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The Effect of Computer-Assisted Cognitive Rehabilitation on Working Memory in Children with ADHD

Somaye Robatmili, PhD*
Department of Psychology
Islamic Azad University
Science and Research Branch, Tehran, Iran
somayemili@yahoo.com

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Working memory (WM) is responsible for producing, maintaining, and manipulating cognitive representations of stimuli, searching for the same or similar stimuli in memory, and maintaining appropriate behavioral responses. WM is assumed to play a significant role in extant models of Attention Deficit Hyperactivity Disorder (ADHD). Using a single-case design with multiple baselines, we applied a computer-based cognitive rehabilitation program with adaptive training of WM tasks on 6 children with ADHD (inattention type) during 15 sessions – with each lasting 30 min– and evaluated the effects of the training. The obtained data were analyzed using visual analysis, percentage of recovery, and Reliable Change Index. The findings suggested that the program significantly enhanced the trainee’s performance in abilities pertaining to central executive functioning (CE), phonological loop (PH), and visuospatial sketchpad (VS) subsystems of WM. These results demonstrate that performance on WM tasks can be significantly improved by training, implying that that WM training has the potential to be of clinical use for ameliorating the symptoms of ADHD.

Keywords: computer-assisted cognitive rehabilitation, working memory, ADHD

Worldwide, about 5.3% of children are diagnosed with Attention-Deficit-Hyperactivity Disorder (ADHD); and symptoms persist into adulthood for about two-thirds (Hoogman, et al, 2017). ADHD is a prevalent, chronic, and impairing disorder occurring in 3% to 7% of school-aged populations (Angold, Erkanli, Egger, & Costello, 2000). Symptoms are divided into two categories of inattention and hyperactivity/impulsivity; the latter include behaviors like failure to pay close attention to details, difficulty-organizing tasks and activities, excessive talking, fidgeting, or an inability to remain seated in appropriate situations (American Psychiatric Association [APA], 2013). The Fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) is based on nearly two decades of research showing that ADHD, although a disorder that initiates in childhood, can continue through adulthood for some of the affected population. Hence, the development of treatments that can alleviate the core symptoms of ADHD is of paramount importance. ADHD has been placed in the neurodevelopmental disorders chapter to highlightes the cortical development correlates the disorder. A large body of research has emphasized that children and adolescents with ADHD demonstrate deficiencies in abilities falling within the executive function domain (Barkley, 2006).

Attention, flexibility of thought, planning, and the regulation of goal-directed behaviors are the executive functioning processes. Right, but WM is not a process. WM is responsible for a variety of processes. WM impairments are responsible for many of the behavioral deficits of ADHD (Castellanos & Tannock, 2002). WM is a system that mediates temporary storage, modification of the information and its protection from interference (Bledowski, Kaiser, & Rahm, 2010). WM deficits in ADHD have been consistently demonstrated in several studies

(Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Westerberg, Hirvikoski, Forssberg & Klingberg, 2004). It has been associated with persistent neural activity in many brain regions (Fuster, 1999) and is considered to be a core cognitive process that underpins a wide range of behaviors from perception to problem solving. According to the influential WM model, proposed by Baddeley and Hitch (1974) and extended by Baddeley (2000), WM includes three components: two storage systems (i.e., phonological loop and visuo-spatial sketchpad) and one control system (i.e., the central executive). The current study's conceptualization of working memory is based on Baddeley's multi-component model, as it is the most commonly used model in ADHD research (Rapport, Alderson, Kofler, Sarver, Bolden & Sims, 2008; Rapport, Bolden, Kofler, Sarver, Raiker, & Alderson, 2009). The working memory system is comprised of the central executive (CE) that is primarily responsible for focusing and dividing controlled attention among concurrent tasks, and independent phonological (PH) and visuospatial (VS) storage/rehearsal subsystems (Baddeley, 2007). A recent study found impairments in all three components of Baddley's model of WM in children with ADHD (Rapport et al., 2008).

In the last decade alone, working memory has been investigated in children with ADHD (Alloway & Cockcroft, 2014), as well as in children who are learning two or more languages (Blom, Kuntay, Messer, Verhagen & Leseman, 2014; Morales, Calvo & Bialystok, 2013). Since working memory is so integral to learning, it is important to determine its structure early when assessment information can lead to treatments and prevention of learning problems (Nevo & Breznitz, 2013).

Currently, primary treatments for developmental psychopathologies such as ADHD often involve medications, which sometimes show side effects. Even these effects, however, attenuate over time and can generate a number of unwanted side effects. As a result, parents and clinicians are often reluctant to embrace drug-based therapy despite the scarcity of safe and effective treatment alternatives. In the other hand, there is evidence suggesting that despite these improvements, neurobiological and cognitive deficits remain, to some extent (Hechtman et al., 2004; Schweitzer et al., 2004). Residual impairments of working memory, attention or inhibition could still adversely influence the academic achievement and vocational success. In light of such limitations in pharmacological-based remedies, brain training may represent an attractive adjunct to common pharmacological treatment. It refers to the engagement in a specific program or activity that aims to enhance a cognitive skill or general cognitive ability as a result of repetition over a circumscribed timeframe. Such training can produce changes measured at behavioral, neuroanatomical, and functional levels (Rueda, Posner, and Rothbart, 2005). Some of these programs have been developed and tested for children with ADHD. Holmes, Gathercole, and Dunning (2009) identified 22 children who scored low on verbal WM. Children completed either an adaptive WM training in which task difficulty was matched to the child's current memory span or a placebo to control for expectancy effects. They found that the majority of children who completed the adaptive training improved on four WM measures at post-treatment and at a 6-month follow-up. In addition, children receiving the adaptive training improved at the 6-month follow-up on mathematical reasoning. Chein and Morrison (2010) gave an intensive WM training to children with

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ADHD and normal adults. After participating in 20 sessions of an adapted complex WM span task over 4 weeks, healthy individuals improved on measures of temporary memory and verbal reasoning; furthermore, they showed an increase on their cognitive control, as indexed by their performance on the Stroop task. The participants also had improvement in their reading comprehension, which correlated with increases in spatial WM. Klingberg, Forssberg, and Westerberg (2002) did an intensive WM training to children with ADHD and normal adults. The training was also adaptive and included an algorithm to increase training difficulty as performance improved. The control group trained on a placebo treatment, which was the WM program without the algorithm, making their training less rigorous. They found at post-treatment that the children who received full treatment did significantly better than the control group on measures of visuo-spatial WM, nonverbal reasoning, and response inhibition. They also displayed fewer head movements, which have been shown to correlate with behavioral ratings of hyperactivity. As an investigation of the applicability of cognitive rehabilitation techniques to the WM deficits of ADHD in Iran, the present study investigated the effectiveness of computer-based cognitive rehabilitation (CBCR) in improving WM of children with ADHD.

Method

The participants were 6 ADHD children from 7 to 11 years of age (M¼11.75, 6 boys). They were recruited from a private psychiatric clinic, located in Tehran city. Each child received a diagnosis following a clinical assessment which included the Child and Adolescent Psychiatric Assessment and the revised Conner’s Parents Rating Scale-Long Version (CPRS-R: L;

Conner's, 1998), administered by a trained interviewer. All children met the DSM-V diagnosis for ADHD (inattention type). The exclusion criteria included known neurological conditions, known psychotic symptoms, left handedness, or IQ less than 75. Further, none of them were taking stimulant medications.

For the present study, multiple-baseline design was used. A multiple-baseline design consists of a series of replicated single-case designs, in which the replications are performed at the same time. It extends the basic single case AB phase design by implementing several AB designs simultaneously to different people, behaviors, or settings (Ferron & Scott, 2005; Onghena & Edgington, 2005). Here, we had 3 binary groups. Once a stable baseline occurred for the first group (after Session 3), the WM training intervention was introduced for them. For the other two groups, intervention started after the 5^{th} and 7^{th} sessions.

Instruments

Corsi Block-Tapping Test (CBTT)

CBTT assesses the capacity of visuospatial short-term memory and WM (Kessels, Zandvoort & Postma, 2000). In the present study, the same test format (size of board and blocks, distances between blocks) was used as in Pier, Prins, Sebastiaan et al (2011) study and the same scoring procedure was used as in Geurts et al (2004) study. The task consisted of nine cubes (blocks of 30_30_30mm) that were positioned on a square board (225_225 mm). The blocks, numbered one through nine, were visible for the test leader only. The test leader would tap a sequence of blocks, starting with a sequence of three blocks, which the child must repeat three times in the correct order (e.g., 1-2-3>1-2-3). If the child reproduces at least one of three sequences of a particular number of blocks correctly, the sequence is extended with one block to a maximum of eight blocks. After three successive errors within the same sequence length, the test would be stopped. The last sequence length in which the child has reproduced at least two sequences correctly is considered his/her memory span. The minimum score on the CBTT is two and the maximum score is eight. The CBTT takes approximately 10 minutes.

Forward Digit Recall Test (FDRT)

FDRT assesses the capacity of Phonological loop subcomponent of WM (Gathercole & Pickering, 2000). In the present study, the same test format was used as in Woods, Kishiyama, William, Herron, Edwards, Poliva, Hink & Reed (2010) study. Testing was performed using a standard PC. Responses were recorded automatically by computer. First, the testing procedure was explained orally to each participant. After hearing sequences of digits, participants attempted to recall in the same sequence. Lists were constructed by sampling randomly and without replacement, ranging from 1 to 9 and were presented at the rate of one digit per second. A typical digit sequence is 5, 1, and 3. A maximum of four lists were presented at each length, with list length increasing by one if a child correctly recalled three lists at a particular sequence length. Testing commenced with two-digit lists and continued until two or more lists of a particular length were recalled incorrectly. The maximum list length at which at least three lists were correctly recalled was calculated for each child. A test-retest reliability correlation coefficient for digit span of .68 was obtained in a study of 70 4- and 5-year-old children (Gathercole, 1995).

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Backward Digit Recall Test

The backwards digit recall test assesses the capacity of central executive subcomponent of WM (Gathercole & Pickering, 2000). It employed the same procedure as the digit recall test in all respects except that the child was required to recall the sequence of digits in reverse order. Thus, the sequence 8, 5, 2 would be correctly recalled as 2, 5, 8. Two practice trials were given in order to ensure that the child understood the concept of `reverse'. Test trials commenced with four trials containing two digits, followed by lengthier sequences if three or more lists were correctly recalled. The total number of lists correctly recalled was scored. Split-half reliability for the WISC-III UK version of digit span, which includes both forwards and backwards recall of digits, is .85 (Golombok & Rust, 1992).

Computerized Training Program

The WM training consisted of a computer-based training program[1]. Cogniplus is a training system for training the cognitive functions, which reliably identifies the client's ability, level and adapts automatically to it. In the present study, WM programs were used; it included 15 sessions completed in about 5 weeks, with each session taking approximately 30 to 40 minutes. Each session included three trials of WM exercises. The exercises included visuo-spatial WM, Coding and Nback training programs, most of which presented objects in a specific sequence and then had participants reproduce this sequence. For example, In the NBACK training program, the client sees a representation

[1] The working memory training program used was Cogniplus developed by SCHUHFRIED company, Vienna

of a digital picture frame on his screen. A succession of photographs appears in the frame; the photos have different subject matters (animals, landscapes, colors etc.). The client's task is to decide whether the current photograph matches the one that was shown one, two or three places before (the number of places varies with the level). If it matches, the participant should press the green button and if it does not match, the red button must be pressed. The client receives feedback on his/her performance at regular intervals (approx. every 5 minutes). The aim of this feedback is to maintain the client's motivation at an optimal level. NBACK has 15 difficulty levels and adapts to the client's ability in four ways. 1. The difficulty is varied by changing the number of stimuli that the client must remember. At the lower levels the current stimulus needs only to be compared with the immediately preceding one. At the highest levels the current stimulus must be compared with the one that was displayed three places back. 2. The semantic similarity of the pictures represents an additional difficulty parameter. At higher levels the pictures become more similar. 3. The picture content becomes more abstract and hence more difficult to verbalize. 4. The picture presentation time becomes shorter as the difficulty increases. A trained research staff member viewed the results of each session, and each week talked with the participants and their parents about the quality of their sessions.

Data analyzed using visual analysis, percentage of recovery and Reliable Change Index.

Results

The results of descriptive statistics have been reported in forward digit (see Table 1), backwards digit (see Table 2) and corsi span (see Table 3). In these tables, the scores of the subjects are presented during different stages of evaluation, pre-test (baseline), post-test (intervention) and follow-up. The results show that scores of subjects in all three subscales of WM (forward digit, backwards digit and corsi span) are increased in the post-test and follow-up compared with the baseline. In forward digit span, backwards and corsi, total improvement was %48.69, %47.73 and %39.1, respectively. To determine the significant difference of the scores, Reliable Change Index (RCI) was calculated. For first to sixth subject, RCI in forward digit span was 4.85, 3.69, 2.38, 3.27, 3.34 and 2.72, respectively. Moreover, RCI in backwards digit span (for first to the sixth subjects, 2.71, 2, 2.92, 2.9, 3.01, 3.06 and 2.64, respectively) and corsi span (for first to the sixth subjects, 2.82, 2.08, 2.51, 2.65, 2.04 and 2.25, respectively) indicate that the changes which had been made on the subject, was statistically significant (RCI>1.96). Accordingly, computer based cognitive rehabilitation could improve therapeutic targets in all WM subscales.

Moreover, the following figures show subjects' profiles in the forward digit span (see Fig. 1), backward digit span (see Fig. 2) and corsi span (see Fig. 3) during baseline, intervention, and follow-up. As the figures show, the scores of forward, backward, and corsi span has increased significantly in post-test and follow up stages. So it can be concluded that computer based cognitive rehabilitation was effective in improving WM.

Table 1
Forward Digit Span Scores of Subjects at Baseline, Treatment and Follow-up

	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6
baseline 1	2	2	1	2	2	2
baseline 2	2	2	2	2	2	2
baseline 3	2	2	1	2	2	2
baseline 4			2	2	2	2
baseline 5			1	2	2	2
baseline 6					2	2
baseline 7					2	3
session 1	3	2	2	2	2	3
session 3	3	2	2	3	3	3
session 6	3	4	3	3	3	3
session 9	4	4	3	3	4	3
session 12	5	4	4	4	3	4
session 15	5	5	4	4	4	4
follow up 1	4	5	4	4	4	4
follow up 2	5	5	4	4	4	4
follow up 3	5	5	4	4	4	4
	64.51%	61.51%	40.64%	45%	42.17%	37.36%

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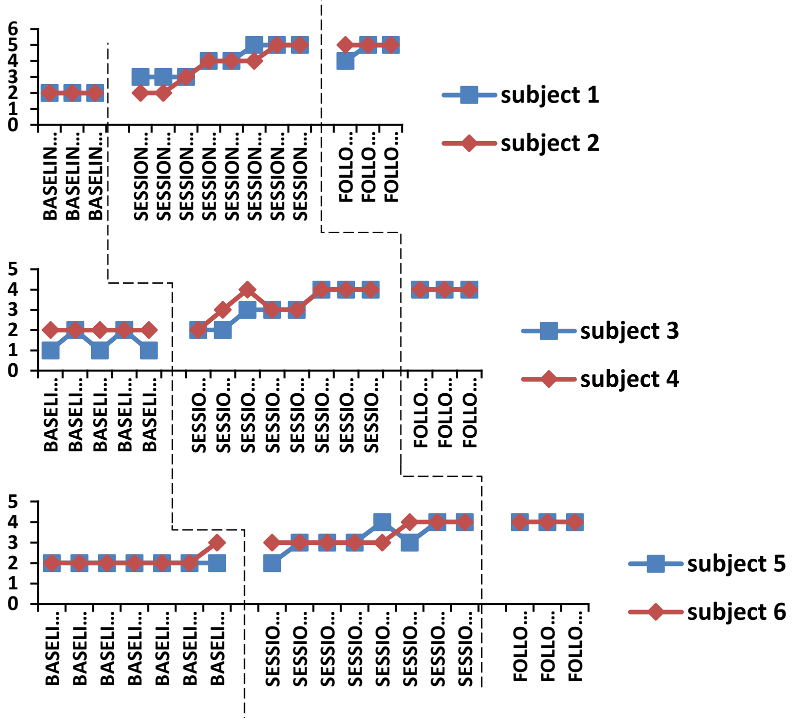

Figurte 1. Subjects' Profile in Forward Digit Span during Baseline, Treatment and Follow-up

Table 2

Backward Digit Span Scores of Subjects at Baseline, Treatment and Follow-up

	subject 1	**subject 2**	**subject 3**	**subject 4**	**subject 5**	**subject 6**
baseline 1	2	2	1	1	1	1
baseline 2	2	2	1	1	1	1
baseline 3	2	2	2	1	1	2
baseline 4			1	1	1	2
baseline 5			1	2	2	1
baseline 6						1
baseline 7						2
session 1	2	2	1	2	2	2
session 3	2	3	2	2	2	2
session 6	3	2	2	3	3	3
session 9	4	3	3	3	3	3
session 12	4	3	3	3	3	3
session 15	4	4	3	4	4	3
follow up 1	4	4	3	4	4	3
follow up 2	4	4	3	4	4	3
follow up 3	4	4	3	4	4	3

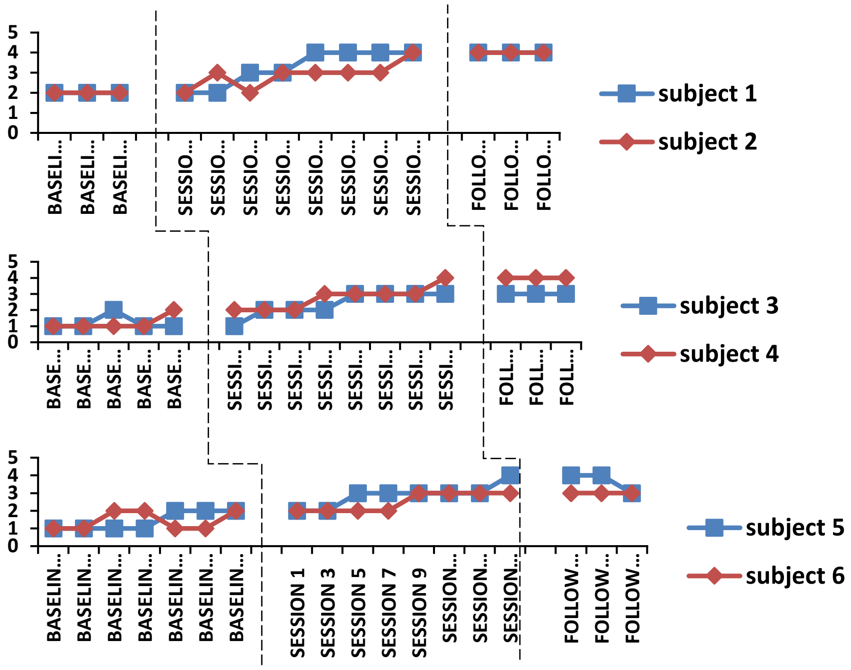

Figure 2. Subjects' Profile in Backward Digit Span during Baseline, Treatment and Follow-up

Table 3
Corsi Span Scores of Subjects at Baseline, Treatment and Follow-up

	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6
baseline 1	2	2	2	2	2	2
baseline 2	2	2	1	2	2	1
baseline 3	2	2	1	1	1	2
baseline 4			2	2	2	2
baseline 5			2	2	2	2
baseline 6					2	2
baseline 7					2	2
session 1	2	3	2	2	2	2
session 3	3	2	2	2	2	2
session 6	3	2	2	3	3	2
session 9	4	3	3	3	3	3
session 12	4	4	3	3	3	3
session 15	4	4	3	3	3	4
follow up 1	4	4	3	3	3	3
follow up 2	4	4	3	4	4	3
follow up 3	4	4	3	4	4	4

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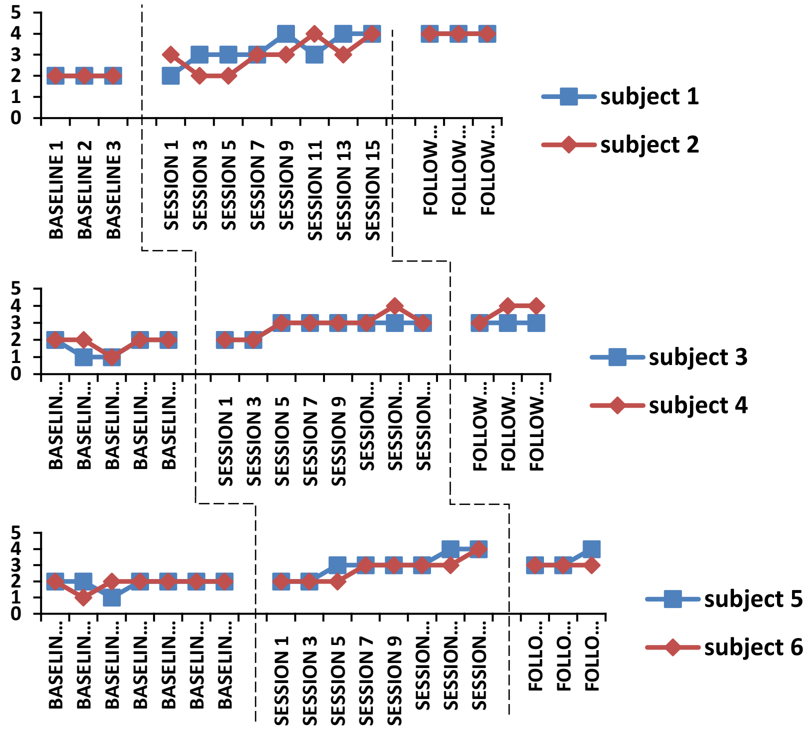

Figure. 3

Subjects' Profile in Corsi Span during Baseline, Treatment and Follow-up

Discussion

In the present study, computerized WM training gradually increased the volume of information that the subjects could keep in WM. The improved performance occurred over weeks of training, which is similar to the results of Klingberg study. Deficits in working memory are thought to be of central importance in explaining many cognitive and behavioral problems in ADHD. Westerberg (2004) compared WM tasks with other tasks and indicated that children had most problems with WM tasks. A meta-analysis of 46 studies confirmed WM deficits in ADHD and also showed that the deficits were most pronounced in the visuospatial domain. Olesen (2004) found developmental changes in the activity of dorsal-lateral, frontal, and parietal lobes using functional magnetic resonance imaging (fMRI) after WM training. These areas, similar to frontal areas, are implicated in pathology of ADHD. These findings suggest that the neuroplasticity of neural systems is related to WM. Indeed, in explaining the findings, it should be noted that WM can be improved through intense neuronal activation. It is assumed that the mapping of brain can grow to a wider area by a specific type of sensory experience through this activation. Research has shown that WM training leads to changes in the density of cortical dopamine neurotransmitter receptors (McNab, Varrone & Farde, 2009). As the findings of this study and the results of other studies have revealed, by computer-assisted cognitive rehabilitation, working memory can improve in children with ADHD. We could explain the observed effectiveness by considering ADHD within a neuropsychological framework, and since ADHD has been classified as a neurodevelopmental disorder in DSM 5 given its neurocognitive determinants.

In explaining the effectiveness of cognitive rehabilitation on WM, we can refer to principles of neuroplasticity and recovery, according to the following reasons: 1. The brain is a dynamic organ and has neurological reorganization capacity during the life; 2. The base of behavioral changes is structural changes in the brain, particularly in dendritic and synaptic fields; 3. Cognitive abilities are usually improvable; 4. Structured stimulation of experiences for brain is associated with raising recovery of neuronal behavioral functioning; 5. Functional reconstruction usually involves the use of damaged areas and areas close to their counterpart in the other hemisphere; 6. Behavioral results reflect the complex interaction between top-down and bottom-up processes as well as the effects between and within the hemispheres (Sohlberg & Mateer, 2001). This research could improve this variable by providing structured opportunities for practicing various aspects of WM over time.

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