The ExeSystem Computer Program in the Rehabilitation of Adult Neurological Patients with Executive Dysfunctions

Program komputerowy ExeSystem w rehabilitacji dorosłych chorych neurologicznych z dysfunkcjami wykonawczymi

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Abstract
A special challenge in the neuropsychological rehabilitation of adult patients with acquired brain injury is therapy in disorders of the executive (or supervisory) system. This is mainly due to the broad meaning of this term, including functions from the highest, prefrontal level of hierarchical cerebral regulation, and the lack of professionally-prepared therapeutic programs for this diverse group of patients. In the article, the authors present ExeSystem – the first Polish computer program containing tasks to be used in the rehabilitation of patients with executive dysfunctions. These tasks are primarily functional, involving the executive aspects of attention, working memory, the ability to plan complex actions, learning to remember effectively and the social aspects of behaviour. Apart from therapeutic applications, the program may facilitate scientific research on the effectiveness of neuropsychological rehabilitation and the development of its standards. The authors also present preliminary data on the usefulness of the ExeSystem in rehabilitation based on the opinions of neuropsychologists implementing the program and patients undergoing therapy.

Słowa kluczowe
dysfunkcje wykonawcze, rehabilitacja neuropsychologiczna, terapia wspomagana komputerowo

Streszczenie
Szczególnym wyzwaniem w rehabilitacji neuropsychologicznej chorych po nabytym w dorosłości ogniskowym uszkodzeniu mózgu są pacjenci z zaburzeniami systemu wykonawczego (nadzorczego). Wynika to między innymi z dużej pojemności znaczenia tego terminu, obejmującego funkcje z najwyższego, przedczołowego poziomu hierarchicznej regulacji mózgowej oraz niedostatku profesjonalnie przygotowanych programów terapeutycznych dla tej zróżnicowanej grupy chorych. W artykule przedstawiono pierwszy polski program komputerowy ExeSystem zawierający propozycje zadań terapeutycznych do stosowania w procesie rehabilitacji pacjentów z dysfunkcjami wykonawczymi. Ćwiczenia są przede wszystkim funkcjonalne, angażujące wykonawcze aspekty uwagi, pamięć operacyjną, zdolność planowania złożonych działań, uczenie się efektywnego zapamiętywania oraz społeczne aspekty zachowania. Program – oprócz zastosowań terapeutycznych – może ułatwiać prowadzenie badań naukowych na temat skuteczności rehabilitacji neuropsychologicznej oraz wypracowanie jej standardów. Autorzy przedstawiają też wstępne dane dotyczące użyteczności programu ExeSystem w rehabilitacji na podstawie opinii stosujących go terapeutów oraz pacjentów poddawanych terapii.

INTRODUCTION

In the rehabilitation of adult patients with acquired, non-progressive brain damage (most often as a consequence of stroke or traumatic injury), it is important not only to improve motor skills, but also to work on the restoration of those non-motor, including cognitive, executive and emotional-affective abilities[1]. Non-motor dysfunctions, often in the foreground of patient disablement, can be manifested by, for example, amnesia, aphasia and perceptual disorders. The com-

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plete clinical image of impaired and preserved abilities mainly depends on the location and volume of the brain damage.

Despite some differences regarding the opinions of the authors presented in literature on the topic, the following skills are most often included in the executive system:

- Inhibitory capacity: the ability to resist impulsive reactions, or automatic and stereotypical behaviour;
- Executive attention: selective, divided, and sustained for a sufficiently long period;
- Working memory: active maintenance and constant, selectively updating specific information during processing in the brain, which is necessary during the implementation of a complex, purposeful task; this applies to information received on an on-going basis from the environment as well as that retrieved from long-term memory; working memory is critical function for perceiving relationships between various elements of information, the abilities to abstract and generalise, create plans, predict the effects of an action;
- Cognitive flexibility: the ability to quickly alter attitudes depending on the changing characteristics of tasks and the environment in which one acts;
- Planning: preparing a phased programme of aim-directed action and organising it over time (new plans are usually partly based on already existing behaviour patterns, sometimes requiring the different use and arrangement of innovative procedures);
- Decision-making: starting an action with the intention to carry it out, after analysing the situation, based on registered in memory experiences, with sufficient motivation, after assessing the risks and benefits;
- Memory strategies (also known as mnemonics): different ways of organising information in order to memorise it better and then retrieve it faster.

Apart from those mentioned above abilities, for the efficiency of the executive system, it is also necessary to maintain optimal drive and motivation to act, as well as to adjust and control emotions.

The described skills are leading for effective human behaviour in various domains, including: linguistic communication, creative thinking, understanding social activities.

The cognitive-behavioural human functioning, its complexity and the historically changing scientific description cause that the standards of rehabilitation for patients with disorders in this area are still at the stage of initial formulation. This makes the work of therapists difficult and slows down the collection of evidence for its effectiveness. In previous studies, it has been shown that the effectiveness of interventions in neuropsychological rehabilitation is insufficiently confirmed. Research projects are too often limited to controlling only practiced skills, without assessing the generalization effect on other behaviours important in everyday functioning. The exercises vary in intensity and duration, and are conducted at different stages of the recovery process, often by therapists with varying competences. Rehabilitation concerns patients with different demographic and clinical characteristics, although these could – theoretically – be controlled with appropriate research accuracy. In addition, therapeutic programmes tend to be highly individualised, characterised by the creativity of therapists (a feature otherwise desirable in rehabilitation). In accordance with current medical requirements, experimental designs require high standards, often multicentre studies, involving large groups of patients, with added control interventions[2].

Taking the above limitations into account, as part of the research on the effectiveness of rehabilitation methods, e.g. in disorders of executive functions, systematic reviews[3-7] and meta-analyses[8] are conducted. Based on the quality of the projects, the analysed therapies are assessed according to 3 categories of effectiveness: a) practical standard, b) recommendation, and c) therapeutic option. It is worth mentioning that the team of experts from the Cognitive Rehabilitation Task Force - the European Federation of Neurological Societies (EFNS), did not include executive function disorders as a separate dysfunction syndrome in the research reviews carried out so far[9-11].

In the summary of the current recommendations, metacognitive training (self-control and -regulation of behaviour) and problem-solving training are recommended in mild and moderate executive post-traumatic disorders[12]. In patients with more severe executive dysfunctions, it is recommended that these training units be conducted in conjunction with practical activities. As a therapeutic option, in people with mild and moderate post-traumatic impairment, group therapy can be carried out, which is aimed at practicing solving everyday problems, controlling the social aspect of behaviour and improving self-awareness of one's own deficits and preserved abilities. In severe executive disorders following stroke or traumatic injury, functional training of everyday skills is recommended, guided by the so-called principle of errorless learning[12].

Researchers and clinicians are still faced with the question of the extent to which behavioural therapies, i.e. exercises modulating behaviour towards a more purposeful, effective and adaptive training, positively affect the restoration of disturbed functions, both in the early process of functional brain reorganisation after damage and in the long-term, when spontaneous recovery processes gradually decrease, but there are still learning opportunities.

When creating a therapeutic programme that stimulates the restoration of impaired executive functions (or compensates for these deficits), it should be adjusted by the clinician to the actual clinical condition of the patient and try to make it functional. It is also important to provide the trainee with feedback on the effectiveness of his/her actions, based on objective parameters[6]. To help a neuropsychologist implement these principles, s/he should, *inter alia*, have a base of professional exercises, in order to select and adjust them to the individual needs of a patient.

While relatively less complex cognitive functions (e.g. naming, reading) are easier to describe in terms of psychological structure and brain organisation (although there are also many problems not fully explained here), and also to create a program for their exercises, strongly interconnected and interdependent executive skills are a greater challenge for rehabilitation. It is worth remembering that intentional human activities require not only cognitive performance, but are modulated by emotional factors as well as autonomic and endocrine systems supporting and controlling the organism's motivational and driving factors[13]. Therefore, the treatment of a patient often has to cover many different aspects of behaviour, being reasonably attractive, motivating and similar to everyday needs and abilities.

Not only the organisation of the rehabilitation process, but also the diagnostics of the executive system that precede it, require specialised competences: knowledge, the ability to use and interpret psychological measurement tools, experience in collecting an interview, observing the patient's behaviour and creative processing of information from these various sources.

Rehabilitation should be a systematic, functionally oriented set of therapeutic interactions, the basis of which is the assessment of the patient's actual clinical picture, and the primary objective of the patient's improvement being the achievement of maximal independence in a natural environment. Such general formulations, however, are not sufficient to know "how" to achieve this goal. Since the syndrome of executive dysfunctions is a set of many deficits, varying in severity, the therapist may have a dilemma whether to practice individual, disturbed functions separately (e.g. selective attention, working memory) or to improve complex everyday skills essential for independence. Regardless of the answer to this question, for each form of rehabilitation, materials are needed, i.e. exercises prepared in such a way that the therapist can select them from a specific base and implement them according to the needs.

In the early stage of recovery and with more severe disorders, specific exercises stimulating "single" functions belonging to the executive system (e.g. divided attention) are more often used. With milder deficits, or later in the recovery process, more time is spent practicing complex skills important to one's natural life functioning. They are also associated with the improvement of self-awareness regarding disease-related deficits, as well as preserved skills, in the overarching aim of improving the effectiveness of action and social adjustment.

For several decades, the development of technology has made it possible to create specialised computer programs for the therapy of cognitive functioning following brain damage[14]. Such therapy has many advantages, the most important of which are: extended accessibility (e.g. remote rehabilitation for people living outside medical centres), intensification of exercises (e.g. continuation at home), automatic recording of the effects of therapy, as well as flexible adjustment of difficulty levels depending on successes in completed exercises[15]. For an increasing number of people, exercises with the use of a computer are perceived as a natural activity, and this form of therapy is often considered more attractive. In addition to these advantages, modern technologies make it possible to create scenarios that better imitate everyday situations. Different strategies of task performance can be analysed with the patient in terms of their optimisation, without exposing the patient to stressful evaluation, when making a worse decision[16]. Training everyday behaviour (i.e. containing so-called ecological value) increases the probability of generalisation effects of exercises on activities undertaken outside the therapeutic situation[17-18].

Neuropsychologists in Poland have access to adaptations of foreign computer programs supporting rehabilitation, including: RehaCom (www.rehacom.com; Hasomed GmbH, Magdeburg, Germany), and CogniPlus (www.schuhfried.com/cogniplus; Schuhfried GmbH, Mödling, Austria). However, in order to enrich the base of culturally closer exercises, with the possibility of adapting them to different levels and nature of disorders, members of the Clinical Neuropsychology Laboratory - the Institute of Psychiatry and Neurology, in co-operation with the "Harpo" company (having experience in creating IT devices in rehabilitation), prepared a specialised program to support the rehabilitation of patients with executive dysfunctions.

ExeSystem – PROGRAM CHARACTERISTICS

When creating the program, several assumptions were made, including compliance with the international recommendations of experts in neurorehabilitation[6], bringing therapeutic tasks closer to everyday situations, as well as the possibility of recording the effects of the rehabilitation process. An important assumption was also to minimise technical barriers in the practical use of the application.

Training related to everyday behaviour predominantly involve executive functions: ability of inhibiting impulsive and stereotypical behaviours, selectivity, shifting and maintaining concentration, working memory, planning and problem solving, noticing and understanding social contexts regarding a situation, as well as learning strategies of effective memorisation.

The application consists of 8 modules (Table 1).

The names of the modules refer to everyday activities. For example, packing a suitcase for a trip, remembering the route during a bike ride, buying the right ticket from a ticket machine, etc. To make the tasks more attractive, photos, graphics and videos have been introduced. This is particularly important in the specified group of patients due to their decreased motivation to exercise because of limited insight into acquired disease deficits (so-called anosognosia).

Neuropsychological rehabilitation experts emphasize the need to teach patients with mild executive dys-

Table 1

ExeSystem program modules and practiced functions	
ExeSystem program modules	**Executive functions**
"Moving to a new house"	Executive attention, working memory
"Garbage segregating"	
"Bike ride"	
"Things to do"	Problem solving and planning
"Packing a suitcase"	
"Ticket machine"	
"An attentive observer"	Social cognition
"Improving memory"	Memory strategies

functions effective memory strategies, which is why the ExeSystem program includes a module on such mnemonics.

The exercises in the program are characterised by different difficulty levels of the tasks so that they can be easily adapted to the possibilities of an individual patient. After setting the thresholds for correctly or incorrectly performed exercises in a given module, the program automatically adjusts the difficulty level for subsequent tasks. The progress of the rehabilitation process is recorded in a standardised manner for all modules, and the results of exercises are presented in numerical and graphic form. This allows to monitor the effects of individual therapy and generate a report on the sessions, and to further use the data in scientific research.

In order to make the use of the program as simple as possible, the use of a touch screen has been implemented. In addition, for people with motor disabilities, there is a scanning option (Big Switch type with the use of 1 or 2 buttons), consisting in moving the frame over active screen elements and the possibility of the patient indicating the appropriate field by pressing the button when the frame is on the correct item.

DESCRIPTION OF ExeSystem PROGRAM MODULES

Moving to a new house

In the task, we see an image of a car in which there are identical boxes with items packed in them. The task requires memorising the locations of specific boxes. By indicating consecutive ones, their content is presented for a short time period. The location of the boxes with specific items has to be memorised. The higher the difficulty of the task, the greater the number of boxes. There is also delay between presenting the content of the boxes and the need to indicate the location of those correct. At the highest levels of difficulty, the boxes change their location, which needs to be carefully observed.

The task trains sustained attention and visual working memory.

Garbage segregation

Different colours of waste sorting bins are visible against the background of an urban landscape. At certain intervals, waste appears on the screen, e.g. an empty bottle, a cardboard box, etc. The task is to indicate the correct waste bin into which the item should go. With the increasing difficulty of tasks, more and more elements requiring divisibility and shifting attention are introduced: the number of containers increases and their position on the screen changes, vehicles for waste collection appear, radio messages are introduced and some of them need to be responded to (e.g. emptying specified containers on the relevant days of the week, changes in collection dates, vehicle breakdowns of the city cleaning company).

The task allows to exercise various subsystems of attention (sustaining, selectivity, dividing and shifting), as well as working memory.

Bike ride

The task is to remember the routes of bicycle ride documented on video recordings. During the presentation of the video, the recording is paused from time to time in order to indicate and remember some characteristic point of the route. After completing the route, its characteristic points should be placed in the correct order. At higher difficulty levels, the route become longer with more and more places to memorise are added.

The task exercises visual-spatial and working memory.

Things to do

In the task, descriptions of various everyday situations are presented. These situations require making a decision. After analysing the content of the task and taking various constraints into account, the best solution should be chosen from the provided options. As the difficulty levels of the exercise increase, the situations become more complex, and the amount of information to be analysed and considered also increases, as well as the number of possible solutions to choose from. The 'help' option is a facilitation in the task, which, through questions and tips directing attention towards the most important elements of the described situation, aid in the analysis.

The task exercises abilities of: planning and problem solving, cause-and-effect thinking, generalisation and abstraction.

Packing a suitcase

In the task, the patient should become acquainted with a detailed description of one of the planned trips and based on this information, s/he packs his/her luggage, selecting the necessary things from the appropriate sections of the wardrobe. At higher difficulty levels, the amount of important information increases regarding, among others, the purpose and time of departure, weather, conditions of stay at the destination, planned ac-

tivities. Sometimes there is a need to repack the suitcase due to unexpected changes in travel conditions, e.g. in the weather forecast, baggage allowance.

The task is aimed at improving planning abilities and cognitive flexibility in accordance with changing situational conditions.

Ticket machine

The task is to choose the cheapest ticket for the described journey. At the initial difficulty levels, the types and the correct number of tickets are selected, and payment is made. At higher levels of difficulty, a trip by public transport needs to be planned to the selected destination, the number of stops checked, travel time and zoning on the map must be considered, and possible discounts, baggage transport conditions as well as rush hour must be taken into account.

The task improves aim-directed complex activities, with planning and controlling behaviour.

An attentive observer

The task presents video recordings of various everyday situations in which inappropriate or correct behaviours should be identified within the context of social norms. For example, there is a video of a minor purchasing alcohol and various reactions from the seller. The patient has to choose which reaction of the seller is the most appropriate.

The exercise intentionally improves the adaptability of behaviour, including understanding the rules of social life, the ability to empathise and recognise other people's emotions.

Improving memory

The task presents various strategies used to improve memory, i.e. mnemonics. The strategies are divided into 2 groups. The first contains mnemonics based on the organisation of the material, such as: portioning and grouping, the so-called 5P method, mind maps. The second group presents strategies that use notions such as: creating stories and the hook method. Training tasks in each mnemonic are preceded by educational material describing the assumptions of individual strategies and the course of exercises in an example task. As tasks become more difficult, so does the amount of material to remember.

USEFULNESS OF ExeSystem – PRELIMINARY OBSERVATIONS

The ExeSystem program was used in the treatment of 15 patients with executive dysfunctions as a result of acquired brain damage of traumatic and stroke etiology. The demographic and clinical characteristics of the study group are presented in Table 2. The therapeutic program consisted of 15, 1-hour sessions and was implemented over a 3-week period. Eight patients were treated during hospitalisation at the inpatient neurological rehabilitation ward, and in the case of the remaining patients – as part of the day ward. All patients worked under the supervision of a neuropsychologist. In the 2nd week of therapy, 7 patients required only a little support with regard to technical operation of the program, while in the 3rd week, they were able to operate the program on their own.

The usefulness of the program in terms of its content, visual attractiveness, accessibility and technical simplicity of use, as well as general satisfaction with using it, were assessed by both therapists and patients themselves.

Neuropsychologists evaluated the value of the program in according to 2 questionnaires designed for this purpose. The first was focused on various technical functions of the application and their correct operation (including starting, creating a patient's account, setting task parameters). In total, 73 features of the program were analysed. Several minor comments were made regarding the functionality, which, however, did not concern the essence of the program's operation. In conclusion, neuropsychologists expressed positive opinions about the content and visual value of the program.

The 2nd questionnaire completed by neuropsychologists concerned how patients perceive exercises from the ExeSystem program. The survey consisted of 9 statements relating, *inter alia*, to understanding the instructions and content of tasks, the ability to use the application, the reception of its visual aspect, motivation to exercise, as well as spontaneously reported willingness to continue exercises after completion of the designated therapy cycle. Each statement was rated on a 5-point scale (for the extreme values: 1 – "I completely disagree", to 5 – "I fully agree"), and the higher the score, the higher the program usability rating. For the maximum number of 45 points, the averaged result of the survey was 37 points. The highest results were noted in aspects of the program such as comprehensibility of instructions and essence of tasks, as well as the attractiveness of the graphical aspect of the exercises. Lower scores, on the other hand, were observed mainly in the

Table 2

Demographic and clinical characteristics of the study group

Group size (n)	Sex (f/m)	Age (M±*SD*)	Education – years (M±*SD*)	Etiology of brain injury (b/hs/is)	Time since onset (Med±IQR)	Barthel Index (Med±IQR)
15	7/8	40.8±14	15.9±2.85	5/7/3	7±10	9±15

f – females; m – males; b – brain injury; hs – haemorrhagic stroke; is – ischemic stroke; M – mean; *SD* – standard deviation; Med – median; IQR – interquartile range

responses regarding the ability to fully individually use the program by patients and the spontaneously declared willingness to continue therapy with it. The specificity of executive dysfunctions, primarily related to the impaired ability to plan and control activity, may partly explain difficulties in independent use of the program, especially during the first training sessions. Lack of spontaneously declared willingness to continue therapy with the use of the program by some patients may result from their limited spontaneity in initiating activity and planning ability, including long-term therapeutic management, which is part of the essence of executive dysfunctions.

Neuropsychologists were also asked to provide a rough percentage of the patients' ability to exercise on their own using the program. Such estimates were within the range of 50-80%. In the opinion of therapists, at least half of the patients undergoing therapy would be able to use the program on their own, e.g. by continuing therapy at home. This estimate, however, requires confirmation in a separate research project.

Apart from the questionnaires described above, opinions of the rehabilitated patients were collected. For this purpose, the Therapy Satisfaction Scale was created, consisting of 7 questions relating to the attractiveness of tasks, the impact on the exercised abilities (attention functions, planning, memorising, social contacts), the usefulness of exercises in everyday life and the willingness to continue therapy using the program in the future. The answers were given on a 3-point scale ("rather yes" - "average" - "rather no"). In Table 3, there is a list of the patients' responses to each of the questions.

Analysing the patients' opinions, it may be concluded that the level of satisfaction with the use of the ExeSystem program, particularly with regard to the attractiveness of the exercises and the willingness to continue them, was rated high. The patients' assessment of the willingness to continue the therapy explains the inconsistency that appears between the therapists' observations, indicating that some patients were not interested in continuing exercise. It follows that the patients did not spontaneously declare their willingness to continue, while when asked about it, they directly confirmed their interest in continuing the exercises.

Most of the patients also indicated the influence of the tasks performed on their abilities of attention, planning and contact with people. When assessing the impact of exercises on memory, the same number of patients indicated "rather yes" and "average", while only one person indicated "rather no". On the other hand, when assessing the usefulness of exercises in everyday life, a similar number of patients indicated "rather yes" and "average". Most of the "on average" answers were given by people who participated in therapy as part of an inpatient stay, which could be a limitation in assessing the impact of exercise on daily, diversified activities. The highest number of "rather no" answers was noted in the question concerning the influence of exercises on attention functions (5 such answers). This was also only question that did not have an "average" answer, so 2/3 of the patients stated that exercise - "rather" - had a positive effect on attention-related functions.

Table 3

Evaluation by patients according to Therapy Satisfaction Scale

Question topics	Patient grade		
	Rather yes	Average	Rather no
Exercise attractiveness	11	3	1
Improvement in concentration	10	0	5
Improvement in planning	8	4	3
Improvement in memory	7	7	1
Improvement in contact with people	8	3	4
Usefulness in everyday life	6	7	2
Willingness to continue	11	2	2

CONCLUSION

The ExeSystem program for computer-assisted rehabilitation of neurological patients with executive dysfunctions is primarily aimed at improving the professional work of neuropsychologists, providing an extensive collection of exercises from which one can draw upon creating an individualised therapeutic programme (which is the superior rule). In some patients, it may also facilitate the continuation of rehabilitation at home, with the help of relatives, although under the remote supervision of a professional therapist. Exercises included in the programme relate to practical skills and those important in everyday functioning, which should favour the transfer of training effects to behaviour in natural situations.

Initial information – gathered both from therapists and patients - regarding the usefulness and attractiveness of the ExeSystem application in the treatment of executive dysfunctions is positive.

The authors hope that the proposed therapeutic exercises will be enriched, contributing to the future creation of practical standards regarding neuropsychological rehabilitation for patients with executive dysfunction syndrome.

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