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THE IMPACT OF REHABILITATION ON THE RECOVERY OF EXECUTIVE FUNCTIONS IN STROKE PATIENTS WITH DIFFERENT LOCATION OF THE ISCHEMIC FOCUS

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Abstract

Objectives: Cognitive dysfunction is part of the clinical picture of stroke. Most of the executive dysfunctions are diagnosed in the early stage of rehabilitation, a few weeks after the vascular incident. Coexistence of executive dysfunctions with other disorders in stroke patients may hinder patient's functions, slow down the rehabilitation process, and disrupt self-awareness, interpersonal communication, and professional activity in everyday life. **Material and Methods:** Ninety patients after ischemic stroke were examined (right hemisphere stroke: N = 33, left hemisphere stroke: N = 57). The study group (N = 45) consisted of patients rehabilitated in the Department of Rehabilitation and Physical Medicine of the University Teaching Hospital of the Military Medical Academy in Lodz, Łódź, Poland, in whom a comprehensive neurorehabilitation program was implemented, consisting of motor and neuropsychological rehabilitation. The control group (N = 45) consisted of patients awaiting admission to the department, who were covered by comprehensive environmental rehabilitation including exercise therapy and neuropsychological therapy. Executive function was measured with 3 popular diagnostic tools: the Wisconsin Card Sorting Test (WCST), the Trail Making Test (TMT part A, TMT part B), and the letter test and category test with the Verbal Fluency Test (VFT). The tests were carried out twice: the first time before the start of rehabilitation and 5 weeks later after its completion. **Results:** Although patients with right-hemispheric stroke showed better improvement in executive functions, stroke location did not prove to have significant impact on how effective the rehabilitation was. **Conclusions:** Right hemisphere stroke patients showed greater improvement in restoring executive functions after rehabilitation compared to left hemisphere stroke patients. The location of the stroke did not significantly correlate with the efficiency of the rehabilitation setting. Int J Occup Med Environ Health. 2024;37(4)

Key words:
stroke, rehabilitation, cognitive dysfunction, executive function, neurorehabilitation, neuropsychological rehabilitation

INTRODUCTION

Cognitive dysfunction is part of the clinical picture of stroke. Most of the executive dysfunctions are diagnosed in the early stage of rehabilitation, a few weeks after the vascular incident. They occur with varying frequency, i.e., in 20–60% of cases [1]. Tang et al. [2] showed that its prevalence at 3 months post-stroke was 18.7%. Study additionally conducted that 66.6% of the patients with stroke still had executive function dysfunction 2 years after stroke, mainly at the levels of choice, planning, decision-making, and control behavior disorder in daily life, seriously affecting the quality of life of the patients and

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increasing the risk of dementia. Executive mechanisms are more or less involved in every complex human activity, except the most automated and learned ones. They control human behavior and are responsible for starting, stopping, and shifting activities. Executive functions are considered to be the superior system responsible for integrating and organizing the course of various and usually complex cognitive processes which make human behavior characterized by planning, purposefulness, consciousness, and selectiveness [3–5].

The clinical picture of executive dysfunctions includes many symptoms with varying intensity. Occurrence of a single symptom is a very rare case. Disorders tend to dissociate, which means that after a cerebral incident some executive processes are selectively affected, while others remain normal [6].

Patients with executive dysfunction often have trouble starting a pre-planned activity. Increased difficulties in this area may lead to apathy, deteriorated responsiveness, and even mutism. A frequent symptom is also the inability to make mental and behavioral shifts. In such people, shifting attention is usually impaired, symptoms of rigid thinking appear as well as perseveration (persistent repetitions) and stereotypical reactions. Patients are not able to smoothly, flexibly change their behavior and adapt to a new situation. Another problem is the inability to restrain your own reactions, the so-called disorders of inhibition. There is often excessive impulsivity, responsiveness, disinhibition, and difficulties in receiving feedback, especially negative one. Patient's social life is significantly hindered by the so-called deficient self-awareness. This symptom is manifested by the inability to notice the mistakes made, decreased self-criticism, and lack of cause-and-effect thinking. Patients may develop disorders of abstract thinking, the so-called concrete attitude. The patient understands most circumstances and messages in a literal way and is unable to plan and modify behaviors depending on the requirements of the situation [7–9].

The cerebral source of executive functions, both in terms of their location and etiology, remains a controversial issue. Initially, executive function disorders were believed to mainly come from damage to the frontal lobes of the brain, and the frontal dysexecutive syndrome would be diagnosed. Later studies revealed that executive disorders occur not only in lesions in the frontal cortex, but also in other structures: the subcortical nuclei (amygdala, hippocampus, striatum, thalamus, hypothalamus), the cerebellum and the cortex of other lobes. The most common ischemic causes of executive disorders are infarctions of the frontal lobes, striate body, and thalamus [9,10].

Coexistence of executive dysfunctions with other disorders in stroke patients may hinder patient's functions, slow down the rehabilitation process, and disrupt self-awareness, interpersonal communication, and professional activity in everyday life [11]. The studies have shown an association between executive dysfunction and walking ability. The degree of executive dysfunction is associated with differences in walking ability in patients with stroke [12].

Research into the relationship between pathology laterality and severity of executive disorders is still scarce in professional literature. The study aimed to evaluate the impact of rehabilitation on executive functions recovery in stroke patients with different location of the ischemic focus.

MATERIAL AND METHODS

The authors examined 90 patients after ischemic stroke: right hemispheric stroke (N = 33) and left hemispheric stroke (N = 57). The study group (N = 45) consisted of patients rehabilitated at the Department of Rehabilitation and Physical Medicine of the University Clinical Hospital of the Military Medical Academy in Lodz, Łódź, Poland. The control group (N = 45) were patients awaiting admission to the clinic, who received community-based rehabilitation.

In both groups, a rehabilitation program including physiotherapy, speech therapy, and cognitive training. Physiotherapy was done with the use of modern neurophysiological methods, including proprioceptive neuromuscular facilitation and the Bobath concept, as well as biofeedback methods.

Neuropsychological rehabilitation was based on computer programs (RehaCom, Hasomed, Magdeburg, Germany) and traditional paper-pencil methods. Executive functions therapy consisted for example of: solving problems by defining them, developing strategies and instructions, and verifying the results. At the same time, therapeutic efforts concentrated on restoring attention, perception, memory, visual-spatial, and language functions. Therapy aims were established individually for each patient, after in-depth neuropsychological diagnosis of their cognitive functions. Examinations in both groups were carried out twice: first time before rehabilitation commenced, and 5 weeks later after its completion.

Patients who qualified were those who had suffered ischemic cerebral stroke from 1 month up to 1 year prior to the study. All subjects were right-handed. The entire sample has the same dominant hemisphere and a similar size of damaged area. The qualification was made by a doctor based on brain imaging methods. Patients were excluded if they had left and right hemispheric injuries and diffuse brain damage, previous central nervous system dysfunctions, complete aphasia, as well as when dementia was suspected or patients had psychotic symptoms. The purpose of the study was very clearly communicated to all patients, and they agreed to participate. They were informed of the fact that participation is voluntary and they may choose to resign without giving a reason. The study was approved by the Bioethics Committee. Executive functions were measured with 3 popular diagnostic tools: the Wisconsin Card Sorting Test (WCST), the Trail Making Test (TMT part A and part B), as well as the letter test and the category test from the Verbal Fluency Test (VFT).

The WCST is one of the most frequently chosen tools for the assessment of executive functions by researchers. The WCST consists of 2 identical decks of cards (each deck contains 64 cards), 4 reference cards, and a record sheet. The task of the test person is to match each card from both decks to 1 of the reference cards using the feedback about the correctness of sorting provided by the examiner. The WCST test is considered complete when the test person correctly arranges the cards according to the following 6 criteria (color, shape, number, color, shape, number) or when he has used all cards from both decks. Higher executive dysfunction is indicated by higher scores on WCST metrics: total errors, perseverative responses, perseverative errors, percentage of perseverative errors, non-perseverative errors, attempts to complete the first category, failure to maintain set, and lower scores for percentage of conceptual-level responses and number of categories completed.

The following indicators from the WCST were used in the research to assess executive functions:

- total errors – the number of responses that do not match the currently sorted criterion,
- perseverative responses – the subject persistently considers the currently inappropriate feature,
- perseverative errors – perseverative responses that do not include the current one sort criterion,
- percentage of perseverative errors– number of perseveration errors divided by number of tests run,
- non-perseverative errors – the number of incorrect attempts, excluding those marked as perseverative,
- percentage of conceptual-level responses – correct answers in the series at least 3 consecutive attempts, divided by the number of tests performed,
- number of categories completed – number of 10 consecutive correct choices, matching to the current sorting criterion,
- attempts to complete the first category – the number of attempts until the first category has been passed,
- failure to maintain set – number of sequences of ≥5 correct answers followed by at least 1 error before passing the category.

The TMT tests psychomotor speed (part A) and visual-spatial working memory and the ability to switch to a new criterion after learning one reaction rule (part B). In part A of the TMT test, the test person is presented with 25 circles with consecutive numbers arranged on a piece of paper. The subject's task is to connect the numbers in the correct order (from 1 to 25) in the shortest possible time. When evaluating the test results, the time counted in seconds and the number of errors made are taken into account. In TMT part B, the test person is instructed to alternately connect the circles marked with numbers and letters in the correct order of numbers and letters (1-A, 2-B, 3-C, etc.). This task requires the subject to maintain in immediate memory information on 2 applicable response criteria, as well as adequate control of 2 separate processes. Patients with executive dysfunctions are unable to switch from a number to the next letter and often pay attention only to the numbers that they connect sequentially.

The diagnostic value is primarily the time ratio of performing part B to part A. People with brain damage spend 3 times more time on part B of the test than on part A. Parameter B/A >3 indicates serious disorders of executive functions.

The VFT assesses the verbal aspect of executive functions. In the category test, the task of the tested person is to give as many names of animals, fruits and vegetables as possible in 1 min for each category. In the letter test, the subject lists as many words as possible beginning with a given letter of the alphabet (F, A, S) within 1 min for each letter. The test result is the number of words spoken within 3 min in each test, the number of repetitions (perseverations) and the number of words inconsistent with the criterion. People without brain damage say an average of 13–14 words starting with a given letter and name 16–17 names from a given category per min.

In order to evaluate the effects of rehabilitation, the t-test for dependent data was used to indicate the significance of differences between mean values of the results in different rates in the 2 groups of people after stroke: treated in the hospital and treated at home in different lesion locations (right/left) obtained before and after rehabilitation. Descriptive data are presented as means and standard deviations. The level of significance $p < 0.01$.

In order to investigate the relationship between the location of the stroke (right/left hemisphere) and the effects of applied rehabilitation (in the area of executive functions) depending on the rehabilitation setting (hospital vs. community), a 2-factor analysis of variance was used. The stroke locations and rehabilitation settings were used as grouping variables. The improvement rates for individual test indicators (test parameters) (i.e., the differences between the results of individual test indicators used to assess executive functions achieved by the subjects after and prior to rehabilitation) were the dependent variables. This way, each improvement rate was analyzed to verify whether there is a 2-way interaction between stroke location (right/left hemisphere) and the rehabilitation setting. In other words, it was verified whether and to what extent (η^2 indicator) the stroke location correlated with the impact of the rehabilitation setting on improvement in each studied indicator. Finally, the t-test for independent data was performed to examine the significance of differences between the mean improvement rates for each test in the compared groups.

RESULTS

The study involved a psychometric evaluation of executive functions in stroke patients who received rehabilitation in the hospital or community-based setting and had left or right location of ischemic focus.

To be able to assess the effectiveness of the rehabilitation in improving executive functions in right hemisphere stroke patients (hospital setting group and community setting group) and in left hemisphere stroke patients (hospital setting group and community setting group), the authors verified the significance of differences between the mean values of results recorded before and after rehabilitation measured by: WCST, TMT part B, TMT part B/ part A, the category test of the VFT, and the letter test of the VFT.

The differences between the mean results of tests taken before and after rehabilitation in right hemisphere stroke patients turned out to be statistically significant. This was the case both for the group rehabilitated in the hospital setting and the one rehabilitated in the community setting in the following WCST indicators: total number of errors, perseverative responses, perseverative errors, non-perseverative errors, percentage of conceptual-level responses, number of categories completed (Table 1).

For the percentage of perseverative errors, the results were significant only in the hospital setting group, and insignificant in the community-based group. Attempts to complete the first category and failure to maintain set were irrelevant in both groups ($p > 0.01$) (Table 1).

The differences between the mean results of tests taken before and after rehabilitation in left hemisphere stroke patients turned out to be significant only for the hospital-based group in the following indicators: total error number, percentage of conceptual-level responses, and number of categories completed. In the community setting group with left-hemispheric stroke, no significant differences were found in any of the studied WCST parameters. Results of the applied WCST tests showed no correlation between the stroke-affected side of the brain and the impact of the setting in which rehabilitation was delivered (hospital vs. community) (Table 1).

To conclude, right hemisphere stroke patients rehabilitated both in the hospital and in the community-based setting improved their executive functions in a larger number of WCST tests than the left hemisphere stroke patients.

Progress in regaining executive control measured with TMT part B was significant across all study groups: left hemisphere stroke patients rehabilitated in the hospital setting, left hemisphere stroke patients rehabilitated in the community setting, right hemisphere stroke patients rehabilitated in the hospital setting, and right hemisphere stroke patients rehabilitated in the community setting – Table 2). Improvement in the TMT part B/part A test was significant only in right hemisphere stroke patients rehabilitated in the hospital setting (Table 2).

The verbal dimension of executive functions was assessed with the letter test and the category test taken from the VFT. Differences between the mean results of tests taken before and after rehabilitation in right hemisphere stroke patients rehabilitated in the hospital setting was significant for the following indicators of the VFT's letter test: number of F-words, number of A-words, number of S-words, as well as the following parameters from the VFT's category test: number of ZW-words, number of O-words, number of W-words (6 indicators).

The differences between the mean results of tests taken before and after rehabilitation in left hemisphere stroke patients rehabilitated in the hospital setting were significant for the following indicators of the VFT: number of F-words, number of A-words, number of S-words, as well as for the following indicators of the VFT's category test: number of O-words (4 indicators).

The differences between the mean results of tests taken before and after rehabilitation in left hemisphere stroke patients rehabilitated in the community setting were significant for the following indicators of the VFT: number of F-words, number of A-words, and number of S-words (3 indicators) (Table 3).

To conclude, of the 4 studied groups the patients with right-hemispheric stroke rehabilitated in the hospital setting improved their verbal executive functions in the largest number of test indicators as compared to the other groups.

The rates of improvement in right hemisphere stroke patients were higher compared to those with left-hemispheric stroke for the following WCST indicators: total errors (M±SD 24.10±19.24), perseverative responses (M±SD 21.00±26.60), perseverative errors (M±SD 16.40±17.51),

Table 1. The results of Wisconsin Card Sorting Test (WCST) conducted before and after rehabilitation with patients in the hospital (group 1) and the community setting (group 2) depending on the location of the ischemic stroke focus (right/left hemisphere), 2013–2021, Łódź, Poland

Variable	Before rehabilitation		After rehabilitation		T	df	η^2	p[a]
	M	SD	M	SD				
Total errors [n]								
group 1								
right hemisphere	62.63	10.56	38.53	17.14	6.861	29	0.619	**0.000**
left hemisphere	66.47	14.19	47.60	13.55	5.421	14	0.677	**0.000**
group 2								
right hemisphere	55.08	8.77	43.24	12.88	4.966	24	0.507	**0.000**
left hemisphere	53.95	12.93	52.00	15.86	0.711	19	0.026	0.486
Perseverative responses [n]								
group 1								
right hemisphere	49.33	22.20	28.33	14.96	4.323	29	0.392	**0.000**
left hemisphere	50.13	26.09	34.13	10.18	2.307	14	0.275	0.037
group 2								
right hemisphere	51.16	17.22	40.76	13.73	3.011	24	0.274	**0.006**
left hemisphere	45.45	14.11	38.00	11.06	2.191	19	0.202	0.041
Perseverative errors [n]								
group 1								
right hemisphere	36.83	14.87	20.43	9.96	5.129	29	0.476	**0.000**
left hemisphere	39.40	16.85	24.00	7.64	3.357	14	0.446	**0.005**
group 2								
right hemisphere	32.52	11.81	25.72	9.77	2.910	24	0.261	**0.008**
left hemisphere	26.25	15.17	22.50	10.06	1.236	19	0.074	0.232
Perseverative errors [%]								
group 1								
right hemisphere	28.90	11.57	18.60	6.53	4.534	29	0.415	**0.000**
left hemisphere	36.93	21.24	19.33	5.34	3.137	14	0.413	**0.007**
group 2								
right hemisphere	25.72	9.24	21.32	7.06	2.562	24	0.215	0.017
left hemisphere	20.15	11.75	18.05	7.78	0.956	19	0.046	0.351
Non-perseverative errors [n]								
group 1								
right hemisphere	25.77	10.89	18.13	12.74	2.674	29	0.198	**0.012**
left hemisphere	27.07	12.36	23.60	9.52	0.964	14	0.062	0.351
group 2								
right hemisphere	22.28	10.32	17.04	8.44	2.878	24	0.257	**0.008**
left hemisphere	28.55	12.84	30.05	12.59	–0.750	19	0.029	0.462

Table 1. The results of Wisconsin Card Sorting Test (WCST) conducted before and after rehabilitation with patients in the hospital (group 1) and the community setting (group 2) depending on the location of the ischemic stroke focus (right/left hemisphere), 2013–2021, Łódź, Poland – cont.

Variable	Before rehabilitation		After rehabilitation		T	df	η^2	p[a]
	M	SD	M	SD				
Conceptual-level responses [%]								
group 1								
right hemisphere	43.77	13.13	60.30	8.64	–6.498	29	0.593	**0.000**
left hemisphere	38.73	17.03	59.80	10.02	–5.110	14	0.651	**0.000**
group 2								
right hemisphere	53.04	11.10	61.56	11.03	–4.267	24	0.431	**0.000**
left hemisphere	50.95	15.19	55.00	16.87	–1.882	19	0.157	0.075
Categories completed [n]								
group 1								
right hemisphere	1.60	1.45	4.40	1.69	–8.764	29	0.726	**0.000**
left hemisphere	1.36	0.84	3.93	1.49	–6.395	13	0.745	**0.000**
group 2								
right hemisphere	1.68	1.57	3.44	2.38	–4.864	24	0.496	**0.000**
left hemisphere	1.35	1.50	2.00	2.22	–1.898	19	0.159	0.073
Attempts to complete the first category [n]								
group 1								
right hemisphere	25.87	24.87	19.60	16.70	1.332	29	0.058	0.193
left hemisphere	35.79	29.61	15.29	11.70	2.515	13	0.311	0.026
group 2								
right hemisphere	23.96	22.20	17.08	19.25	1.028	24	0.042	0.314
left hemisphere	23.95	25.07	18.95	17.87	0.726	19	0.027	0.477
Failure to maintain set [n]								
group 1								
right hemisphere	1.87	1.59	1.40	1.33	1.353	29	0.059	0.186
left hemisphere	2.21	1.76	1.79	1.12	0.822	13	0.046	0.426
group 2								
right hemisphere	3.00	2.04	2.12	1.99	2.107	24	0.156	0.046
left hemisphere	2.90	1.65	2.25	2.55	1.135	19	0.064	0.270

Bolded are statistically significant values.
Attempts to complete the first category – the number of attempts until the first category has been passed; failure to maintain set – number of sequences of ≥5 correct answers followed by at least 1 error before passing the category; non-perseverative errors – the number of incorrect attempts, excluding those marked as perseverative; number of categories completed – number of 10 consecutive correct choices, matching to the current sorting criterion; percentage of conceptual-level responses – correct answers in the series at least 3 consecutive attempts, divided by the number of tests performed; perseverative errors – perseverative responses that do not include the current one sort criterion; percentage of perseverative errors – number of perseveration errors divided by number of tests run; perseverative replies – occurs when the subject persistently considers the currently inappropriate feature; total number of errors – the number of responses that do not match the currently sorted criterion.
[a] $p < 0.01$.

Table 2. The results of Trail Making Test (TMT) part B and TMT part B/part A tests conducted before and after rehabilitation with patients in the hospital (group 1) and the community setting (group 2) depending on the location of the ischemic stroke focus (right/left hemisphere), 2013–2021, Łódź, Poland

Variable	Before rehabilitation		After rehabilitation		T	df	η^2	p[a]
	M	SD	M	SD				
TMT part B [s]								
group 1								
right hemisphere	306.0	173.14	198.1	126.25	8.422	29	0.710	**0.000**
left hemisphere	278.2	197.55	167.6	67.27	2.796	14	0.358	**0.014**
group 2								
right hemisphere	177.0	86.43	160.1	85.44	2.643	24	0.225	**0.014**
left hemisphere	278.9	133.14	219.5	92.25	4.108	19	0.470	**0.001**
TMT part B/part A [s]								
group 1								
right hemisphere	2.983	1.296	2.446	0.986	3.683	29	0.319	**0.001**
left hemisphere	2.700	1.632	2.317	0.814	1.330	14	0.112	0.205
group 2								
right hemisphere	2.528	0.959	2.555	1.223	−0.137	24	0.001	0.892
left hemisphere	2.714	0.912	2.539	0.810	0.790	19	0.032	0.439

Bolded are statistically significant values.
[a] $p < 0.01$.

Table 3. The results of Verbal Fluency Test (VFT) – the letter test conducted before and after rehabilitation with patients in the hospital (group 1) and the community setting (group 2) depending on the location of the ischemic stroke focus (right/left hemisphere), 2013–2021, Łódź, Poland

Variable	Before rehabilitation		After rehabilitation		T	df	η^2	p[a]
	M	SD	M	SD				
F-words [n]								
group 1								
right hemisphere	7.77	3.66	10.27	4.04	−5.221	29	0.484	**0.000**
left hemisphere	5.47	2.70	8.67	2.61	−5.527	14	0.686	**0.000**
group 2								
right hemisphere	10.12	4.00	11.48	3.34	−2.557	24	0.214	0.017
left hemisphere	5.80	3.94	7.15	3.25	−2.896	19	0.306	**0.009**
A-words [n]								
group 1								
right hemisphere	7.10	3.57	10.20	4.30	−4.406	29	0.401	**0.000**
left hemisphere	4.87	2.83	7.87	2.17	−4.392	14	0.579	**0.001**
group 2								
right hemisphere	9.36	4.10	10.80	3.86	−1.838	24	0.123	0.078
left hemisphere	4.80	3.12	6.80	3.04	−4.472	19	0.513	**0.000**

Table 3. The results of Verbal Fluency Test (VFT) – the letter test conducted before and after rehabilitation with patients in the hospital group (group 1) and the community setting group (group 2) depending on the location of the ischemic stroke focus (right/left hemisphere), 2013–2021, Łódź, Poland – cont.

Variable	Before rehabilitation		After rehabilitation		T	df	η^2	p[a]
	M	SD	M	SD				
S-words [n]								
group 1								
right hemisphere	7.83	3.96	10.13	4.52	–3.614	29	0.311	**0.001**
left hemisphere	5.20	2.73	7.73	2.25	–3.919	14	0.523	**0.002**
group 2								
right hemisphere	9.04	4.03	10.64	4.25	–1.864	24	0.126	0.075
left hemisphere	4.40	2.91	6.20	2.76	–4.811	19	0.549	**0.000**
ZW-words [n]								
group 1								
right hemisphere	9.97	4.43	12.63	4.26	–5.049	29	0.468	**0.000**
left hemisphere	8.20	4.68	9.40	3.60	–1.317	14	0.110	0.209
group 2								
right hemisphere	12.40	5.16	13.44	5.38	–1.368	24	0.072	0.184
left hemisphere	7.50	5.09	8.60	4.51	–1.325	19	0.085	0.201
O-words [n]								
group 1								
right hemisphere	8.93	3.32	11.53	3.58	–4.152	29	0.373	**0.000**
left hemisphere	6.93	4.10	9.53	3.02	–4.223	14	0.560	**0.001**
group 2								
right hemisphere	10.64	4.45	11.52	3.77	–1.745	24	0.113	0.094
left hemisphere	6.80	4.31	8.05	4.33	–1.978	19	0.171	0.063
W-words [n]								
group 1								
right hemisphere	7.73	3.16	9.83	3.32	–4.608	29	0.423	**0.000**
left hemisphere	4.67	3.33	7.73	3.56	–2.730	14	0.347	0.016
group 2								
right hemisphere	10.08	3.76	10.28	3.42	–0.327	24	0.004	0.746
left hemisphere	6.20	4.11	7.80	3.83	–2.002	19	0.174	0.060

Bolded are statistically significant values.
[a] $p < 0.01$.

non-perseverative errors (M±SD 7.63±15.63), percentage of conceptual-level responses (M±SD 22.57±19.02), number of categories completed (M±SD 2.80±1.75), failure to maintain set (M±SD 0.47±1.89) .

The rates of improvement in right hemisphere stroke patients rehabilitated in the home setting were higher compared to left hemisphere stroke patients for: total errors (M±SD 11.84±11.92), perseverative responses (M±SD 10.40±17.27), perseverative errors (M±SD 6.80±11.68), percentage of perseverative errors (M±SD 4.40±8.59), non-perseverative errors (M±SD 5.24±9.10), percentage of conceptual-level responses (M±SD 10.20±11.95), number of categories completed (M±SD 1.76±1.81), attempts to complete the first category (M±SD 6.88±33.47), failure to maintain set (M±SD 0.88±2.09).

The rates of improvement in left hemisphere stroke patients rehabilitated in the hospital setting were higher compared to right hemisphere stroke patients for: percentage of perseverative errors (M±SD 17.60±21.73) and attempts to complete the first category (M±SD 20.50±30.49).

The rates of improvement in left hemisphere stroke patients with community-based rehabilitation were lower across all indicators compared to right hemisphere stroke patients (Table 4). The WCST indicators revealed no correlation between the rehabilitation setting and stroke location (right/left hemisphere) (Table 4).

The improvement rates for TMT part B and TMT part B/part A were higher for left hemisphere stroke patients rehabilitated in both the hospital setting and the community setting compared to patients with right-hemispheric stroke (Table 2). The TMT part B and TMT part B/part A indicators showed no correlation between the rehabilitation setting and stroke location (Table 5).

Verbal executive functions in the studied groups were assessed using the letter test and the category test taken from the VFT. The rates of improvement in right hemisphere stroke patients rehabilitated in the hospital setting were greater than in left hemisphere stroke patients for the following VFT indicators: number of A-words (M±SD 3.10±3.85), number of ZW-words (M±SD 2.67±2.89), number of O-words (M±SD 2.60±3.43).

The rates of improvement in right hemisphere stroke patients who received community-based rehabilitation were higher than in left hemisphere stroke patients in the following VFT indicators: number of F-words (M±SD 1.36±2.66).

The rates of improvement in left hemisphere stroke patients who received hospital-based rehabilitation were higher than in right hemisphere stroke patients in the following VFT indicators: number of F-words (M±SD 3.20±2.24), number of S-words (M±SD 2.53±2.50), number of W-words (M±SD 3.07±4.35).

The rates of improvement in left hemisphere stroke patients rehabilitated in community-based setting were higher than in right hemisphere stroke patients for the following VFT indicators: number of A-words (M±SD 2.00±2.00), number of S-words (M±SD 1.80±1.67), number of ZW-words (M±SD 1.10±3.71), number of O-words (M±SD 1.25±2.83), number of W-words (M±SD 1.60±3.57) (Table 6).

The results of the VFT's letter test and category test did not reveal correlation between the rehabilitation setting and stroke location (Table 6). Although patients with right-hemispheric stroke showed better improvement in executive functions, stroke location did not prove to have significant impact on how effective the rehabilitation was.

The results of the indicators taken from the WCST were used as measures of the condition of executive functions: total errors, perseverative responses, perseverative errors, percentage of perseverative errors, non-perseverative errors, percentage of conceptual-level responses, number of categories completed, attempts to complete the first category, and failure to maintain set, the results of TMT part B, category test of the VFT, and finally the letter test from the VFT.

DISCUSSION

Many researchers confirm there is a significant decrease in the level of executive functions in stroke patients. Studies focusing on the relationship between the lateralization of the pathology (not only the frontal lobes) and the severity of executive dysfunctions and their impact on the course of treatment and rehabilitation are still scarce in professional literature [13–16].

Table 4. Improvement rates in Wisconsin Card Sorting Test (WCST) in patients from the hospital (group 1) and the community setting (group 2) depending on the location of the stroke (right/left hemisphere), 2013–2021, Łódź, Poland

Group	Stroke location				F	df	η^2	p[a]
	right hemisphere ($N_{group\ 1} = 15$, $N_{group\ 2} = 18$)		left hemisphere ($N_{group\ 1} = 30$, $N_{group\ 2} = 27$)					
	M	SD	M	SD				
Total errors [n]					0.502	1.00	0.006	0.481
group 1	24.10	19.24	18.87	13.48				
group 2	11.84	11.92	1.95	12.27				
Perseverative responses [n]					0.045	1.00	0.001	0.832
group 1	21.00	26.60	16.00	26.86				
group 2	10.40	17.27	7.45	15.21				
Perseverative errors [n]					0.095	1.00	0.001	0.759
group 1	16.40	17.51	15.40	17.77				
group 2	6.80	11.68	3.75	13.57				
Perseverative errors [%]					2.837	1.00	0.032	0.096
group 1	10.30	12.44	17.60	21.73				
group 2	4.40	8.59	2.10	9.82				
Non-perseverative errors [n]					0.225	1.00	0.003	0.636
group 1	7.63	15.63	3.47	13.92				
group 2	5.24	9.10	1.50	8.94				
Conceptual-level responses [%]					0.095	1.00	0.001	0.758
group 1	22.57	19.02	19.13	14.50				
group 2	10.20	11.95	4.75	11.29				
Categories completed [n]					1.405	1.00	0.016	0.239
group 1	2.80	1.75	2.57	1.50				
group 2	1.76	1.81	0.65	1.53				
Attempts to complete the first category [n]					1.486	1.00	0.017	0.226
group 1	6.27	25.77	20.50	30.49				
group 2	6.88	33.47	5.00	30.82				
Failure to maintain set [n]					0.042	1.00	0.000	0.838
group 1	0.47	1.89	0.43	1.95				
group 2	0.88	2.09	0.65	2.56				

[a] $p < 0.05$.

The aim of the study was to assess the impact of comprehensive neurorehabilitation on correcting those deficits in post-stroke patients with different localization of the ischemic focus (right/left hemisphere).

Right hemisphere stroke patients rehabilitated both in the hospital setting and in the community-based setting were found to improve their executive functions in more WCST indicators than the left hemisphere stroke patients. Improve-

Table 5. Improvement rates in Trail Making Test (TMT) part B and TMT part B/part A tests in patients from the hospital setting (group 1) and the community setting (group 2) depending on the location of the stroke (right/left hemisphere), 2013–2021, Łódź, Poland

Group	Location of the stroke				F	df	η^2	p[a]
	right hemisphere ($N_{group\ 1} = 15$, $N_{group\ 2} = 18$)		left hemisphere ($N_{group\ 1} = 30$, $N_{group\ 2} = 27$)					
	M	SD	M	SD				
TMT part B [s]					1.242	1.00	0.014	0.267
group 1	107.90	70.17	110.6	153.2				
group 2	16.84	31.86	59.35	64.61				
TMT part B/part A [s]					0.740	1.00	0.009	0.392
group 1	0.54	0.80	0.38	1.11				
group 2	0.03	0.98	0.17	0.99				

[a] $p < 0.05$.

ment in executive control measured with TMT part B turned out to be significant in all patients: with left hemisphere stroke patients rehabilitated in the hospital setting, with left hemisphere stroke patients rehabilitated in the community setting, with right hemisphere stroke patients rehabilitated in the hospital setting and with right hemisphere stroke patients rehabilitated in the community setting. However, as regards the TMT part B/part A parameter, only the right hemisphere stroke patients rehabilitated in the hospital setting showed significant progress. Also, patients with right-hemispheric stroke rehabilitated in the hospital setting improved their verbal executive functions in the largest number of VFT parameters compared to the other groups. Although right hemisphere stroke patients achieved greater progress in restoring executive functions, stroke location did not prove to significantly correlate with the effectiveness of the rehabilitation.

Depression may have played a role in achieving poorer results by the left hemisphere stroke group. Some researchers report that depression correlates positively with the degree of frontal dysfunction, mainly in terms of executive functions. Research by Nowakowska et al. [17], however, found no statistically significant relationship between the severity of executive dysfunction and the severity of depressive symptoms in stroke patients.

Patients with right-hemispheric stroke reported a stronger belief in having an executive function disorder compared to other patients; they also performed worse in tests. This result is in contradiction with results of other studies which did show correlation between damage to the right hemisphere and anosognosia, i.e., reduced awareness of one's own deficits and the consequential mood inadequate to the situation [18]. Other studies have shown that patients with right hemisphere brain injury are more likely to experience anxiety, anger, and depression than those with left hemispheric injuries. Negative emotions may appear despite limited insight into one's own deficits, or that anosognosia may occur to a partial extent [19]. According to Szepietowska [20], patients' subjective assessment of their executive dysfunctions may be explained by the that the right hemisphere participates in constructing the self, managing executive functions, and regulating emotions. Deficits in those areas disrupt emotional control strategies, which contributes to maintaining a high level of anxiety and a sense of cognitive deficits.

In Szepietowska's study [20], people with damage to the left hemisphere showed different results: the self-rating *Dysexecutive Questionnaire* (DEX-S) and item

Table 6. Improvement rates in Verbal Fluency Test (VFT) – the category test in patients from the hospital (group 1) and the community setting (group 2) depending on the location of the stroke (right/left hemisphere), 2013–2021, Łódź, Poland

Variable	Location of the stroke				F	df	η^2	p[a]
	right hemisphere ($N_{group\ 1}$ = 15, $N_{group\ 2}$ = 18)		left hemisphere ($N_{group\ 1}$ = 30, $N_{group\ 2}$ = 27)					
	M	SD	M	SD				
F-words [n]					0.437	1.00	0.005	0.510
group 1	2.50	2.62	3.20	2.24				
group 2	1.36	2.66	1.35	2.08				
A-words [n]					0.203	1.00	0.002	0.654
group 1	3.10	3.85	3.00	2.65				
group 2	1.44	3.92	2.00	2.00				
S-words [n]					0.001	1.00	0.000	0.982
group 1	2.30	3.49	2.53	2.50				
group 2	1.60	4.29	1.80	1.67				
ZW-words [n]					1.028	1.00	0.012	0.313
group 1	2.67	2.89	1.20	3.53				
group 2	1.04	3.80	1.10	3.71				
O-words [n]					0.085	1.00	0.001	0.781
group 1	2.60	3.43	2.60	2.38				
group 2	0.88	2.52	1.25	2.83				
W-words [n]					0.093	1.00	0.001	0.761
group 1	2.10	2.50	3.07	4.35				
group 2	0.20	3.06	1.60	3.57				

[a] $p < 0.05$.

results were low, as was the level of anxiety. Dysfunctions within the left hemisphere affect internal speech mechanisms thus disrupting cognitive flexibility and attention to verbal stimuli. The researcher claims that the low score in the subjective assessment questionnaire could have been influenced by impaired linguistic competences in the group with left hemisphere damage Slachevsky et al. [21], who also used the DEX-S questionnaire, showed that stronger complaints were reported by patients with injury to both hemispheres compared to patients with damage only to the left or right hemisphere [22].

Similarly, Van Rijsbergen et al. [23] revealed that the location and lateralization of stroke did not affect the patients' subjectively reported symptoms of executive dysfunctions.

Executive functions deficits that may appear in patients with different localization of the ischemic focus impact the treatment and rehabilitation process [24]. Forgetting or not understanding instructions given to the patient, lack of insight, disturbed awareness of the symptoms of the disease, impulsivity, and aggression make physiotherapy very difficult and often cause negative emotions on the part of doctors, therapists and other members of the rehabilitation team [25–27].

Executive function disorders are also a big challenge to the family and caregivers, as they experience permanent stress

and are forced to change their emotional ties, their lifestyle, or leisure time. Patients' attempts to return to professional activity usually fail [28–31]. The psychosocial consequences of impaired executive functions are sometimes more dramatic than motor problems and are the cause of permanent disability in people after stroke [32,33].
All things considered, it is important to properly diagnose and treat cognitive dysfunctions, including executive dysfunctions, which, as studies have shown, may occur in post-stroke patients with different localization of the ischemic focus [34–36]. In particular, patients with damage to the left hemisphere requires more attention when developing and implementing the rehabilitation protocol, because this group is marked by lower progress rates of treating impairments.

CONCLUSIONS

1. Right hemisphere stroke patients showed greater improvement in restoring executive functions after rehabilitation compared to left hemisphere stroke patients.
2. The location of the stroke did not significantly correlate with the efficiency of the rehabilitation setting.
3. Stroke patients with impaired executive functions require comprehensive neurorehabilitation.

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