doi: 10.14735/amcsnn2018269

Computer-based cognitive rehabilitation for cognitive functions after stroke

Počítačová rehabilitace kognitivních funkcí po cévní mozkové příhodě

The authors declare they have no potential conflicts of interest concerning drugs, products, or services used in the study.
Autoři deklarují, že v souvislosti s předmětem studie nemají žádné komerční zájmy.
The Editorial Board declares that the manuscript met the ICMJE "uniform requirements" for biomedical papers.
Redakční rada potvrzuje, že rukopis práce splnil ICMJE kritéria pro publikace zasílané do biomedicínských časopisů.

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Accepted for review: 27. 7. 2017
Accepted for print: 6. 3. 2018

Abstract
Aim: According to literature sources, cognitive dysfunction is one of the most common stroke-induced disorders. Despite the high number of cases of cognitive disorders after stroke, treatment options are still rather limited. The aim of this study was to assess the efficiency of cognitive training in individuals after stroke, in particular computer-based cognitive rehabilitation (CBCR) programmes. *Methods:* The analysis included studies where intervention of a CBCR programme was applied to subjects after stroke. We searched PubMed (Medline), Cochrane Database, and EBSCO for publications between January 2007 and July 2016. All the included studies were published in English. *Results:* Ten studies met the inclusion criteria. The included studies consisted of nine randomised controlled trials and one randomised pilot study. All the studies targeted general or domain-specific cognitive functions. The majority of the included studies resulted in the improvement of the assessed functional outcome measures. *Conclusion:* The overview conducted by the authors of this article allows us to claim that CBCR programmes may help to improve cognitive functions in subjects after stroke.

Souhrn
Cíl: Kognitivní dysfunkce je podle literárních pramenů jednou z nejčastějších poruch vyvolaných cévní mozkovou příhodou. Navzdory vysokému počtu případů kognitivních poruch po cévní mozkové příhodě jsou možnosti jejich léčby stále poněkud omezené. Cílem této studie bylo posoudit u osob po cévní mozkové příhodě účinnost kognitivního tréninku a zejména programů počítačové kognitivní rehabilitace (computer-based cognitive rehabilitation; CBCR). *Metody:* Do analýzy byly zahrnuty studie, ve kterých byl u subjektů po cévní mozkové příhodě použit některý z programů CBCR. V databázích PubMed (Medline), Cochrane Database a EBSCO jsme vyhledali publikace vydané od ledna 2007 do července 2016. Všechny zahrnuté studie byly publikovány v angličtině. *Výsledky:* Kritériím pro zahrnutí vyhovovalo deset studií. Zahrnuté studie tvořilo devět randomizovaných kontrolovaných studií a jedna randomizovaná pilotní studie. Všechny studie byly zaměřeny na obecné nebo doménově specifické kognitivní funkce. Výsledkem většiny zahrnutých studií bylo zlepšení hodnocených funkčních parametrů. *Závěr:* Přehled vypracovaný autory tohoto článku nám umožňuje konstatovat, že programy CBCR mohou u subjektů po cévní mozkové příhodě přispět ke zlepšení kognitivních funkcí.

Key words
stroke – cognitive dysfunction – cognitive training – computer-based training – computer therapy

Klíčová slova
cévní mozková příhoda – kognitivní dysfunkce – kognitivní trénink – trénink s využitím počítače – počítačová terapie

Introduction
Stroke is a leading cause of death and a source of persistent disability around the world [1]. One year after a stroke, 35% of patients are functionally dependent, indicating that stroke is a leading cause of disability [2]. Some of the patients remain disabled due to cognitive, psychosocial, and motor dysfunction, which limits their daily activity and working capacity. Stroke becomes a big burden both to patients and their caregivers. For example, a stroke can

result in various problems when performing activities of daily life, such as eating, clothing, bathing and moving, which event. leads to partial or complete dependence of a person who has suffered a stroke [3].

Stroke affects the cognitive domain, which involves attention, memory, language, and orientation functions [4]. Cognition is important for comprehensive recovery. Impairment of cognition reduces an individual's ability to plan and initiate autonomous activities, solve problems, sustain and divide attention, memorise information and understand task instructions [5]. Moreover, people after a stroke often experience emotional and behavioural changes: they may experience fear, anxiety, frustration, anger, sadness, and a sense of loss. Emotional disturbances after a stroke can have an influence on rehabilitation outcomes.

According to Bernhardt et al, early rehabilitation is widely regarded as an important feature of effective care of stroke patients [6]. The guidelines for Adult Stroke Rehabilitation and Recovery indicate that treatment gaps and future research directions identified include newer technologies, such as virtual reality, body-worn sensors, and communication resources, including social media [7]. One method proposed for optimising the effectiveness of therapy is the use of computerised cognitive rehabilitation training. Most cognitive rehabilitation programmes use a variety of activities, including those that require attention, planning or working memory with a pencil and paper, or computerised activities, and those that teach compensatory strategies [7]. Bahar–Fuchs et al suggest that cognitive training traditionally involves guided practice on a set of standardised tasks designed to reflect particular cognitive functions, such as memory, attention, or problem solving. Tasks may be presented in a paper and pencil format or may also be computerised [8].

As reported by Prigatano, it is necessary to constantly develop new techniques for the remediation of disturbed higher cerebral functioning, while still attending to the patients' personal experiences and helping them adjust to their neuropsychological deficits in the context of interpersonal situations [9]. According to the recommendations of evidence-based studies, computer-based interventions include active participation of a therapist to foster insight into cognitive strengths, and may be used as part of a multi-modal intervention for various cognitive deficits and weaknesses to develop compensatory strategies, and to facilitate the transfer of skills into real-life situations. Cognitive rehabilitation is effective in helping patients learn and apply compensations for residual cognitive limitations [10].

The guidelines of the European Federation of Neurological Societies indicate that the use of virtual environments has shown positive effects on verbal, visual, and spatial learning, and that memory training in virtual environments is rated as possibly effective (Level C recommendation) [11]. According to the 2015 update of the Canadian Stroke Best Practice Recommendations: Mood, Cognition and Fatigue Module, direct remediation/cognitive skills training should focus on providing intensive specific training to directly improve the impaired cognitive domain. The recommended methods include drill and practice exercises, mnemonic strategies or computer-based tools directed at specific deficits (evidence Level B) [12].

Cognitive rehabilitation interventions are usually classified into two methods. The first one is conventional cognitive rehabilitation, which usually consists of the performance of paper-and-pencil tasks and may therefore restrain cognitive training [5]. The second one is computer-based cognitive rehabilitation (CBCR) that provides standardised and structuralised training programmes, and allows users to adjust the degree of task difficulty to their individual cognitive levels [13]. CBCR enables an integrated and personalised cognitive rehabilitation training that simultaneously targets several cognitive domains, such as memory, attention, executive functions and visuospatial abilities in a more valid approach [5].

Technological innovations have resulted in computerised cognitive training and virtual reality cognitive training, which provide more cost-effective, accessible, flexible, and comprehensive interventions [14]. Such programmes are designed to address specific cognitive functions in people whose functions are impaired after brain damage due to a stroke. The choice of a specific computer programme depends on which hemisphere of the brain was damaged – left or right, cortical vs. subcortical – and on the level of cognitive impairment. In addition, it provides instant and direct feedback on the performance of the damaged area [15].

The aim of this study was to assess the efficiency of cognitive training with CBCR programmes for individuals who have suffered a stroke.

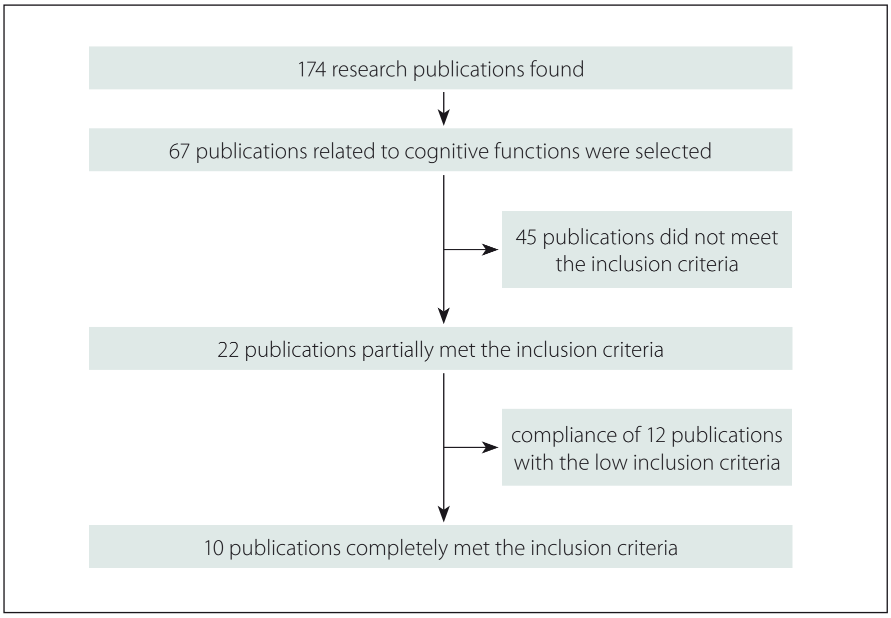

Fig. 1. Diagram of search strategy.
Obr. 1. Diagram vyhledávací strategie.

Methods

Independently selected studies for this systematic review were CBCR programme-related studies of stroke patients published between January 2007 and July 2016.

Mixed search methods were used, including computer-based and manual searches. Electronic databases included PubMed (Medline), Cochrane Database, and EBSCO, identifying key words and medical subject headings (MeSH terms). Population search terms were restricted to stroke and cognitive dysfunction, and intervention search terms included cognitive training, computer-based training, computer therapy, and computer-assisted cognitive rehabilitation.

The inclusion criteria for the studies were as follows: 1. participants were adults diagnosed with a stroke; 2. the intervention was a CBCR programme; 3. evaluation of cognitive functions was performed using standardised tests; and 4. the publication was in English. The exclusion criteria were as follows: 1. diagnosed dementia; 2. intervention was not CBCR programme training and did not target cognitive function;

Tab. 1. Overview of publications.

Author's	Title of journal (year)	Subjects/ participants	Type of stroke	Education	Action/intervention: Method	Action/intervention: Inclusion criteria	Action/intervention: Duration	Assessment	Cognitive domain (s) targeted	Results/key findings
Ressner et al [20]	Neurology& Neurophysiology (2014)	total N = 36 N = 15 ADG (M/F – 7/8) mean age 71.5 years N = 21 SG (M/F – 12/9) mean age 60.5 years	ischemic/ subacute/ /SG (11 in the left hemisphere, 3 – in the right hemisphere, 7 – in the both hemispheres)	+	NEUROP-4	ischemic stroke MMSE > 10	two periods of 1.5 h each week for 3 months	WAIS-III, MMSE, ACE-R, HADS	cognitive function	In the SG recorded significantly higher scores: IQc (median 84 before vs. 88 after; p = 0.001), IQv (83 vs. 92; p = 0.029), IQp (78 vs. 86; p = 0.001), VC (91 vs. 97; p = 0.017), PO (82 vs. 94; p = 0.001), SOP (71 vs. 8; p = 0.0003), ACE-R (79 vs. 84; p = 0.01). In the ADG only the ACE-R was increased (75 vs. 83; p = 0.008).
Park et al [13]	Journal of Physical Therapy Science (2015)	total N = 30 EG = 15 (M/F – 6/9) mean age 64.7 (8.9) years CG = 15 (M/F – 8/7) mean age 65.2 (8.0) years	unknown/ acute	–	CoTras	no more than one stroke K-MMSE ≤ 23 ability to understand instructions without unilateral hemispatial neglect and hemianopsia	30 min 5×/week, 20 sessions for 4 weeks	LOTCA, MVPT-3	cognitive function; visual perception	After treatment, the LOTCA and MVPT scores, measuring the cognitive function of both groups significantly increased (p < 0.05) and there was a statistically significant difference between both groups at the end of treatment (p < 0.05).
Westerberg et al [16]	Brain Injury (2007)	total N = 18 EG = 9 (M/F – 8/1) mean age 55.0 (8) years CG = 9 (M/F–4/5) mean age 53.6 (8) years	infarct (CG = 7, EG = 3), hemorrhage (CG = 2, EG = 6)/ chronic	+	Robo Memo from Cogmed	ages 30–65 self-reported deficits in attention stroke documented	40 min 5×/week for 5 weeks	neuropsychological tests: WAIS R-NI, Claeson-Dahl, WAIS R, Raven's progressive matrices, Word list delayed recall, PASAT version A, RUFF 2&7, CFQ	working memory	Statistically significant training effects were found on the non-trained tests for WM and attention, i.e., tests that measure related cognitive functions but are not identical to tasks in the training program (Span board p < 0.05; PASAT p < 0.001; Ruff 2&7 p < 0.005). There was a significant decrease in symptoms of cognitive problems as measured by the CFQ (p < 0.005).

Tab. 1 – continuing. Overview of publications.

Author's	Title of journal (year)	Subjects/ participants	Type of stroke	Education	Action/intervention: Method	Action/intervention: Inclusion criteria	Action/intervention: Duration	Assessment	Cognitive domain (s) targeted	Results/key findings
Kang et al [18]	Clinical Rehabilitation (2009)	total N = 16 EG = 8 mean age 59.5 (10.7) years CG = 8 mean age 62.5 (9.6) years	infarct, hemorrhage (in b. MCA dex.)/ chronic	–	EG-CAM-SHFT algorithm; CG-PssCog Rehab	left hemiplegia MMSE > 18 MVPT < 109	30 min 3×/ week for 4 weeks	MMSE, Motor-free Visual Perception Test, Modified Barthel Index (K – MBI)	visual perception	After training the mean (SD) Motor-free Visual Perception Test score increased significantly in both group (EG – from 65.8 [19.5] to 77.8 [28.7], CG – from 68.3 [11.4] to 74.1 [14.8]; p < 0.01). Modified Barthel Index increased significantly in both groups, with the EG recording a higher increase. Mean (SD) interest scale score was greater in the EG (2.2 [0.8]) than in CG (1.3 [0.7]), p < 0.01.
Park et al [15]	Journal of Physical Therapy Science (2015)	total N = 20 CG = 10 (M/F – 5/5) age 60–89 years EG = 10 (M/F – 4/6) age 60–89 years	ischemic (CG = 4, EG = 8), hemorrhage (CG = 6, EG = 2)/ chronic	–	CG-PssCog Rehab, EG-repetitive transcranial magnetic stimulation (rTMS)	left hemiplegia K-MMSE ≤ 23	20 min 3×/week for 4 weeks	K- MMSE, LOTCA-G	cognitive function	The cognitive functions of both groups significantly improved after intervention. In the LOTCA-G score in CG was more significant than in EG (p < 0.05), no significant difference was found in the K--MMSE scores (p > 0.05). In the CG significant improvements were shown in the details of the LOTCA-G, including perception, visuomotor organization, memory, attention (p < 0.05).
Zucchella et al [17]	Functional Neurology (2014)	total N = 87 CG = 45 (M/F – 23/22) mean age 70 (62.5; 76.5) years EG = 42 (M/F – 23/19) mean age 64 (56.2; 74.2) years	ischemic, hemorrhage/ /acute left hemisphere (CG = 14, EG = 12) right hemisphere (CG = 27, EG = 18), bilateral (CG = 1, EG = 1), brain stem (CG = 3, EG = 8), cerebellum (CG = 0, EG = 3)	+	„Una palestra per la mente“ (Gollin, 2011), „Training di riabilitazione cognitiva“ (Powell ir Malia, 2009)	first-ever stroke age 45–80; MMSE > 10	1 h 4×/week for 4 weeks	neuropsychological tests: Digit Span and Corsi's Test, RAVLT, 47-PM47, FAB, TMT-A, TMT-B, Attentive Matrices, Rey-Osterrieth, AAT, HDRS, MMSE,FIM	cognitive function	In the EG, significant improvements (p < 0.05) were detected in all neuropsychological measures at the post-training evaluation, while the CG showed mild (not statistically significant) improvements on cognitive tests. Between-group analysis revealed statistically significant differences in the domains of memory and visual attention.

Tab. 1 – continuing. Overview of publications.

Author's	Title of journal (year)	Subjects/ participants	Type of stroke	Education	Action/intervention: Method	Action/intervention: Inclusion criteria	Action/intervention: Duration	Assessment	Cognitive domain (s) targeted	Results/key findings
Cho et al [3]	Journal of Physical Therapy Science (2015)	total N = 25 CG = 13 (M/F – 9/4) mean age 63.7 ± 6.3 years EG = 12 (M/F – 7/5) mean age 60.0 ± 4.7 years	unknown/ chronic left hemisphere (CG = 5, EG = 3) right hemisphere (CG = 8, EG = 9)	+	Reha Com	MMSE 18–23 able to follow verbal instructions	30 min 2×/week for 6 weeks	QEEG-8, computerized neurocognitive function test (CNT)	memory, attention	After the intervention, the EG group showed significant differences in the frontal lobe (Fp1, Fp2, and F4) and in the parietal lobe (P3 and P4), and also showed significant differences in CNT memory (DST and VST forward/backward test) and attention (VCPT correct responses), but no notable changes were observed in the CG.
Yoo et al [22]	Journal of Physical Therapy Science (2015)	total N = 46 CG = 23 (M/F – 9/14) mean age 56.3 ± 7.9 years EG = 23 (M/F – 8/15) mean age 53.2 ± 8.8 years	unknown/ chronic	–	Reha Com	unknown	30 min 5×/week for 5 weeks	the computerized neuropsychological test (CNT), FIM	cognitive function	After 5 weeks of therapy, the EG presented statistically significant improvement in cognitive function assessment items of digit span, visual span, visual learning, auditory continuous performance, visual continuous performance, and others compared with the CG but did not present statistically significant improvement in activities of daily living.
Prokopenko et al [21]	Journal of the Neurological Science (2013)	total N = 43 CG = 19 (M/F – 10/9) mean age 66 (61; 69) years EG = 24 (M/F – 13/11) mean age 61 (57; 69) years	unknown/ acute	+	„U.M. N.I.K. 2011–2012"	MMSE > 20 medically stable not aphasia	30 min 7×/week for 2 weeks	MMSE, FAB, the Clock Drawing Test, MoCA, Shultes's Test, IADL, SSQL, HADS	cognitive function	It was noted significant improvement of cognitive function according to MMSE, FAB, Clock drawing test, Schulte's test, and MoCA (p < 0.01) in the EG, while all the tested parameters in the CG were not changed (p > 0.06) after the treatment course. We did not find significant changes in the IADL and the SS-QOL2. Degree of anxiety and depression after completing the therapy has not changed significantly in both groups.

Tab. 1 – continuing. Overview of publications.

Author's	Title of journal (year)	Subjects/ participants	Type of stroke	Education	Action/intervention: Method	Action/intervention: Inclusion criteria	Action/intervention: Duration	Assessment	Cognitive domain (s) targeted	Results/key findings
Kim et al [19]	Annals of Rehabilitation Medicine (2011)	total N = 28 CG = 13 (M/F – 6/7) mean age 62.0 ± 15.8 years VRG = 15 (V/M – 5/10) mean age 66.5 ± 11.0 years	ischemic (CG = 9, VR = 12), hemorrhage (CG = 4, VR = 3)/ left hemisphere (CG = 5, VR = 6) right hemisphere (CG = 8, EG = 9)/ acute	–	VRG = IREX system + ComCog CG = ComCog	K-MMSE 10–24 not aphasia able to follow verbal instructions good sitting balance	VRG: IREX system 30 min 3×/week and ComCog 30 min 2×/week CG: ComCog 30min 5×/week All for 4 weeks	computerized neuro psychological Test (CNT, MaxMedica), TOL, K-MBI, MI, K-MMSE	cognitive function	After rehabilitation the VRG showed significant improvement in these tests: K-MMSE, CPT, DST, VST, TOL, K-MBI, MI, while the CG showed significant improvement in K-MMSE, DST, TMT-A, TOL, K-MBI, MI scores. The changes in the VCPT and BVST in the VRG after rehabilitation were significantly higher than those in the CG.

47-PM47 – Raven's Colored Progressive Matrices; AAT – Aachener Aphasie Test; ADG – Alzheimer disease group; ACE-R – Addenbrooke's Cognitive Examination, revised; BVST – Backward visual span test; CAMSHIFT – continuously adaptive mean shift algorithm (a computerized visual perception rehabilitation programme with interactive patient – computer interface for visual perception training); CFQ – Cognitive Failure Questionnaire; CG – control group; CNT – computerized neurocognitive function test; CPT – Continuous performance test; DST – Digit span test; EG – experimental group; F – female; FAB – Frontal Assessment Battery; FIM – Functional Independence Measure; HADS – Hospital Anxiety and Depression scale; HDRS – Hamilton Depression Rating Scale; IADL – The Lawton Instrumental Activities of Daily Living Scale; IQc – IQ score global; IQv – IQ score verbal; IQp – IQ score performance; K – MMSE – Korean Mini-Mental State Examination; LOTCA – Loewenstein Occupational Therapy Cognitive Assessment; LOTCA-G – Lowenstein Occupational Therapy Cognitive Assessment–Geriatric Version; M – male; MI – Motricity Index; MMSE – Mini-Mental State Examination; MoCA – Montreal Cognitive Assessment; MVPT-3 – Motor – free Visual perception Test-3; PASAT version A – Paced Auditory Serial Addition Test version A; PO – Perceptual organization; PssCogRehab – Cognitive Rehabilitation Therapy System (Psychological Software Service, USA); QEEG-8 – Quantitative Electroencephalograph measure; RAVLT – Rey Auditory Verbal Learning Test; RUFF 2&7 – Ruff 2 & 7 Selective Attention Test; SG – stroke group; SOP – Speed of processing; SS-QOL2 – Stroke Specific Quality of Life Scale; TMT-A – Trail making test – type A; TMT-B – Trail making test – type B; TOL – Tower of London test; VC – Verbal comprehension; VCPT – Visual continuous performance test; VRG – virtual reality group; VST – Visual span test; WAIS-III – Wechsler Adult Intelligence Scale; WAIS R – Wechsler Adult Intelligence Scale-Revised; WAIS R-NI – Wechler Adult Intelligence Scale – Revised NI; WM – working memory

3. no neurocognitive or functional outcome measures were included; and 4. full texts of articles were not available.

Results

The search that we carried out returned 174 results. After performing a thorough screening according to selected key words, 67 articles that analysed cognitive functions were selected. Overall 45 articles out of these 67 were rejected because they did not meet the inclusion into the study criteria. This was performed by reviewing them and making a decision depending on the title and abstract of hit articles. After detailed evaluation of the remaining 22 articles, 12 more were rejected because they did not specify the methodology of the application of computer-based programmes. At the end of the screening process, a total of 10 articles that could be easily accessed met the study criteria and were included in the final review (Fig. 1). CBCR, virtual reality, non-invasive brain stimulation programmes were used in stroke survivors. Various researchers evaluated the effect with standardised assessment tools. The included studies consisted of nine randomised controlled trials and one randomised pilot study. The detailed results of the conducted overview are presented in this paper.

The total number of the subjects of our overviewed studies was 349; 177 of them used CBCR programmes for cognitive rehabilitation, and 172 were subjects in control groups (with other intervention methods or conventional rehabilitation used for their rehabilitation). The smallest number of subjects in the analysed studies was 16 and the highest was 87 subjects. Their age ranged from 34 to 89 years. Five studies targeted patients with acute/subacute stroke, and the remaining five included patients with chronic stroke (> 5 months). Various studies of CBCR programme influence on cognitive functions at acute or chronic stroke stage showed that there was substantial improvement of cognitive functions in experimental groups. Only in the study by Zucchella et al there was significant difference in memory and visual attention between the two groups [17]. The majority of the studies that we looked at indicated the type of stroke analysed – both ischemic and hemorrhagic stroke were analysed in five studies [15–19], and only ischemic stroke was analysed in one study [20]. Four analysed studies reported on stroke in general, regardless of its type. All the studies recorded the age and gender of their subjects; however, five of them also indicated the length of education in years. An overview of all the studies covered by our research is presented in Tab. 1.

The analysed studies used the following CBCR programmes: NEUROP – 4, CoTras (Netblue Co., Ltd, Daegu, Korea), Cogmed (Cognitive Medical System AB, Stockholm, Sweden), PssCogRehab (Psychological Software service, Indianapolis, USA), Una palestra per la mente (Gollin, 2011), Training di riabilitazione cognitive (Powell and Malia, 2009), RehaCom

(Hasomed GmbH, Magdeburg, Germany), U.M.N.I.K. 2011–2012, ComCog, IREX system® (Vivad group, Toronto, Canada), and CAMSHFT. Treatment sessions and periods varied among studies (Tab. 2). Interventions were implemented for 4–6 weeks in most of the studies (N = 8). The duration of one analysed study was 2 weeks [21], and other studies lasted for 12 weeks [20]. The shortest intervention of a CBCR programme applied was 60 min per week, and the longest 240 min per week. The duration of programme application over the entire rehabilitation period ranged between 240 and 1,080 min.

Tab. 2. CBCR program intensity and duration.

N = 10	Max. intensity per week (min)	Program duration (week)	Max. intensity in study period (min)
Ressner et al 2014 [20]	90	12	1080
Park et al [13]	150	4	600
Westerberg et al [16]	200	5	1000
Kang et al [18]	90	4	360
Park et al [15]	60	4	240
Zucchella et al [17]	240	4	960
Cho et al [3]	60	6	360
Yoo et al [22]	150	5	750
Prokopenko et al [21]	210	2	420
Kim et al [19]	150	4	600

CBCR – computer-based cognitive rehabilitation

In order to evaluate the cognitive functions of subjects, 7 studies used the Mini-Mental State Examination, 5 studies used different Neuropsychological Tests Batteries, and 2 studies used Montreal Cognitive Assessment or Loewenstein Occupational Therapy Cognitive Assessment. Some studies also employed Activity Daily Life (ADL) assessment, Functional Independence Measure (N = 3), and Modified Barthel Index (N = 2), and 1 study used the IADL scale. Other assessment tools were also used; they are listed in Tab. 1. All the studies targeted general or domain-specific cognitive functions, including attention, execution function, general cognition, language, memory, processing speed, visuospatial ability, verbal fluency, working memory, and visual perception. General cognitive functions were analyzed in 7 studies, memory in 2 studies, visual perception in 2 articles, and attention was the focus of only 1 article. All the analysed studies had inclusion and exclusion criteria, determined as well as experimental, and control groups involved. In 7 studies, traditional rehabilitation was applied to subjects of control groups. In 3 other studies, the cognitive functions of control subjects were trained using a CBCR programme, and the results achieved were compared with the data of experimental groups where cognitive functions were trained using other interactive technologies [15,18,19]. A CBCR programme was applied in subjects of experimental groups in 7 studies; subjects of control groups were administered traditional rehabilitation measures [3,13,16,17,20–22].

Discussion

Cognitive function is an important parameter which may help to establish the prognosis of the damage caused by stroke, and which determines the quality of a patient's subsequent life [15]. Preliminary evidence from literature on this topic suggests that cognitive impairment can increase disability and indirectly affect functional recovery after stroke as a result of reduced participation in rehabilitation and poor adherence to treatment guidelines [23]. The shortage of rehabilitation providers and resources in different countries has limited the provision of adequate and appropriate rehabilitation services to stroke survivors [24]. Novel strategies are becoming available to overcome the modest benefits of conventional rehabilitation [14]. Various CBCR programmes have been developed to treat different areas of cognitive impairment.

This systematic review evaluated studies that assessed the efficiency of CBCR programme interventions aimed at improving cognitive function in individuals after stroke. The strengths and limitations of these studies are discussed to understand their application in practice and to learn about the research design for future studies assessing the effectiveness of CBCR in patients after stroke.

The results of these studies reveal that CBCR is effective for recovery of cognitive functions in stroke patients who present cognitive impairment and who would be expected to have a quicker rehabilitation [3,13,20,22]. After conducting a study, Ressner et al claim that brain plasticity is probably crucial for successful CBCR, and one might anticipate a greater effect of CBCR in patients with acute demarcated brain lesions (as in stroke) than in patients with a diffuse neurodegenerative disorder [20].

In all the studies that met our inclusion criteria, the influence of CBCR in patients after stroke with mild cognitive impairment was reviewed. The majority of the analysed studies assessed only general cognitive functions, and only a few were dedicated to the analysis of separate cognitive functions (memory, working memory, attention, space perception). Some studies showed that a specific CBCR programme may contribute toward the recovery of visual perception [13,18]. Several trials revealed statistically significant differences between groups in the domains of memory and visual attention [3,17,19]. Some studies suggested that the loss of attention after stroke could interfere with the recovery of other cognitive functions [3,17,19,21]. Zucchella et al discussed that rehabilitation of mild cognitive impairment is usually based on the retraining method, which demonstrates positive effects particularly in the domain of attention [17]. Participants of the reviewed studies using a CBCR programme demonstrated significantly greater improvements compared with participants using conventional cognitive rehabilitation on aspects such as memory, attention, visual perception, and executive functioning.

As noted by researchers, future studies should focus not only on how general cognitive capacity changes in the course of the study, but should also distinguish and analyse in detail cognitive functions – memory, attention, space perception etc. [13,18]. As other researchers on the topic have indicated, sample size of studies should be greater, and it is necessary to conduct studies with subjects classified by post-onset duration of stroke, damaged area, and cognitive function [22]. A number of studies in rehabilitation apply interventions that develop cognitive functions in chronic patients; however, some authors claim that CBCR programmes applied in the early stage after stroke may produce an expected optimal benefit and guarantee faster recovery of cognitive functions [13,17]. According to Kim, the priorities at the acute care unit are both diagnostic as well as therapeutic interventions. Depending on medical conditions (hemorrhagic or non-hemorrhagic lesion, size and site of stroke, underlying health status), treatment options are determined. It is suggested that early rehabilitation intervention is necessary even if a diagnostic or therapeutic plan is not completed. At this phase, rehabilitation starts with a less intensive approach [25].

The risk of post-stroke cognitive impairment is related to both the demographic factors such as age, education and occupation, and to vascular factors [26]. Many studies have demonstrated that higher levels of intelligence as well as of educational and occupational attainment are good predictors of which individuals can sustain greater brain damage before demonstrating functional deficit. Rather than suggesting that the brains of these individuals are grossly anatomically different from those with less reserve (e.g. they have more synapses), the cognitive reserve hypothesis posits that they process tasks in a more efficient manner [27]. In all reviewed studies research subjects were divided by gender and brain damage localisation, but the effect of CBCR programme was not discussed with respect to these parameters. On the other hand, Gottesman and Hillis argued that gender differences in the distribution of cognitive dysfunction after stroke might be attributable to differences in stroke mechanisms between men and women [28]. The role of the gender of patients in recovery after stroke is contradictory. According to some studies, female patients need rehabilitation programmes to focus more on improving their physical functioning and to diagnose and treat depression because of gender disparities in recovery and outcomes after stroke [29].

Research where changes in cognitive functions were analysed applying a CBCR programme in combination with another intervention for developing cognitive functions (CAMSHFT algorithm, IREX system) shows that virtual reality training combined with CBCR may be of additional benefit for treating cognitive impairment in stroke patients [18,19].

In the analysed studies, the majority of subjects were middle or older age. There is a stereotype in society that individuals of these age groups struggle in performing tasks with computers. However, Zucchella et al in their 2014 study found that compliance with the programme was generally high, even among older patients less familiar with computers; the computer interface was very simple and user-friendly and, instead of being a limiting factor, might have made the treatment more pleasant and motivating for patients, as suggested by the satisfaction score, which was significantly higher in the study group [17].

Our results show that a variety of computer programmes for developing cognitive functions exists. The duration and intensity of their application is different. The majority of the studies analysed reported a similar duration of intervention (4–6 weeks), and only in one study was the CBCR programme applied for 3 months [20]. Prokopenko et al conducted a study where a CBCR programme was applied for only 2 weeks [21]. There is a lack of detailed guidelines in the analysed literature that would define the optimal intensity and duration of application of each computer programme in case of different disorders. The overview performed as part of our research demonstrates that some studies applied the same computer programme of different intensity – 2–5× per week and 240–1,080 min in total time [3,22].

In order to evaluate the continuity of performed studies, reports on the repeated assessment of cognitive functions a few months following rehabilitation are insufficient in the majority of analysed studies. Only Ressner et al claim to have planned a repeated assessment of subjects after one year [20]. The majority of analysed studies comprised small sample sizes of subjects (only two studies had more than 20 subjects per group [17,22]), which was probably a result of adhering to strict inclusion into/exclusion from a study's criteria. The studies emphasize that due to small sample size it is difficult for them to prove the effectiveness of new programmes. None of the studies reported an a priori sample size calculation to determine the sample size needed to reveal clinically significant effects.

Conclusions

The conducted systematic overview of 10 selected studies allowed us to identify the efficiency of CBCR programme intervention for improvement of cognitive functions in subjects after stroke. Current evidence regarding effectiveness of these interventions for improvement of cognitive functions in subjects after stroke is limited. The majority of the studies analysed in this research project indicated that such interventions might contribute to improvement of cognitive function, especially attention concentration and memory. However, not all the studies reported to have observed a significant difference between the study groups.

The most common limitations in the conducted studies are the following: too small sample size; separate cognitive functions (subcategories) are recommended for analysis; interventions are suggested to be delivered in the early stages of stroke; monitoring of performed interventions is needed after some time (continuity); the age range of subjects is too broad; and the chosen research instruments are inappropriate. However, this overview provides basic information necessary to promote the implementation of new, innovative technologies in rehabilitation and further application of computer-based interventions. By analysing different studies of other researches in the field, our team was trying to find out if these CBCR programmes have standardised application guidelines that would define the uniformity of their application for patients after stroke. After performing this analysis, we are planning to carry out a study during which a CBCR programme will be applied to patients after a stroke.

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