Computerized working memory training after stroke – A pilot study

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Abstract

Aim: To examine the effects of working memory (WM) training in adult patients with stroke.
Methods: A randomized pilot study with a treatment group and a passive control group; 18 participants (12 males) in a vocational age group (mean age 54 years) were randomized to either the treatment or the control condition. The intervention consisted of computerized training on various WM tasks for five weeks. A neuropsychological test battery and self-rating on cognitive functioning in daily life (the CFQ) were administered both before and after the treatment.
Results: 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 programme (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 ($p < 0.005$).
Conclusion: More than one year after a stroke, systematic WM training can significantly improve WM and attention.

Keywords: *Working memory training, attention deficit, stroke, cognitive rehabilitation*

Introduction

Deficits in working memory (WM) and executive attention are common problems after acquired brain injury [1–4]. WM is the ability to hold and manipulate information during a short delay, and to be able to make a response based on that internal representation. WM and attention are closely related; WM is a prerequisite for the selection of relevant information to attend to and the filtering out of irrelevant information – functions that also can be described as control of attention [5–7].

Stroke-induced deficits in WM and attention are often severe and result in impairments to vocational performance and social functioning. The degree of WM impairment, for tasks that require WM, is crucial for predicting recovery from stroke [1] and

predicting the probability of returning to work [8, 9]. Because WM capacity and the ability to attend are fundamental cognitive abilities upon which rehabilitation of other functions depend [1, 10], deficits in these areas are crucial to the treatment approach.

Attention training was evaluated in the phase of spontaneous recovery, only weeks after brain injury, in four controlled studies [11–14]. Several interventions resulted in improved performance on trained tasks, compared to a control group, but the training effect did not generalize to measures of attention in daily life. Alternative treatments were compared in three studies [11–13]. In two studies, significant improvements were found on cognitive functions tested after as compared to before training, but this improvement was not significantly larger than the spontaneous recovery in the control group.

Schottke [12] could distinguish treatment effects in one group from spontaneous recovery in a control group, but there was no generalization to measures of attention in daily life.

Several studies investigated the effectiveness of attention training in the chronic stage (>1 year) after brain injury in adults [15–22]. For a review see Cicerone et al. [2, 3]. But only two earlier randomized, controlled studies on rehabilitation of attention have had positive findings: Niemann et al. [17] and Gray et al. [18]. Gray et al. reported that after training, the treatment group showed improvement compared to the control group on the Paced Auditory Serial Addition Test (PASAT) [23], a test requiring working memory and control of attention, and on the sub-test picture completion from WAIS-R [24]. But when the pre-morbid intelligence score and time since injury were controlled for, the treatment effect was no longer significant. However, at the six-month follow-up after training, there was a significant difference between the groups in measures of attention and WM; the PASAT and the arithmetic subtest of the WAIS-R. In the Niemann et al. study (1990), the treatment group improved significantly more than an alternative treatment group using conventional memory training on several measures of attention- and WM-related tasks, including the PASAT. So far, the only study showing that cognitive intervention can improve daily life functioning is the one by Sohlberg et al. [20], where 20 weeks of attention process training was shown to improve not only laboratory tests of attention and memory but also, as measured by questionnaires; executive functioning in daily life.

The rationale for most of the reported interventions is to restore basic attention capabilities through practice of specific components of attention, e.g., training of vigilance as well as sustained, divided and shifting attention [3, 13, 15]. The computerized training method used in this pilot study differs from previous studies on cognitive rehabilitation after stroke, in that it is specifically focused on WM training and does not include training of other cognitive functions. Moreover, to optimize the training effect, the difficulty of each task is automatically adjusted, so that training is always performed close to the WM capacity of the participant. The practice of adaptively varying the intensity and difficulty parameters has proven to be effective in other training studies that intended to increase sensory functioning [25, 26].

Earlier studies of the computerized method for WM training in children with attention deficit hyperactivity disorder (ADHD) [27, 28] and in healthy adults [29] showed that: (a) training can increase WM capacity [27–29], (b) training-induced changes in brain activity occur [29], and (c) that training effects can be generalized to tests on attention, reasoning and problem solving [27–29]. By using the same method in this pilot study, we evaluated the effects of WM training on cognition in a group of patients with stroke ($N = 18$). We recruited only participants of working age who had suffered their first stroke 12–36 months earlier.

Most studies to date have relied on psychometric measures to assess improvements in attention that is attributable to treatment, and only a few studies included behavioural ratings. The pilot study on WM training reported here compared pre- and post-training assessments from a neuropsychological test battery and from a self-rating scale on cognitive functioning in daily life (the Cognitive Failure Questionnaire (CFQ)) [30]. All comparisons were made between the treatment group and the passive control group. The neuropsychological test battery covered: (a) *WM tests*: Digit span [24] and Span board [31], (b) *other cognitive tests requiring WM and attention control*: PASAT [23] and RUFF 2&7 [32], (c) *an interference control test*: the Stroop test [33], (d) *a reasoning and problem-solving test*: Raven's progressive matrices [34], and (e) a *declarative memory test*: Claeson-Dahl [35].

Method

Inclusion and exclusion criteria are listed in Table I.

Twenty four former patients of the stroke rehabilitation unit at the Danderyd Hospital in Stockholm, Sweden were contacted by phone for a screening interview. This unit specializes in rehabilitation of persons who are of vocational activity age (<65 years). Three out of the 24 people originally contacted declined to participate and three out of the remaining 21 who underwent baseline-testing, withdrew before the post-training assessment (see the 'Procedures' section in this document). The age range of the remaining 18 participants was between 34 and 65 years, with a mean age of 54 (SD 7.7 years): see Table II. Twelve participants were male and six female. Post-event time was 12–36 months (mean 20.1). Table II lists patient aetiology, severity, and brain-injury localization.

The regional ethics committee at Karolinska Hospital in Stockholm approved the study. Participants submitted written informed consent before testing, as per the Declaration of Helsinki.

Outcome measures

Eight neuropsychological tests were used as outcome measures: (i) Span board from the Wechsler Adult Intelligence Scale-Revised NI (WAIS R-NI) [31], which measured visuo-spatial WM; (ii) the Stroop

Table 1. Participant inclusion- and exclusion criteria.

Inclusion criteria	Exclusion criteria
Suffering stroke between 12 and 36 months ago	IQ < 70. IQ was based on the age-normalized results from the WAIS-R test. *All participants were assessed with the WAIS-R test within 6 months before entering the study
Stroke documented by PET, MR or CT	Motor or perceptual handicap that would prevent use of the computer program
Ages 30–65	Changing medication during the study period
Having daily access to a PC with Internet connection at home	Fulfilling criteria for major, depressive-disorder diagnosis as per the DSM-IV diagnosis code [36]: 296.2x F32.2
Self-reported deficits in attention	Known history of abuse of alcohol or illicit drugs

Table II. Characteristics of the participants.

	Control ($n = 9$)	Treatment ($n = 9$)	All
Age	53.6 (8)	55.0 (8)	54 (7.7)
IQ	101 (13)	103 (11)	102 (12)
Male/female	4/5	8/1	
Years of education	12.1 (1.8)	12.4 (1.7)	12.3 (1.7)
First ever stroke	$n = 8$	$n = 8$	
Time since stroke (months)	20.8 (6.2)	19.3 (6.2)	20.1 (6)
Stroke description			
Type	2 haemorrhages, 7 infarctions	6 haemorrhages, 3 infarctions	
Hemisphere	3 left, 4 right,	4 left, 4 right	
Lobe	1 medial, 1 bilateral	1 medial	
	1 frontal, 3 parietal,	4 frontal, 1 temporal	
	5 subcortical	5 subcortical	
Severity (1 = mild – 3 = severe)	1.9 (0.8)	2.1 (0.6)	2 (0.7)
No of training days	–	23 (2.2)	

interference test, which demonstrated ability to inhibit an over-learned response [33]; (iii) Claeson-Dahl [35], a word list recall test which measures learning and declarative memory. A fixed sequence of 10 words is repeated until the participant has learned them (maximum 10 presentations). Thirty minutes later they are asked to recall as many of the words as possible. The Claeson-Dahl is a Swedish test. Construct and criterion validity ranges between 0.42–0.52, and test/retest reliability is 0.85 for encoding and 0.41 for recall; (iv) Digit span from WAIS R [24], which measured auditory WM; (v) Raven's progressive matrices [34], which measured non-verbal reasoning ability. This pilot study used the standard version of Raven's matrices. The test was split into two parallel versions with 18 items. Odd numbers were given before the training period and even numbers after. This modification was made to shorten the assessment time – which we considered necessary because many of the participants had problems concentrating for a prolonged time during the baseline testing; (vi) Word list delayed recall [35], in which the participants were asked to recall as many as possible of the ten words

memorized 30 minutes earlier; (vii) PASAT version A [23] (with an inter-stimuli interval of 2.4 seconds) and (viii) RUFF 2&7 [32] (a serial cancellation test) were given as *non-trained* tests for WM and attention, i.e., tests that measure closely related cognitive functions but are not exactly identical to tasks in the training programme. The tests were administered in the exact order as quoted above. The CFQ [30], a self-rating scale, was used to rank cognitive failures in daily life, e.g., attention lapses and memory problems. The CFQ is a frequency scale and includes 25 items. Each item was ranked from 0 (never) to 4 (very often). The score is the total for all of the items (the maximum is 100). The original CFQ instructions state that the evaluation should be based on the participants' subjective rating of their own behaviour 'during the last six months'. For this pilot study, the response was changed to 'during the last week'. The adjustment was done to enable detection of changes that could occur during the limited, five-week training period. The modifications to the Raven test and the CFQ may affect the tests' validity and reliability, but in the current study all comparisons were made

between test–retest results in the training group vs. the control group. It is unlikely that using the same procedure would have affected the groups differently. Raw scores were used in analyses of test results unless otherwise specified.

Intervention

The training method was implemented with a software product (RoboMemo© from Cogmed Cognitive Medical Systems AB, Stockholm, Sweden), which was used at home on a PC. Table III describes the battery of visuo-spatial and auditory WM tasks that were performed using the software. The training method has been evaluated in children with attention problems [27, 28] and we have also carried out feasibility studies in adults with acquired brain injury (unpublished). In the pilot study reported here, the training method is evaluated for the first time in adults following stroke.

All tasks involved: (i) maintenance of multiple stimuli at the same time, (ii) short delays during which the representation of stimuli should be held in WM, (iii) unique sequencing of stimuli order in each

trail, (iv) the difficulty level adapting as a function of individual performance. The training plan specified that participants must complete 90 trials each day (taking about 40 minutes), five days a week for five weeks. The criterion for sufficient compliance was defined before the study, i.e., more than 20 days of training. The software directly included reinforcement, which was implemented via scores and positive verbal feedback on performance, e.g., 'well done'. The participants completed their training on a PC at home and reported their daily results via the Internet to a server at the hospital. The reasons for having participants report their results were to: (a) enable compliance monitoring (frequency and duration of training), and (b) accumulate data on training quality (e.g., changes in performance) as a basis for feedback. A certified psychologist (HW) provided feedback once a week via telephone. The control group condition was passive; the participants only performed the neuropsychological test battery and completed the CFQ twice – with no training in between – at the same time-points as the training group performed their pre- and post training tests. This was done to control for non-specific,

Table III. WM training tasks in the software product. Responses in all tasks were made by using a mouse to move the cursor to the memory stimuli and by clicking on them.

Task	Description
Reproducing a light sequence in a visuo-spatial grid	Lamps arranged in a four-by-four grid were displayed. Participant watched several lights go on and then reproduced the same sequence.
Indicating numbers in reverse order	A keyboard with numbers was displayed and then digits were read aloud. Participants responded by indicating the same numbers *but* in reverse order.
Identifying letter positions in a sequence	Letters were read aloud, one at a time. Participant had to remember the letters and order in which the letters were read. A row of lights was then visible and a flashing light cued the participant to indicate the letter that was read in the sequence. For example, if light number 3 lit, then participants reported the third letter that they had just heard.
Identifying a letter sequence in pseudo words	Participants kept track of letters displayed in columns. A sequence of letters was vocalized, while a light (above each column) flashed for each letter that was spoken. Participants clicked on the letter that was said first, then the second, third, and so on until the entire pseudo word was reproduced.
Finding mismatched letters	Two sequences of letters (pseudo words) were vocalized. Each sequence was nearly the same but there was one difference in the second sequence. Participants had to click on a button, which indicated the letter that did not match the first sequence. For example, if P D A was said first and then P D I, then they clicked the button above I.
Reproducing a light sequence in a rotated grid	A rotating version of the visuo-spatial grid task described above. After the sequence of lights went on, the grid panel rotated 90° clockwise and participants had to reproduce the sequence in the panel's new position.
Reproducing a light sequence in a 3D visuo-spatial grid	Lights were symmetrically positioned in a 3D 'room' with five inner 'walls'. Participants watched several lights go on and then reproduced the same sequence.

test–retest effects. The control group did not receive phone calls during the five weeks between test and retest.

Procedures

As a measure of full-scale IQ, all participants were assessed with the WAIS-R test [31] during the six months prior to entering the pilot study. Three psychologists at the Karolinska Hospital (PC, TH, and HW) administered neuropsychological assessments and the CFQ. Before and after the training period, the same psychologist assessed each participant. The tests were administrated in a fixed sequence (see the 'Outcome measures' section, items i–viii). There was no need to control for order effects, because we compared group differences at two time-points. During the initial neuropsychological assessment, the psychologist and the participant were blind to which group (training or control) the participant would be randomized to. After the assessment, a sealed, pre-addressed envelope (prepared by persons unrelated to the study), which revealed the randomization to either the treatment or control group, was opened and from this point test administrators were no longer blind to the study. The participants randomized to the treatment group were given a CD with the training software and asked to complete five weeks of WM training at home. After five weeks of either treatment condition, or control group condition, the same neuropsychological test battery was repeated. Three participants withdrew; two from the treatment group (one because of computer problems, one because of depression and changed medication) and one was originally in the control group and withdrew due to epilepsy debut. These participants scored within group mean level in the baseline assessment.

Statistical analysis

Training effects were evaluated by comparing outcome scores in the neuropsychological tests after training between the two groups – using a general linear model and controlling for baseline scores. This analysis is equivalent of an ANCOVA analysis with baseline score as one of the covariates. Analyses did not reveal any effects based on age, IQ or months elapsed since stroke on any of the tests, and these covariates were therefore not included in the further analyses. The effect sizes (ES) were calculated by subtracting the difference between pre- and post training scores in the control group from the difference between pre- and post training scores in the treatment group and dividing the sum by the pooled standard deviation from both groups ((delta treatment group-delta control group)/pooled SD). Analyses were performed using JMP v4.0 (SAS Institute Inc, Cary, NC).

Results

The mean number of fulfilled training days, in the nine participants who completed 20 days or more of training and thus were qualified for post-training assessment, was 23.0 (SD 2.2). Results of the training tasks were continuously recorded and improvements were found.

Neuropsychological tests

Table IV shows the mean values and standard deviations (SD) from raw data on the neuropsychological tests and the self-rating scale. There were significant differences between groups on the WM tests; Span board, $(p < 0.05)$ and Digit span, $(p < 0.005)$. But the greatest treatment effect was found in a non-trained test for WM and attention,

Table IV. Mean values and standard deviations (SD) from raw data on the neuropsychological tests and self-rating scale.

	Pre-training		Post-training			
	Control	Treatment	Control	Treatment	p	ES
Self-rating questionnaire						
CFQ total	41.0 (14)	36.9 (10.2)	43.0 (13.8)	29.2 (12.1)	0.005	0.80
Neuropsychological tests						
Span board	5.7 (1.4)	5.2 (1.0)	5.7 (1.8)	6.2 (1.0)	0.05	0.83
Digit span	5.7 (0.9)	5.8 (1.0)	5.7 (1.3)	7.3 (1.0)	0.005	1.58
Stroop time (sec.)	147.0 (54)	108.0 (11)	124.0 (48)	93.0 (19)	NS	0.24
Stroop raw score	96.5 (3.4)	98.9 (1.6)	97.8 (2.4)	99.1 (1.27)	NS	0.32
Raven (max 18)	15.3 (2.0)	16.0 (1.9)	16.7 (1.4)	17.2 (1.1)	NS	0.1
PASAT	46.4 (9.9)	47.0 (9.9)	47.0 (8.4)	53.6 (6.4)	0.001	0.61
Ruff 2&7 (sec.)	115.2 (21.1)	115.4 (21.7)	112.7 (17.3)	130.3 (21.9)	0.005	0.81
Word list learning						
No. of repetitions	6.9 (2.9)	6.3 (2.7)	7.4 (2.79)	6.0 (2.5)	NS	0.30
Delayed recall	5.6 (2.0)	6.0 (1.9)	5.9 (2.1)	6.4 (1.7)	NS	0.05

i.e., the PASAT, ($p < 0.001$). Significant improvement was also found on the RUFF 2&7 test, ($p < 0.005$). No treatment effects were found on the Raven test, the Stroop test or on the test for declarative memory.

Ratings of cognitive failure symptoms

There was a significant reduction of cognitive symptoms as measured by the self-rating scale CFQ ($p < 0.005$): see Table IV. The regression analyses of rating-scale data were based on the sum of all 25 questions from each individual's self-rating. Based on the self-rating, 8 out of 9 participants improved, with an average improvement of 9 (± 6) symptom scores.

Adverse events

There were no reported adverse events related to use of the WM training software.

Discussion

This pilot study evaluated the effect of intense, adaptive WM training in various visuo-spatial and auditory modalities for a group of patients with stroke. The treatment group improved significantly more than the passive control group on the non-trained tests that measured WM and attention. Furthermore, there was a significant treatment effect, as indicated by the self-rating on symptoms of cognitive failures (as measured by the CFQ). The results suggest that the method for WM training used here (i) improved cognitive functioning as measured by neuropsychological tests and (ii) affected the subjective experience of cognitive functioning in daily living.

Treatment effects were found for the non-trained WM tasks (Span board and Digit span). In these WM tests, the stimuli, presentation, and response modes varied from the WM tasks that were part of the training programme. Compared to the test–retest differences in the control group, the treatment group improved 19% more on the Span board test. This is equivalent to 1 SD or an ES of 0.83 in test–retest differences between the groups. Furthermore, improvements were also significant on the non-trained tests for WM and attention (PASAT and RUFF 2&7), which are frequently used clinical and brain-injury research tests. Improvement in the Span board test is consistent with improvements found in two previous studies that used the same training method in children with ADHD, where treatment groups were compared to a control group that undertook an alternative (and less effective) treatment [27, 28]. In those studies, the control groups

improved 0–0.2 SD, while the treatment group improved 0.7–0.9 SD on the Span board test, which is comparable to the corresponding numbers in this pilot study (0.11 SD for the control group and 0.8 SD for the treatment group).

Among the treatment studies carried out during the chronic stage following stroke, six studies (including this pilot study) included the PASAT, which enables comparisons to be made between treatment effects across studies. Slightly different versions of the test were used with regard to parameters such as the Inter Stimuli Interval (ISI) and the total number of stimuli. To compare studies, we calculated the ES ((delta treatment group − delta control group)/pooled SD) on the raw scores from the PASAT in each study. The ESs, displayed in parentheses for each study, were: Cicerone [21] (0.90), Sohlberg et al. [20] (0.12), Park et al. [19] (0.26), Gray et al. [18] (0.31), Niemann et al. [17] (−0.16) (in the Niemann et al. study, the control group improved slightly more than the treatment group, which explains the small ES), and this pilot study (0.83). The mean ES over all six studies was 0.33. What we can conclude from this comparison is that: (i) cognitive training showed positive results and (ii) the two studies with the highest ES included WM training, i.e., Cicerone KD (2002) and this pilot study.

There was no significant treatment effect, nor any trend for an improvement (ES = 0.05) for the declarative memory task. The lack of improvement in the declarative memory task suggests that the training specifically targets WM, not memory in general. This is consistent with the negative result on the same declarative memory test from another study on attention training after brain injury: Boman et al. [22], which also found significant (within group) pre-post training differences on more complex attention tests but not on the test for declarative memory.

No treatment effects were found either for the Stroop test or the Raven test. Regarding the Stroop test, there are discrepancies in the results of timed tasks compared with non-timed tasks in other training studies on adults with acquired brain injury. Several have failed to show improvements in tests that involve speed of processing, although they have found improvements in other tests [15, 16, 20, 23]. There was a speed improvement in the training group of this pilot study, but because the groups varied significantly at baseline (the control group performed slower), this may have affected the test-time interaction between groups. But the negative results of the Raven test are inconsistent with the previous studies of WM training in children with ADHD and young healthy adults [27–30]. This could be due to ceiling effects in this pilot study

because we decided to use the Raven's standard matrices instead of its more demanding advanced matrices. Before training, the mean score in the Raven test was 15.5 correct where 18 was the maximum score, and after training, eight out of nine participants (89%) in the treatment group had a score of 16–18.

There was a significant decrease in the self-rating scores regarding cognitive failure symptoms: see Table IV. The ES for the improvement, as measured by the scores from the CFQ, was 0.80 post-intervention, which suggests a strong clinical effect [37]. One limitation of this pilot study was that the WM training was not compared to an alternative treatment and that the effect of expectancy (the placebo effect) on rated cognitive symptoms is difficult to differentiate from the effect caused by WM improvement *per se*. In an attempt to explore indications on the specificity of WM training, we examined items on the CFQ that revealed the largest difference between test and retest, i.e., items that indicated a lower symptom rating by deviating more than one SD from the mean test–retest difference. The items that showed a decrease in test–retest difference – larger than one SD (item number 1, 7, 9, 13, 17, 19 and 21) – include statements such as 'daydreaming instead of listening', 'failure to concentrate on content when reading', and 'doesn't hear what people say when engaged in another activity'. The common factor for these items is that they relate to attention. Items that showed no change or even higher symptom scores at retest seem to be more related to problems with temper, hesitancy, clumsiness, and lack of initiative (item number 3, 4, 10, 14, 15, 22, 24 and 25). Bearing in mind the low number of participants in this study, no conclusions can be made but the aggregation of theme indicates that the improvement of cognitive symptoms may be associated with improvement of WM function. If the changes in self-rating had been due to a placebo effect, there might have been a more general reduction in cognitive symptoms.

Computerized cognitive training is a novel field and to date there are no other reports on computerized WM training applied to ameliorate negative effects on WM and attention caused by stroke. One of the rationales for using WM training after stroke is that WM supports a wide range of cognitive abilities that are crucial for accomplishment of vocational performance and daily living tasks, e.g., reasoning [6], control of attention [5], and ability to resist distraction from irrelevant stimuli [38]. The role of WM and attention for cognitive functioning in general is also implicated in a recent study by Nys et al. [39], which showed that weak, early, post-Stroke performance in executive functioning and attention predicted cognitive and functional

impairment seven months later [39]. Moreover, WM and attention functioning contributes, among other cognitive variables, to the prediction of the likelihood of returning to work and to the performance of other significant activities [8–10]. In a retrospective study on factors that predict re-entry to work after stroke, cognitive ability was among the major indicators [40]. To be able to return to work is also a key factor for subjective well-being and life satisfaction [40]. Moreover, in a study in which ability to independently carry out daily living activities was evaluated in elderly patients with stroke, it was found that for patients with cognitive impairment, the costs were three times higher compared to those without cognitive impairments [41].

Other studies have included WM among other tasks in their method of cognitive rehabilitation, e.g., Gray et al. [18] and more recently, Cicerone [21] investigated the effect of training 'working attention' in four participants. However, in previous studies it has been difficult to demonstrate a generalization to improvement of symptoms in daily life. The present study is the first to demonstrate such effects. The results in this study are also consistent with previous studies using the same method [27–29] in showing that training of WM improves not only the trained tasks, but also non-trained tests of WM and attention. The reason could be that WM and attention are overlapping concepts. The effectiveness of this method may, besides targeting the specific construct of WM, be partly explained by the fact that the training is computerized and thus the difficulty level for each task can be automatically adjusted to the individual's performance. And the uploading of training results from participants' home PCs (via the Internet) enable appropriate feedback plus supervision of compliance with the training regimen.

One reason to schedule the intervention during the chronic phase, rather than during the early phase after the stroke, is that it is not until the chronic phase, when patients try to go back to normal life and old working habits, that they become aware of their cognitive deficits [42] and may be motivated to re-train these functions.

Limitations

Conclusions from this study are limited by the low number of participants. Furthermore, there was only a passive control group, and no follow-up. A larger study, including both a passive and an active control group, will be needed to confirm the effect of WM training following stroke.

Conclusion

The results provide some evidence that, one to three years after a stroke, intensive training can improve an individual's WM and attention performance and that training effects can be generalized to cognitive functioning in daily living. These results are also consistent with the effect of WM training in previous studies

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Conflict of interest

T. Klingberg and H. Westerberg are minor stock holders in Cogmed Cognitive Medical Systems AB, the company that produced the software used for training. For the other authors, no conflict is declared.

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