC, Shum D, Toulopoulou T, Chen EY. Assessment of executive functions: review of instruments and identification of critical issues. Arch Clin Neuropsychol 2008; 23: 201-216.
84. Evans JJ. Basic concepts and principles of neuropsychological assessment. In: Halligan PW, Kischka U, Marshall C (eds.). Handbook of clinical neuropsychology. New York: Oxford University Press; 2010, p. 15-26.
85. Rasquin SM, Lodder J, Ponds RW, Winkens I, Jolles J, Verhey FR. Cognitive functioning after stroke: a one-year follow-up study. Dement Geriatr Cogn Disord 2004; 18: 138-144.
86. Skidmore ER, Whyte EM, Holm MB, Becker JT, Butters MA, Dew MA, et al. Cognitive and affective predictors of rehabilitation participation after stroke. Arch Phys Med Rehabil 2010; 91: 203-207.
87. Ownsworth T, Shum D. Relationship between executive functions and productivity outcomes following stroke. Disabil Rehabil 2008; 30: 531-540.
88. McDowd JM, Filion DL, Pohl PS, Richards LG, Stiers W. Attentional abilities and functional outcomes following stroke. J Gerontol B Psychol Sci Soc Sci 2003; 58: 45-53.
89. Langhorne P, Bernhardt J, Kwakkel G. Stroke rehabilitation. Lancet 2011; 377: 1693-1702.
90. Cumming TB, Marshall RS, Lazar RM. Stroke, cognitive deficits, and rehabilitation: still an incomplete picture. Int J Stroke 2013; 8: 38-45.
91. Björkdahl A, Åkerlund E, Svensson S, Esbjörnsson E. A randomized study of computerized working memory training and effects on functioning in everyday life for patients with brain injury. Brain Inj 2013; 27: 1658-1665.
92. van Vleet TM, Chen A, Vernon A, Novakovic-Agopian T, D'Esposito MT. Tonic and phasic alertness training: a novel treatment for executive control dysfunction following mild traumatic brain injury. Neurocase 2015; 21: 489-498.
93. Lin ZC, Tao J, Gao YL, Yin DZ, Chen AZ, Chen LD. Analysis of central mechanism of cognitive training on cognitive impairment after stroke: Resting-state functional magnetic resonance imaging study. J Int Med Res 2014; 42: 659-668.
94. van de Ven RM, Murre JM, Veltman DJ, Schmand BA. Computer-based cognitive training for executive functions after stroke: A systematic review. Front Hum Neurosci 2016; 10: e150.