Original Papers

Polish Psychological Bulletin
2013, vol. 44(1), 31-39
DOI -10.2478/ppb-2013-0004

*Emilia Łojek**
*Anna Bolewska**

The effectiveness of computer-assisted cognitive rehabilitation in brain-damaged patients[1]

Abstract *This study examined the effects of computer-assisted cognitive rehabilitation in a group of 16 brain-damaged patients. Therapeutic effectiveness was assessed by improvement on computer tasks, the results of neuropsychological tests and quality of life ratings. Participants suffered from mild to moderate attention and memory problems or aphasia. The procedure involved baseline assessment (pretest), a 15-week course of therapy conducted twice a week (30 hours in total) and posttest. Neuropsychological tests assessing attention, memory and language problems and quality of life ratings were administered twice: in pre- and posttests. Twelve healthy controls were also examined twice (with a 15-week interval) using the same battery of neuropsychological tests. The RehaCom program and the Polish computer therapy program for aphasics called Afa-System were used for rehabilitation. The computer-assisted rehabilitation tasks were selected individually for each patient. The results showed significant improvement on computer-assisted tasks in all brain-damaged subjects. However, none or very little improvement was observed on neuropsychological tests and quality of life ratings. The results of the study confirm the importance of using different types of measures to estimate the effectiveness of computer-assisted neuropsychological rehabilitation as well as the necessity of applying various kinds of therapy to improve cognitive, emotional and social functioning in brain-damaged patients.*

Key words: *neurocognitive rehabilitation, computer-assisted therapy, effectiveness*

Introduction

Technological progress is changing our lives. It is also exerting a powerful effect on neuropsychological diagnosis and rehabilitation, whose purpose is to provide psychological assistance to patients with higher psychological functioning impairment due to brain damage. Neuropsychological rehabilitation of brain-damaged patients is very time-consuming, laborious and expensive, and does not always produce the effects desired by the patient, his/her family and society. Computer-assisted neuropsychological rehabilitation therefore raises many hopes and expectations. At the least, it is viewed as a source of support and supplementation of existing, imperfect methods of treatment, and also as a way to reduce the unforeseen costs and time-consuming nature of rehabilitation of patients with brain lesions (Cole, 1999; Gontkowsky et al., 2002; Seniów, 1999).

Two approaches have been distinguished in neuropsychological rehabilitation using electronic equipment: compensation and reconstruction. Within the compensatory approach various electronic devices such as pagers, palmtops, organizers or communicators function as “cognitive prostheses” to ease patients’ everyday functioning. They are maximally adjusted to the individual patient’s needs, but do not fundamentally alter the status of cognitive functions. The reconstructive approach to neuropsychological rehabilitation applies a range of computer software whose purpose is to improve higher psychological functions such as language, memory, attention, spatial orientation, abstract thinking and planning (LoPresti, 2004).

There are various forms of computer-assisted neuropsychological rehabilitation. In the early days, computer games and educational software addressed to children were used in work with adult brain-damaged patients (in the 1970s and 1980s). Such games are poorly adapted to

*** Faculty of Psychology University of Warsaw**
[1] The study was supported by grants at the Faculty of Psychology, University of Warsaw (BST 161 500/17, BST 161500/5).

patients' needs, however, due to the specific nature and content of the tasks involved and their level of difficulty. The first specialist computer software aimed at rehabilitation of individual patients with specific cognitive deficits, e.g. naming dysfunctions, began to be developed (Bruce & Howard, 1987; Pluta & Rączaszek-Leonardi, 2008). Interdisciplinary specialist working groups consisting of neuropsychologists, speech therapists and IT engineers also began to construct more elaborate commercial software to assist in neuropsychological rehabilitation of a range of cognitive abilities.

Some of this software now has several language versions, and some has been specifically developed to meet the needs of a specific country and language. These include, to name a few: *Cogpack* – software which trains a variety of cognitive functions and has an English, French and German version; *RehaCom* – which also has several language versions and is addressed to several functions; the German *Lernreha*, French *Aix Tent* and American *Brain-Train Falconer*. Such software is usually published in two versions, one for the therapist and one for the patient. Basing on the diagnosis, the therapist selects an appropriate program and level of difficulty, which the computer then automatically adjusts to the patient. The patient can practice on his/her version at home. The following software is available in Poland: an incomplete adaptation of *RehaCom*, without the language exercises (Weber, Regel & Krause, 1999) and *Afa-System*, a Polish rehabilitation program developed by E. Paprot, K. Polanowska and J. Seniów for patients with aphasia (Seniów, 2009).

Some individual and commercial rehabilitation software is based on virtual reality which reflects a particular patient's world (Hofman et al., 1996) or has assumed references to everyday situations (Hofman et al., 2003). The Internet is also used increasingly frequently in computer-assisted rehabilitation to facilitate patient-therapist communication (Egan et al., 2004; Mortley, Wade & Enderby, 2004). Therapeutic material or computer assignments are first prepared traditionally and then sent to the patient's personal computer. Telerehabilitation enables work with patients to be continued after discharge from hospital, wherever patients live. It reduces the cost of treatment, enables the therapist to work with a larger number of patients and also improves quality of life (Rogante et al., 2010; Zheng et al., 2005). This method is not without its drawbacks, however. There is no personal patient-therapist interaction and considerable patient self-control is necessary. On the other hand, neurobiotechnological expansion is now enabling direct stimulation of the brain, and brain-computer interfaces are offering new ways in which patients can communicate with the world.

Although computer-assisted neuropsychological rehabilitation is now being applied in the Polish health service, there is still relatively little published research in the Polish literature. A few general outlines of this subject and one or two case studies are worth mentioning (Jodzio, 2011; Otfinowski et al., 2006; Pąchalska, 2007; Pluta & Rączaszek-Leonardi, 2008; Seniów, 1999; Seniów et al., 2003). Polish specialists trained in the schools of Alexander Luria and Mariusz Maruszewski are using computer-assisted rehabilitation programs in addition to other therapeutic aids and materials which can be individually selected and adjusted for difficulty, but it is up to the therapist to select treatment methods (Seniów, 2009).

With the increase in popularity of computer-assisted rehabilitation methods there is also an increasing need to test the effectiveness of these interventions in comparison with other therapies and to evaluate them vis-ŕ-vis various aspects of patients' lives.

Evaluation of the effectiveness of neuropsychological therapies

The World Health Organization's International Classification of Functioning, Disability and Health (IFC) distinguishes three basic levels of description and evaluation of patients' health (cf. Wilmowska-Pietruszyńska & Bilski, 2010). The first level applies to the patient's physical condition, and the structure and function of the body organs. The second level applies to the patient's psychological functioning, i.e. individual activity. The third level applies to the patient's social functioning, i.e. participation in social life. Applying this classification to a hypothetical brain-damaged patient we may say that as a result of a stroke he has a left-hemisphere brain lesion and right-side paralysis (physical effects), severe language and memory impairment and mood disorder (psychological effects), and due to his physical and psychological dysfunction he has had to stop working and claim disability benefits (social effects). We need to evaluate each of these levels of functioning, and the goal of rehabilitation is to return to optimal health in all three aspects to the extent within this particular patient's grasp.

These three aspects are not always considered in evaluations of the effectiveness of neuropsychological rehabilitation and are not always the target of therapeutic intervention. When diagnosing patient functioning, neuropsychologists usually limit themselves to descriptions of impaired and intact functions, basing on the results of specialized tests or clinical trials. When discussing this issue, Barbara Wilson (2002, 2007) argues that three types of effectiveness of neuropsychological rehabilitation should be evaluated: a) economic – the various costs of rehabilitation which may give a hundred-percent return if the patient is able to resume work thanks to therapy, b) clinical – cognitive functioning, and c) quality of life. It has been empirically demonstrated that improvements in each of these domains of neuropsychological rehabilitation can be effective (Cicerone et al., 2005; Klonof et al., 2006; Wood et al., 1999).

In neuropsychological rehabilitation, the choice of research designs enabling evaluation of therapeutic effectiveness is itself problematic. Cicerone et al. (2000, 2005,

2011) reviewed the literature on the neuropsychological rehabilitation of injury survivors to check the methodological soundness of the reported research. They reviewed 258 articles and divided them into three groups according to their methodological soundness. The most methodologically watertight group (46 articles) presented research using prospective, randomized controlled trials. The next group (43 articles) reported prospective cohort studies, retrospective case-control studies or clinical series with well-designed controls. The largest group (169 articles) contained methodologically poor articles presenting clinical series without concurrent controls, or studies with single-subject methodology. Information on the effectiveness of rehabilitative interventions in these studies was usually limited to cognitive functions – the greatest rehabilitative effectiveness is observed for speech and perception, then praxis, memory and attention. A number of interventions are either ineffective, or data on therapeutic effectiveness is missing for various aspects of patients' lives. This critique applies equally to computer-assisted neuropsychological rehabilitation (Cicerone, 2000, 2005; Wertz & Katz, 2004; Pąchalska, 2008).

In contrast to everyday clinical practice, research on computer-assisted neuropsychological rehabilitation is largely based on the following scheme: pretest – therapy – posttest. Depending on a study's objectives, therapy outcomes can also be compared with outcomes of patients not undergoing therapy (e.g. waiting for therapy), participating in other kinds of rehabilitation, or healthy controls. Several areas in which the effects of computer-assisted neuropsychological rehabilitation can be observed have been identified. As in other forms of neuropsychological therapy, improvement can be observed in the practised function (constructive effect), as well as in competencies other than the practised ones; for example, attention processes are rehabilitated and a positive effect is also noted for memory (generalization effect) or for everyday functions or occupational responsibilities (real effect). Below is a short review of the available research, showing the methodology and outcomes of computer-assisted rehabilitation.

Cherney et al. (2006) studied 13 patients with nonfluent aphasia who worked with the *Oral Reading for Language in Aphasia ORLA* computer software for six weeks. Changes in language function were assessed with the Western Aphasia Battery. Improvement in successive ORLA tasks and in aphasia tests was found. The more intensive the therapy, the greater the improvement.

Sing Fai et al. (2004) evaluated four different computerized memory trainings in 26 patients with post-traumatic aphasia. Memory was diagnosed with the *Riverhead Behavioural Memory Test*. Considerable improvement was found in memory functions and there were no differences between the four computer-assisted therapies.

Doesborgh (2004) used the *Multicue* computer software to generate semantic cues to help word actualization in the therapy of eighteen patients with amnestic aphasia. Eight of these patients took part in a 10-hour training series using *Multicue* and ten participated in traditional aphasia therapy. Next, both groups were tested with the Boston Diagnostic Aphasia Examination. Only patients who had used *Multicue* showed improved picture naming. The results of this study may suggest that computer-assisted therapy could be even more effective with some patients than traditional therapy, due to such factors as greater patient interest or involvement.

Our analysis of the research on the effectiveness of computer-based interventions clearly shows, however, that traditional therapy based on the patient-therapist relationship is extremely important, and that it is very inadvisable to conduct computer-based therapy which is not substantively directed and supported by the therapist (Cicerone et al., 2005).

Wertz and Katz (2004) analysed the effect of computer-based reading training on functional language efficiency in patients with aphasia. Fifty-five patients participated in this research project. They were divided into three groups. Each group participated in a different form of rehabilitation activity. The first group used a computerised rehabilitation software, the second group participated in a general cognitive stimulation intervention and the third (control) group had no neuropsychological rehabilitation. A language function test revealed improvement in five language functions in the first group, one language function in the second group and no improvement in the third group. The rehabilitation effect in the first group generalized to spontaneous communicative skills in spoken language.

Lundqvist et al. (2010) used computer-assisted therapy to practice working memory in brain-damaged patients. Twenty-one patients were treated for five weeks. Memory functions were assessed prior to therapy and again at four and twenty weeks after termination of rehabilitation by means of neuropsychological tests (including PASAT and the Stroop test). Participants also completed a questionnaire concerning quality of life and health. The patients showed improvement on computer exercises, neuropsychological tests and overall health ratings, but not on quality of life ratings.

Ranstroom (2011) demonstrated that computer-assisted neuropsychological rehabilitation can in fact have tangible effects. They used the *Stimulation – Activation – Training Programme* to rehabilitate speech in patients with Alzheimer's disease (AD). Five patients with moderate AD participated in this computer-assisted therapy for 12 months. They practised writing, counting, naming and understanding the meaning of words, and dialogic speech. The computer tasks were constructed so as to imitate everyday situations. Language skills were assessed by means of independent, standardized neuropsychological tests. Results improved significantly, and the patients accepted working with a computer as an interesting novelty. Everyday language functioning also improved. The experienced therapist who worked with the patients also conducted qualitative (nonstandardized) ratings of patients' communication skills.

There are still relatively few reports in the literature of systematic evaluations of various aspects of functioning in patients undergoing neuropsychological rehabilitation. Also, the results of existing research show that rehabilitation outcomes may differ somewhat depending on which aspect of patient functioning is assessed. In computer-assisted reconstructive neuropsychological rehabilitation the outcome most frequently assessed and observed is the constructive effect, i.e. improved cognitive functioning in computer tasks and/or neuropsychological tests of the same functions. Assessment and observation of other, non-practised functions or improved everyday functioning are much rarer.

The foregoing discussion applies to situations in which patients participate only in computer-assisted rehabilitation. For methodological reasons, this form of rehabilitation is assessed in isolation in research reports. In clinical practice, meanwhile, it is often just a fragment of a larger rehabilitation program, e.g. holistic neurorehabilitation (Coetzer, 2008; Sarajuuri & Koskinen, 2006;).

The authors of this article have been conducting courses in neuropsychological rehabilitation at the Faculty of Psychology, University of Warsaw, since 1989. These courses are addressed to fifth-year students specializing in neuropsychology, with the participation of patients requiring neuropsychological rehabilitation following brain lesions. The introduction of computer-assisted rehabilitation to these courses inspired the authors to develop and undertake the research project presented below. The purpose of this project was to test the effectiveness of rehabilitation with respect to its constructive and real therapeutic outcomes.

The present study

Although computer-assisted neuropsychological therapies are becoming increasingly popular in Poland, there is still very little research on the effectiveness of this type of rehabilitative intervention on various aspects of patient functioning. The purpose of this study was to evaluate the outcomes of computer-assisted neuropsychological rehabilitation with respect to the level of performance on computerised rehabilitation software assignments and neuropsychological tests of rehabilitated functions before and after therapy, to compare these outcomes with the performance of healthy controls, and to obtain patients' subjective ratings of therapeutic effectiveness in their everyday lives.

Method

Participants

The study was performed on 28 men and women divided into four groups: brain-damaged patients with attention and memory dysfunction (group BD1, n = 9), healthy controls demographically matched with the BD1 patients (group C1, n = 6), brain-damaged patients with mild to moderate aphasia (group BD2, n = 7) and healthy controls demographically matched with the BD2 patients (group C2, n = 6). Participants' demographic data are presented in Table 1.

Table 1. Demographic characteristics of the four groups of subjects taking part in the study.

Measures	BD1 (n=9) Mean (SD)	C1 (n=6) Mean (SD)	BD2 (n=7) Mean (SD)	C2 (n=6) Mean (SD)
Age	47.8 (18.7)	39.0 (17.0)	47.7 (14.4)	45.3 (13.5)
Education (in years)	14.2 (2.1)	13.5 (2.7)	11.8 (0.3)	13.3 (2.9)
Sex	Females=3 Males=6	Females=1 Males=5	Females=4 Males=3	Females=3 Males=3

BD1 – brain-damaged patients with attention and memory dysfunctions; BD2 – brain-damaged patients with aphasia; C1 – healthy controls for group BD1; C2 –healthy controls for group BD2; M – Mean; SD – standard deviation.

There were no significant differences (nonparametric Mann-Whitney U test for independent groups) between groups BD1 and C1, nor between groups BD2 and C2 in terms of age ($U = 18.00$, $p = 0.328$ and $U = 19$, $p = 0.775$ respectively), education ($U = 19.5$, $p = 0.330$ and $U = 20.0$, $p = 0.879$ respectively) or sex ($chi^2 = 0.511$, $p – 0.604$ and $chi^2 – 0.066$, $p – 1.000$ respectively). Most of the treated patients were several years after brain damage onset (mean time from onset was 6.5 years, maximum 25 years, minimum 1.5 years). The cause of brain damage was craniocerebral in two cases and cerebrovascular in the remaining cases.

Procedure

Intervention with the brain-damaged patients was conducted according to the following design: pretest several days prior to therapy, one to three sessions; 30 hours of therapy conducted over 15 weeks, usually with two one-hour sessions per week; posttest, one to three sessions, several days after termination of therapy. Patients were examined twice with an appropriately selected neuropsychological test battery to evaluate the state of cognitive dysfunction before and after therapy. Patients were referred to therapy at the Faculty of Psychology, University of Warsaw from health service establishments in Warsaw and the Warsaw metropolitan area. This type of therapy is conducted at the Faculty of Psychology as part of the coursework for students specializing in clinical neuropsychology (cf. Łojek & Bolewska, 2008). On completion of the research procedure, the patients continued their neuropsychological rehabilitation.

The healthy controls were also examined twice with appropriate psychological tests with a 15-week interval. Patients were examined and treated at the Faculty of Psychology, whilst healthy controls were examined either at the Faculty of Psychology or at home.

The examinations and individual therapies were conducted by Faculty of Psychology students specializing in clinical neuropsychology in 2006-2010 within the requirements of their master's degree dissertations or annual experimental assignments, managed and supervised by the authors of this article. Before commencing work with a patient or patients the students were trained in neuropsychological testing, application of computer-assisted rehabilitation and work with brain-damaged patients.

Neuropsychological tests

The following neuropsychological tests, measuring mainly complex attention, learning and memory, were used to examine group BD1 and C1: the Trail Making Test (TMT) – performance times for parts A and B (Polish adaptation by Kądzielawa, Mroziak, Bolewska & Osiejuk, 1990); the Ruff Figural Fluency Test (RFFT) – the number of unique designs (Łojek & Stańczak, 2005); the Rey Auditory-Verbal Learning Test (AVLT) – the number of correctly reproduced words in five trials (Choynowski & Kostro, 1980); the Rey-Osterrieth Complex Figure Test (CFT) – copy and recall (Strupczewska, 1990), and the Wechsler Adult Intelligence Scale – subtests Digit Span and Digit Symbol (Brzeziński, Gaul, Hornowska, Jaworowska, Machowski, & Zakrzewska, 2004).

Group BD2 (speech disorders) and C2 were examined with the Boston Diagnostic Aphasia Examination (BDAE, Polish adaptation by Ulatowska, Sadowska and Kądzielawa (Kądzielawa, 1990). The following functions were assessed: speech comprehension (word differentiation, recognition of body parts, instructions, complex language material), oral expression (oral competence, verbal competence, automatic word series, recitation, singing, rhythm, word repetition, utterance repetition, reading words out loud, naming in response to questions, naming designates demonstrated in pictures, uttering animal names, reading sentences out loud) and writing (differentiating symbols and words, phonetic associations, understanding lettering, attributing words to appropriate pictures, silent reading of sentences and paragraphs, writing technique, writing symbol recall, finding dictated words, written text formulation).

Before and after therapy patients completed the Satisfaction with Life Scale (SWLS) by Diener et al., Polish adaptation by Juczyński (2001). This scale has five items (e.g. "In many ways my life is almost ideal") and the respondent is asked to rate this item on a scale from 1 ("Completely disagree") to 7 ("Completely agree") with respect to his/her life so far. Upon termination of rehabilitation, patients also answered several open-ended questions concerning the therapy and its effectiveness (e.g. "How did you manage practising on the computer? What did you like? What didn't you like? Has your speech in everyday life improved after therapy?"). For the purpose of the present study, only patients' subjective ratings of improvement of practised functions during therapy and in their everyday life were analysed Patients' responses were divided into two categories: positive ("yes", "rather yes") and negative ("no", rather not").

Computerised rehabilitation software

Two computerised rehabilitation programs were used: the Polish adaptation of *RehaCom* (Weber et al., 1999) and *Afa-System*, a rehabilitation program for patients with aphasia (Seniów, 2009).

RehaCom is used to rehabilitate brain-damaged patients with deficits in various cognitive processes (memory, attention, thinking, perception). Exercises used to rehabilitate attention and memory were selected for the present study. The attention exercises involve pattern comparison. Patients are requested to pick one picture from a group which precisely matches a model. Depending on the level of difficulty, three, six or nine similar pictures are presented on the computer screen, only one of which is identical to the model. There are 24 levels of difficulty in the attention exercises. The memory exercises mainly involve memorizing and recognizing objects. Patients are given tasks consisting of two parts. First, pictures representing objects which are easy to verbalise (e.g. dog) are presented on the computer screen, and the patient has to learn them (learning phase). Patients decide themselves when to terminate this phase by pressing OK on a special keyboard adapted to the program. Then, they pick out words designating the memorized pictures from a set of pictures moving horizontally across the screen, from right to left, by pressing OK. There are 12 levels of difficulty.

Work with the *Afa-System* software for rehabilitation of patients with aphasia involved oral expression, comprehension, and therapy in reading and writing (11-15 levels of difficulty). In the oral expression exercises patients had to name pictures, complete phrases and complete sentences. In the exercises training speech comprehension, patients indicated pictures on the basis of their names or broader definitions read by the program's narrator. In the reading exercises, patients matched words with pictures, organized antonyms and synonyms, and made up sentences with scattered words. In the writing exercises, patients gave names to pictures or completed phrases in writing by means of a special keyboard.

Results

The constructive rehabilitation effect was evaluated by such means as comparing the level of performance of the *RehaCom* and *Afa-System* exercises. The mean levels of exercise difficulties in each part of the two programs in the first and last therapy session are presented in Table 2. Significance of differences between the levels of difficulty in the first and last sessions was calculated with the nonparametric Wilcoxon Z test for dependent groups.

Table 2. Mean level of difficulty of tasks in the first and last sessions of computer-assisted rehabilitation in patients with attention and memory dysfunctions and aphasia

Rehabilitation tasks	First session M (SD)	Last session M (SD)	Wilcoxon's Z	Level of significance
Group BD1				
- Attention	14 (8.5)	22.4 (2.6)	- 2.371	0.018
- Memory	4.8 (1.6)	11.1 (1.3)	- 2.675	0.007
Group BD2				
- Oral expression	4.7 (3.5)	16.0 (3.8)	-2.207	0.027
- Comprehension	2.2 (0.9)	14.7 (5.4)	-1.841	0.066
- Reading	4.4 (2.0)	13.0 (3.6)	-2.371	0.018
- Writing	4.3 (4.9)	11.3 (4.6)	-1.633	0.102

M – Mean; SD – Standard Deviation; BD1 – Patients with attention and memory dysfunctions; BD2 – patients with aphasia.

Table 3. Comparison of neuropsychological test scores for patients with attention and memory dysfunctions and healthy controls, pretest and posttest

Tests	BD1		C1		BD1 Pretest-Posttest Z	BD1 – C1	
	Pretest M(SD)	Posttest M(SD)	Pretest M(SD)	Posttest M(SD)		Pretest U	Posttest U
TMT-A	64.1(24.1)	70.2(49.2)	42.0(27.9)	28.5(9.4)	-0.59	9.00*	1.00**
TMT-B	189.4(114.1)	193.7(129.0)	71.3(34.0)	58.1(21.3)11	-0.70	4.50**	4.50**
RFFT	51.7(12.7)	55.5(173)	104.5(38.6)	4.3(34.8)	-1.18	8.00*	5.00**
AVLT	11.2(2.4)	11.8(2.3)	14.8(0.4)	15.0(0)	-0.85	4.00**	3.00*
CFT-C	35.3(1.3)	35.5(0.7)	36.0(0)	36(0)	-0.37	21.00	18.00
CFT-R	24.7(9.2)	25.0(5.8)	27.6(4.0)	27.5(2.6)	-0.05	23.50	19.50
Digit Span	4.1(1.9)	4.5(1.8)	6.5(1.3)	7.0(1.4)	-1.41	8.00*	8.00*
Digit Symbol	30.6(6.0)	36.7(10.9)	48.5(11.1)	51.3(9.1)	-1.83#	6.00*	7.00*

TMT - Trail Making Test parts A and B; RFFT - Ruff Figural Fluency Test; AVLT - Rey Auditory-Verbal Learning Test; CFT - Rey-Osterrieth Complex Figure Test C – copy, R - recall; M – Mean; SD – Standard Deviation; BD1 – Patients with attention and memory dysfunctions; C1 – healthy controls; Z – Wilcoxon nonparametric test for dependent groups; nonparametric Mann-Whitney U test for independent groups; * level of significance $p < 0.05$, ** $p < 0.01$, # $p<0.7$.

Table 4. Comparison of Boston Diagnostic Aphasia Examination (BDAE) scores for patients with aphasia (BD2) and healthy controls (C2), pretest and posttest

BDAE	BD2		C2		BD2 Pretest-Posttest Z	BD2 – C2	
	Pretest M(SD)	Posttest M(SD)	Pretest M(SD)	Posttest M(SD)		Pretest U	Posttest U
Total	324.5(162.0)	356.5(203.6)	517.1(3.1)	517.6(2.3)	-1.82#	0.01**	0.01**
Comprehension	92.1(32.9)	91.7(39.0)	119.0(0)	119.0(0)	-1.28	0.01**	3.00*
Oral Expression	166.6(89.8)	176.5(112.4)	264.5(2.3)	265.0(1.8)	-182#	0.01**	0.01**
Writing	84.6(50.5)	88.2(54.7)	134.1(0.9)	133.6(0.8)	-1.84#	6.00	6.00

M – Mean; SD – Standard Deviation; BD2 – patients with aphasia; C2 – healthy controls; Z – nonparametric Wilcoxon test for dependent groups; U - nonparametric Mann–Whitney test for independent groups; * level of significance $p < 0.05$ ** $p < 0.01$; # $p<0.7$

Throughout therapy, the level of difficulty of absolutely correctly completed tasks increased in every exercise, which means that patients' skills improved as they worked with the computer. Significant improvement was found in attention, memory, speech expression and reading. Improvement was weakest for speech comprehension and writing, although all patients terminated therapy at higher than initial levels.

The constructive effect was also evaluated by analysing performance on neuropsychological tests in patients with attention and memory deficits, and the control group in the pre- and posttests. The results of these comparisons are presented in Table 3.

As we can see from this table, there was no significant improvement in attention or memory measured with selected neuropsychological tests in patients in group BD1 before and after therapy. These patients displayed very marked deficits compared with the control group before and after rehabilitation. With the exception of the copying test in the Rey-Osterrieth Complex Figure Test (CFT), where healthy controls obtained ceiling effects in both pre- and posttests, controls completed all tests slightly better the second time. No such effect was found in the brain-damaged participants despite rehabilitation. The only test where patients tended to improve was the WAIS-R Digit Symbols subtest.

As we can see in Table 4, before and after therapy patients with aphasia showed speech dysfunction compared with the healthy controls. Despite these deficits, patients became more proficient in speech expression and written speech related skills as demonstrated by the trends for these BDAE measures and the total BDAE score. Healthy controls completed this test twice almost perfectly or with minor errors.

Patients' responses to the request for their subjective ratings of improved functioning on functions trained during therapy and the state of these functions in everyday life are presented in Table 5.

Table 5. Percent of participants declaring improvement in trained functions and functioning in everyday life in patients with attention and memory dysfunction and patients with aphasia

	BD1		BD2		Total	
	I	NI	I	NI	I	NI
Functions trained during therapy	83	17	60	40	72	18
Efficiency of trained function in everyday life	0	100	20	80	9	91

BD1 – Patients with attention and memory dysfunctions; BD2 – patients with aphasia; Total – subjects from both groups BD1 and BD2; I – improvement, NI – no improvement.

Patients were practically unanimous in their subjective ratings of therapy outcomes. There were no significant differences between groups BD1 and BD2 in ratings of functional improvement due to therapy ($chi^2 = 0.749$, $p = 0.545$) and proficiency in cognitive function in their everyday lives ($chi^2 = 1.320$, $p = 0.455$). The vast majority of patients noticed an improvement in the practised functions during therapy, but not in their everyday lives.

No significant differences emerged in SWLS patients' ratings of quality of life before and after therapy (Z = -0.420, p = 674). Two patients in group BD1 and one patient in group BD2 rated post-therapy quality of life more positively than pre-therapy quality of life, whereas four other patients (three with aphasia and one with attention and memory dysfunction) rated post-therapy quality of life as inferior to the pre-therapy level. The remaining participants who completed the SWLS gave identical ratings of their quality of life before and after the therapeutic intervention.

Discussion

This study evaluated the effectiveness of computer-assisted neuropsychological rehabilitation. Level of performance on pre- and post-therapy computerized exercises, patients' pre- and post-therapy neuropsychological test scores, and patients' subjective ratings of the effectiveness of therapy for their everyday functioning were assessed.

Following therapy, patients showed significant improvement in functions trained in the computerised exercises or, in other words, in those aspects of attention, memory and speech which were directly addressed in the computerised therapy. This improvement is attested to by the differences in level of performance of the first and last computer task – patients completed increasingly difficult tasks. Cherney et al. (2006) obtained similar results, finding improvement in performance of successive tasks in the *Oral Reading for Language in Aphasia* program developed by Lundqvist et al. (2010), who used computerised therapy to train working memory.

The obvious improvement in performance on computer exercises did not fully transfer to improvement of the trained cognitive functions, however, when assessed with independent neuropsychological tests. In the present study participants with memory and attention dysfunctions did not show improvement in these functions when they were measured with tests of attention and executive function. Some improvement was found, however, in patients with aphasia with respect to oral expression and speech functions involving writing. Other researchers have also observed a similar effect, including Doesborgh (2004), who trained naming and found a general improvement in speech on the BDAE, Wetz and Katz (2004), who trained reading, and Lundqvist et al. (2010), who trained working memory and found a general improvement in neuropsychological tests.

No improvement in quality of life was found in the present study, although patients responded affirmatively when questioned about improvement in speech, memory, attention and everyday functioning. Perhaps they were affected by the positivity bias and were ashamed to say "no" when interrogated by the therapist. When patients completed the independent test (SWLS), their responses did not suggest improvement and some respondents even said their quality of life had deteriorated after therapy. Therefore we cannot say that the therapy really worked. This is one of the least-common effects reported in the literature, although Wertz and Katz (2004) do mention it. In their patients with aphasia, improvement generalized to spontaneous freedom of oral communication. Lundqvist et al. (2010) found no improvement in quality of life, but their patients who were given therapy demonstrated a general improvement in health. Ramstroom and Ingalill (2011) found improved quality of life.

Therapy in the present study was partly effective and, paradoxically, evaluation of its effectiveness can vary radically depending on how change is assessed. The therapy was certainly very effective in terms of trained tasks, but very little or no effect was found for overall improvement of the trained cognitive functions and no significant real effect of the therapy was observed.

The study and its outcomes have a number of limitations:

a) Few participants – 9 patients with memory and attention deficits and 7 patients with aphasia. Earlier work demonstrating the effectiveness of computer-assisted therapy was conducted on groups of at least 20 (Lundqvist et al., 2010; Sing-Fai et al., 2004; Wertz & Katz, 2004;);
b) Short training period – patients received only 30 hours of therapy. Meanwhile, to give one example, Ramstroom and Ingalilla's (2011) patients received a year's computer training and demonstrated functional improvement even in their everyday lives;
c) Long interval between training and onset of illness – this ruled out so-called spontaneous remission, in which case the observed effects of therapy are much weaker.

Patients expressed satisfaction with their participation in the computer-assisted rehabilitation program. It was a change from previous forms of therapy; they liked the computer exercises even though they had no significant effect on their daily functioning.

To conclude, computer-assisted reconstructive therapy should supplement traditional rehabilitation programs for brain-damaged patients with cognitive dysfunctions. These programs are most effective for performance of the exercises actually trained on the computer. It is much more difficult to obtain significant generalization to other tasks within the trained function or overall fitness in everyday life. Computer-assisted therapy should be supervised by a specialist who first carefully diagnosis the patient and then defines the goals, methods and duration of therapy.

References

Bruce, C., & Howard, D. (1987). *Computer-generated phonemic cues: an effective aid for naming in aphasia. British Journal of Communications Disorders, 22, 191-201.*

Brzeziński, J., Gaul, M., Hornowska, E., Jaworowska, A., Machowski, A., & Zakrzewska, M. (2004). *Skala Inteligencji D. Wechslera dla Dorosłych. Wersja zrewidowana – renormalizowana. WAIS-R (PL). Podręcznik.* [Wechsler Adult Intelligence Scale. Polish revised version. Manual.]. Warsaw: Pracownia Testów Psychologicznych PTP.

Cherney, L., Babbit, E., Cole, R., Van Vuuren, S. Hurwitz, R., & Ngampatpong, N. (2006). Computer Treatment for Aphasia: Efficacy and Treatment Intensity. *Archives of Physical Medicine and Rehabilitation, 87,* 10-26.

Choynowski, M., & Kostro, B. (1980). Podręcznik do „Testu Piętnastu Słów Rey'a". *[Manual for Rey's Fifteen Words Test].* In: M. Choynowski (Ed.), *Testy psychologiczne w poradnictwie wychowawczo-zawodowym. Wydanie drugie.* [Psychological tests in educational and occupational counselling. Second edition]. Warsaw: PWN.

Cicerone, K.D, Dahlberg, C, Kalmar, *K.,* Langenbahn, D. M. & Malec, J. F. (2000). Evidence-based cognitive rehabilitation: recommendations for clinical practice*. Archives of Physical Medicine and Rehabilitation, 81,* 1596-1615.

Cicerone, K.D., Dahlberg, C., Malec, J., Langenbahn, D., Felicetti, T., Kneipp, S., Ellmo, W., Kalmar, K., Giacino, J. T., Harley, J. P., Laatsch, L., Morse, P.A., & Catanes J. (2005). Evidence-based cognitive rehabilitation: updated review of the literature from 1998-2002. *Archives of Physical Medicine and Rehabilitation, 86,* 1681-1692.

Cicerone, K.D., Langenbahn, D., Braden, C., Malec, J.F., Kalmar, K., & Fraas, M. (2011). Evidence-based cognitive rehabilitation: updated review of the literature from 2003 through 2008. *Archives of Physical Medicine Rehabilitation, 92,* 519-530.

Coetzer, R. (2008). Holistic neuro-rehabilitation in the community: Is identity a key issue? *Neuropsychological Rehabilitation, 18,* 766-783.

Cole, E. (1999). Cognitive prosthetics: an overview of a method of treatment. *NeuroRehabilitation, 12,* 39-51.

Doesborgh, S., Mieke, W., van de Sandt-Koenderman, M., Diepel , D., van Harskamp, F., Koudstaal, P., & Visch-Brink, E. (2004). Cues on request: The efficacy of Multicue, a computer program for Word finding therapy. *Aphasiology, 18,* 213-222.

Egan, J., Worall L., & Oxenham, D. (2005). An Internet training intervention for people with traumatic brain injury: Barriers and outcomes. *Brain Injury, 19,* 555-568.

Gontkovsky, S.T., McDonald, N.B., Clark, P.G., & Ruwe, W. D. (2002). Current directions in computer-assisted cognitive rehabilitation. *NeuroRehabilitation, 17,* 195-199.

Hofmann, M., Hock, C., Kühler, A. & Müller-Spahn, F. (1996). Interactive computer-based cognitive training in patients with Alzheimer's disease. *Journal of Psychiatric Research, 30,* 493-501.

Hofman, M., Roesler, A., Schwartz, W., Mueller-Spahn, F., Krauchi, K., Hock, Ch., & Seifritz, E. (2003). Interactive computer-training as a therapeutic tool in Alzheimer's disease. *Comprehensive Psychiatry, 44,* 213-219.

Jodzio, K. (2011). Diagnostyka neuropsychologiczna w praktyce klinicznej. [Neuropsychiatric diagnostics in clinical practice]. Warsaw: Difin SA.

Juczyński, Z. (2001). *Narzędzia pomiaru w promocji i psychologii zdrowia.* [Assessment tools in health promotion and psychology]. Warsaw: Pracownia Testów Psychologicznych PTP.

Kądzielawa, D. (1990). Specyficzne problemy adaptacji testów klinicznych – testy neuropsychologiczne. [Specific problems in the adaptation of clinical tests – neuropsychological tests]. In: A. Ciechanowicz (Ed.), *Kulturowa adaptacja testów.* [The cultural adaptation of tests]. Warsaw: Polskie Towarzystwo Psychologiczne.

Klonoff, P. S., Watt, L.M, Dawson, L.K, Henderson, S.W, Gehrels, J-A, & Wethe, J.V. (2006). Psychosocial outcomes 1 – 7 years after comprehensive milieu-oriented neurorehabilitation: The role of pre-injury status. *Brain Injury, 20*, 601-612.

Lundqvist, A., Grundstrom, K., Samuelsson, K., & Ronnberg, J. (2010). Computerized training of working memory in a group of patients suffering from acquired brain injury. *Brain Injury 24,* 1173-1183.

LoPresti, E.F., Mihailidis, A., & Kirsch, N. (2004). Assistive technology for cognitive rehabilitation: State of the art. *Neuropsychological Rehabilitation 14,* 5-39.

Łojek, E. & Bolewska, A. (2008)(Eds)*. Wybrane zagadnienia rehabilitacji neuropsychologicznej. [Selected issues in neuropsychological rehabilitation].* Warsaw: Wydawnictwo Naukowe Scholar.

Łojek, E., & Stańczak, J. (2005). *Test Płynności Figuralnej Ruffa (RFFT). Polska adaptacja i normalizacja. Podręcznik.* [The Ruff Figural Fluency Test. Polish adaptation and normalization]. Warsaw: Pracownia Testów Psychologicznych Polskiego Towarzystwa Psychologicznego.

Mortley, J., Wade, J., & Enderby, P. (2004). Superhighway to promoting a client-therapist partnership? Using the Internet to deliver word-retrieval computer therapy monitored remotely with minimal speech and language therapy input. *Aphasiology, 18,* 193-211.

Otfinowski, J., Jasiak-Tyrkalska, B., Starowicz, A., & Reguła, K. (2006). Wspomagana komputerowo, skojarzona rehabilitacja zaburzeń poznawczych i funkcji ręki u osób z niedowładem połowiczym po udarze mózgu. Doniesienia wstępne. [Computer-assisted, joint rehabilitation of cognitive and manual dysfunction in stroke patients with hemiparesis. Preliminary report]. *Neurologia i Neurochirurgia Polska, 40,* 112-118.

Pąchalska, M. (2007). Neuropsychologia kliniczna. Urazy mózgu. Tom 1 i 2. [Clinical neuropsychology. *Brain injuries. Vols. 1 and 2*]. Warsaw: PWN.

Pąchalska, M. (2008). *Rehabilitacja neuropsychologiczna.* [Neuropsychological rehabilitation]. Lublin: Wydawnictwo UMCS.

Pluta, A., & Rączaszek-Leonardi, J. (2008). Terapia wspomagana komputerowo w rehabilitacji neuropsychologicznej. Studium przypadku chorego z afazja kinestetyczną. [Computer-assisted therapy in neuropsychological rehabilitation. A case study of a patient with kinesthetic aphasia]. In: E. Łojek, & A. Bolewska (Eds.), *Wybrane zagadnienia rehabilitacji neuropsychologicznej.* [Selected issues in neuropsychological rehabilitation] (pp. 181-200). Warsaw: Wydawnictwo Naukowe Scholar.

Ramstroom. I. (2011). Linguistic development in Alzheimer 's disease: 12 months language training including use of personal computer system. A pilot study. *Developmental NeuroRehabilitation, 14,* 156-163.

Rogante, M., Grigoni, M., Cordella, D., Giacomozzi, C. (2010). Ten years of telerehabilitation: A literature overview of technologies and clinical applications. *NeuroRehabilitation, 27,* 287-304.

Sarajuuri J.M., & Koskinen S.K. (2006). Holistic neuropsychological rehabilitation in Finland: The INSURE program – a transcultural outgrowth of perspectives from Israel to Europe via the USA. *International Journal of Psychology*, *41*, 362-370.

Seniów, J. (1999). Neuropsychologiczna rehabilitacja pacjentów z zaburzeniami funkcji poznawczych spowodowanymi uszkodzeniami mózgu. [Neuropsychological rehabilitation of patients with cognitive dysfunctions following brain damage]. *Neurologia i Neurochirurgia Polska, 5,* 1139-1149.

Seniów, J. (2003). Rehabilitacja chorych z zaburzeniami zdolności poznawczych wynikającymi z ogniskowego uszkodzenia mózgu. Użyteczność programów komputerowych w terapii. [Rehabilitation of patients with cognitive dysfunctions following focal brain damage. Utility of computerized programs in therapy]. In: Talar, J. (Ed.), *Neurorehabilitacja progu XXI wieku.* [Neurorehabilitation at the turn of the 21st century], (pp. 113-120). Bydgoszcz: Wydawnictwo Katedry i Kliniki Rehabilitacji Akademii Medycznej im. Rydygiera.

Seniów, J. (2009). *Proces zdrowienia chorych z afazją poudarową w kontekście współwystępujących nielingwistycznych dysfunkcji poznawczo-behawioralnych. [Recovery in patients with post-stroke aphasia in the context of concurrent nonlinguistic cognitive-behavioural dysfunctions]*. Warsaw: Instytut Psychiatrii i Neurologii.

Seniów, J., Polanowska, K., Mandat, T., & Laudanski, K. (2003). The cognitive impairments due to the occipito-parietal brain injury after gunshot: A successful neurorehabilitation case study. *Brain Injury, 17,* 701-713.

Sing-Fai, T., & Wai-Kwong M., (2004). Evaluating computer-assisted memory retraining programmes for people with post-head injury amnesia. *Brain Injury, 18,* 461-470.

Strupczewska, B. (1990). *Test Figury Złożonej Rey-Osterrieth'a (TFZ). Podręcznik.* [The Rey-Osterrieth Complex Figure Test. Manual]. Warsaw: Centralny Ośrodek Metodyczny Poradnictwa Wychowawczo - Zawodowego MEN.

Weber, P., Regel, H., & Krause, A. (1999). *REHACOM. Komputerowo wspomagana rehabilitacja chorych z zaburzeniami funkcji poznawczych.* [Computer-assisted rehabilitation of patients with cognitive dysfunctions]. Magdeburg: Fa HASOMED GmbH.

Wertz, R.T. & Katz, R.C. (2004). Outcomes of computer-provided treatment for aphasia. *Aphasiology, 18, 229-244.*

Wilmowska-Pietruszyńska, A., & Bilski, D. (2010). ICF jako narzędzie ilościowej oceny naruszenia sprawności w orzekaniu dla potrzeb zabezpieczenia społecznego. [The ICF as an instrument for the quantitative assessment of dysfunction in the formulating of expert opinions for social security purposes]. *Orzecznictwo Lekarskie, 7,* 1-13.

Wilson, B. A. (2002). Towards a comprehensive model of cognitive rehabilitation. *Neuropsychological Rehabilitation, 12,* 97-110.

Wilson, B. A. (2007). Is Rehabilitation Effective? [http://www.ozc.nhs.uk] accessed 16 August 2007.

Wood, R. L. McCrea JD, Wood, L. M., & Merriman, R.N. (1999). Clinical and cost effectiveness of post-acute neurobehavioral rehabilitation. *Brain Injury, 13*, 69-86.

Zheng, H., Black, N. D., Harris, N.D. (2005). Position-sensing technologies for movement analysis in stroke rehabilitation. *Medical and Biological Engineering and Computing, 42,* 413-420.