Research Article

# Effectiveness of the Combined Memory Training Program on Memory Skills and School Achievement of Children with Specific Learning Disorders: A Pilot Randomized Controlled Trial

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## ABSTRACT

**Introduction:** Children with Specific Learning Disorders (SLD) suffer from some cognitive deficits affecting their school achievement. This study investigated the effect of the combined Working Memory Training Program (WMTP) with the Caillou program (the game-like features of computerized cognitive training programs) on memory (as a cognitive function) and academic achievement in children with SLD.

**Materials and Methods:** In this pilot randomized controlled trial study, 30 children with SLD, aged 8-11 years, participated. They were randomly allocated to the intervention and control groups. The intervention group received 20 training sessions in 10 weeks, each lasting 30-45 minutes. The control group only participated in the assessment sessions. The primary outcome was verbal working memory skills assessed by the digit span and letter-number sequencing subtests of the Wechsler Intelligence Scale for Children, the fourth edition (WISC-IV). Also, the grades of science, literature, and mathematics were collected as the secondary outcomes. Children were assessed 3 times: baseline (pre-test), after the intervention (post-test), and 2 months after the intervention (follow-up).

**Results:** Working memory (digit span and letter-number sequencing scores) and mathematics grades were significantly improved in the intervention group, as compared to the control group at the post-test session ($P<0.05$) and remained in the follow-up session.

**Conclusion:** Although this combined program effectively improves working memory and mathematic grades, further research is suggested for more academic achievement.

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## 1. Introduction

Specific Learning Disorder (SLD) is a neurodevelopmental disorder with a biological origin; it is generally recognized during school-age. The biological origin of SLD, including genetic, epigenetic, and environmental factors, is the basis of cognitive disorders associated with behavioral signs. The condition affects the brain's ability to perceive or process verbal or nonverbal information efficiently and accurately. Children with SLD have problems in reading, writing, and mathematics, while their intelligence quotient is average and training opportunities are sufficient [1]. These children suffer from common cognitive deficits in executive functions, attention, visual-motor integration, verbal and non-verbal communications, emotions, behaviors, and memory [2]. They have at least two types of memory problems: Short-Term Memory (STM) or Working Memory (WM) and the retrieval of information from long-term memory [3]. The working memory system is responsible for holding information temporarily to be used further, as well as simultaneously processing them. The working memory model was developed and then extended by Baddeley and Hitch (1974) and Baddeley (2000). It consists of three components: the phonological loop and the visuospatial sketchpad as two storage systems with the central executive as the control system [4]. Impairments in the visuospatial sketchpad and phonological loop working memory may manifest as dyscalculia and dyslexia in SLD, respectively [5]. Meanwhile, numerous studies have demonstrated the relationship between working memory capacity and higher-order cognition outcomes, such as school achievements [6, 7]. Children with SLD suffer from a poor working memory capacity, and they are at a high risk of educational failure and slow progress in all educational domains at school [8].

There are a variety of interventions for improving working memory skills, such as computerized cognitive programs (ex, Cogmed, CogniFit, Jungle Memory, N-back training, and complex span training) [9, 10], play-based activities [11], teaching strategies, such as the rehearsal, chunking, meta-cognitive strategies [12], and brain training [13]. However, there seems to be disagreement regarding the effectiveness of these interventions. Regarding computerized cognitive programs, Luis-Ruizetal. in a systematic review, and Melby-Lervåg et al. based a meta-analysis study, indicated that these pieces of training exclusively improved the to-be-trained WM tasks (near-transfer effects) and cannot be generalized to other skills (far-transfer effects), such as academic achievements [6, 14]. Oldrati et al. based on their meta-analysis study, indicated that the game-like features of computerized cognitive training programs could be more effective interventions than cognitive training programs [15]. Peijnenborgh et al. in their meta-analysis study indicated a lack of research specifically investigating the effectiveness of the WM training methods in the children with SLDs [16]. Vernucci et al. based on a review study, declared that the research studies previously done on this issue had severe weaknesses in terms of methodological quality; also, the critical role of environment and motivation has not been considered [17]. Therefore, the quality of the working memory training program plays a crucial role in achieving the outcomes. It can be concluded that the combined program consisting of game-like features of computerized cognitive training programs with WM training has higher effectiveness.

According to memory intervention, the available evidence points to the factors maximizing the effectiveness of the intervention program. For instance, the WM training program should be designed to be motivating, funny, diverse, and rich in domain-specific activities [13, 17, 18]. These factors were considered in the Working Memory Training Program (WMTP) developed by Nazok et al. [19] and validated by some experts. At the same time, the effectiveness of WM training is that the working memory tasks are generalized to daily life and school achievement [20]; WMTP needs to be considered in this respect as a pilot clinical trial study.

With regard to attaining the most effective working memory training program, we aimed to assess the effectiveness of the combined Caillou program [21] as the game-like computerized cognitive training and Working Memory Training Program (WMTP) [19]. The primary outcome was to investigate the working memory capacity (as near-transfer effect), and secondary outcomes were to assess the effect of the current program on academic achievement (mathematics, literature, and science grades as the far-transfer effect) of the children with SLD.

## 2. Materials and Methods

### Trial design and setting

The present research was designed as a parallel, randomized, single-blind (assessor), and controlled trial study.

Ethical approval was obtained from the Ethics Committee of Iran University of Medical Sciences (Code: IR.IUMS.REC.1394.9311355012). The trial was registered in the Iranian Registry of Clinical Trials (No.

IRCT2015061910806N3 in http://www.irct.ir/). The written informed consent was obtained from the parents of the children prior to assessments.

By using the convenient method of sampling, 30 children who met the criteria were allocated randomly on a 1:1 ratio into the control and intervention groups. It was done by referring to an independent individual who was blinded to the study aims. Sealed opaque envelopes (concealed) were generated using a random number table, and the assessor, blinded to the study's aims, allocated the sequence.

## Study participants

In this study, 30 children with SLD (15 girls, 15 boys) were recruited from four educational and rehabilitation centers for specific learning difficulties in Tehran City, Iran. The inclusion criteria were as follows: having a specific learning disability diagnosed by a psychiatrist, being 8 to 11 years old, and lacking sensory deficiency based on the sensory profile. The exclusion criteria included having epilepsy, comorbidities with other psychiatric disorders based on the Child Symptom Inventory (CSI-4), lacking cooperation, not attending two consecutive treatment sessions, and experiencing brain stimulation during the month before the intervention period.

## Study setting

The children in the intervention group received 20 intervention sessions twice a week. Each session lasted 30-45 minutes in a quiet room located in the Occupational Therapy Clinic of Iran University of Medical Sciences, from 1 PM to 6 PM. All intervention sessions were administered by an occupational therapist who had 2 years of work experience with SLD.

## Study procedure

### Intervention group

To prevent fatigue and increase motivation during the sessions, the combined training program was planned considering the maximum variety and appeal. The training was designed by two common methods of computer games and memory training (supplementary 1). Both parts, equally, lasted 15 to 20 minutes. The order of the implication of these two graded training programs was optional by the participants. In accordance with the memory abilities of the children, the baseline was selected, and the degree of difficulty in WMTP [19] and Caillou program [21] was gradually increased with the improvement of memory.

Caillou program (the game-like features of computerized cognitive training programs) consisted of three graded memory games. Five experts in pediatric games selected three games: following the stars, matching game, and memory game. In the following the stars game, one to eight stars with different colors and sounds started to sparkle randomly. At the end of the trail, the user should click on the stars in the same sequence they started sparkling. In the matching game, one to three leaves were displayed to the child on the monitor for 4 seconds. Then, after four seconds, 6 to 18 leaves were displayed on the right side of the monitor, and the children were supposed to recognize the targets by clicking on them. In the memory game, a series of pictorial cards were displayed on the monitor. Two cards with the same image were among the displayed cards, and the child should find and select them based on trial and error [21].

Working Memory Training Program (WMTP) has been documented by the previous report [19]. However, to describe it briefly, some activities related to the visuospatial and phonological parts of WM, according to Baddeley's model, were selected from different resources such as books, the Internet, memory tests. Then, the activities were classified based on the type of WM (visuospatial or phonological), the type of stimulus (visual or auditory), and their goal (recalling or recognition). The program was validated by an expert panel consisting of 2 occupational therapy professors, a PhD holder in Psychology, and two PhD holders in Cognitive Neuroscience. They were experts in the field of SLD and memory training. They selected the appropriate tasks for the therapy session and classified them based on the type of WM (visuospatial or phonological) and scored based on the degree of difficulty (easy, medium, or hard). The final version of the program is shown in Supplementary 1.

### Control group

To control the passage of time and the probability of any spontaneous improvement in the WM and academic skills of the children with SLD, we hired a control group who did not receive any intervention. They only attended the assessment sessions.

### Outcome measures

The assessor, blinded to the study objectives, assessed the outcome measures. The primary outcome in the present study was working memory, which was assessed using the digit span and letter-number sequencing subtests of the Wechsler Intelligence Scale for children, the fourth edition (WISC-IV) [22]. The memory subtests were assessed three times: the day before the intervention as the pre-test, the day after the end of the 10-week intervention as the post-test, and two months after the end of the intervention period as the follow-up. The secondary outcomes were school achievement in science, literature, and mathematics courses during the intervention. The grades of these courses were extracted from their academic records.

WISC-IV consists of 15 subtests assessing the children's intellectual ability aged 6–16 years. The two subtests of digit span and letter-number sequencing are usually used to measure the working memory [22]. The test-retest reliability of the scale ranged from 0.65 to 0.95, and the split-half reliability coefficients of 0.71-0.86 were reported for the WISC-IV in the case of Iranian children [23].

Verbal working memory WISC-IV digit span is a subtest of the WISC-IV. It is provided to assess the verbal working memory for both forward and backward spans. Participants should listen carefully to digit strings that the assessor says slowly and repeat immediately after completion. The capacity of manipulation and the ability to maintain the components of verbal working memory is measured using the backward and forward span components of WISC-IV [23].

In the subset of verbal working memory WISC-IV letter-number sequencing, the child listens to numbers and letters and recalls them in ascending order [23].

## Statistical analysis

Baseline demographic and clinical characteristics of the groups were compared to assess any disparities. To test the study hypothesis, we used the repeated measures of ANOVA with a between-subject factor at 2 levels (2 groups) and a within-subject factor at 3 levels (time: pre-test, post-test, and follow-up). To assess the interaction effect more precisely, post-hoc analyses were conducted using the Bonferroni multiple comparison adjustment tests. This method included post-test vs pre-test, follow up vs post-test, and follow up vs pre-test sessions in each group, separately. The significance level was set at 0.05. The Cohen's d was calculated at 0.20, indicating a small effect (0.50 as a medium effect and 0.80 as a large effect) [24]. Statistical analyses were performed by a biostatistician blinded to the study (Figure 1).

# 3. Results

The results of assessments of 30 children with SLD who took part in this study were analyzed. The baseline demographic and clinical characteristics are presented in Table 1.

The mean and standard deviation of the primary and secondary outcome measures over time are presented in Table 2. In an intention-to-treat analysis, because of the dropout of 8 children from the follow-up session, scores of the missed children were replaced by the mean scores of the participating children in the follow-up session. Then, the final analysis was undertaken.

## Primary outcomes

### Digit span WM subtest of WISC-IV

The repeated measures ANOVA revealed the main effect of time ($P<0.001$, $\eta=0.78$), group ($P<0.001$, $\eta=0.43$), and the interaction effect of group×time ($P<0.001$, $\eta=0.81$) on the digit span WM scores (Table 3). As shown in Figure 2-A, the intervention group results revealed significant differences between post-test and pre-test sessions (mean difference=8.33, $P<0.001$) and the follow-up and pre-test and sessions (mean difference=8.07, $P<0.001$).

### Letter-number sequencing subtest of WISC-IV

As presented in Table 3, the main effects of time ($P<0.001$, $\eta=0.84$) and group ($P<0.001$, $\eta=0.57$), as well as the interaction effect of group×time ($P<0.001$, $\eta=0.83$), on letter-number sequencing scores were significantly different. Figure 2-B shows significant differences in the intervention group in letter-number sequencing scores between post-test and pre-test sessions (mean difference=8.53, $P<0.001$), as well as between follow-up and pre-test sessions (mean difference=8.47, $P<0.001$).

Interaction effect of the group by time on digit span scores, letter-numbered sequencing scores, mathematics, and science grades=***$P<0.05$; between sessions and the main effect of group difference=$^{+++}$ $P<0.05$.

### Secondary outcomes: Academic grades

Analysis of the repeated measure ANOVA revealed the main effect of time ($P<0.001$, $\eta=0.38$) and the interaction effect of group×time ($P<0.01$, $\eta=0.21$) in the mathematics grades. Figure 2-C shows significant differences between post-test and pre-test sessions (mean difference=0.8, $P=0.004$), as well as follow-up and pre-test

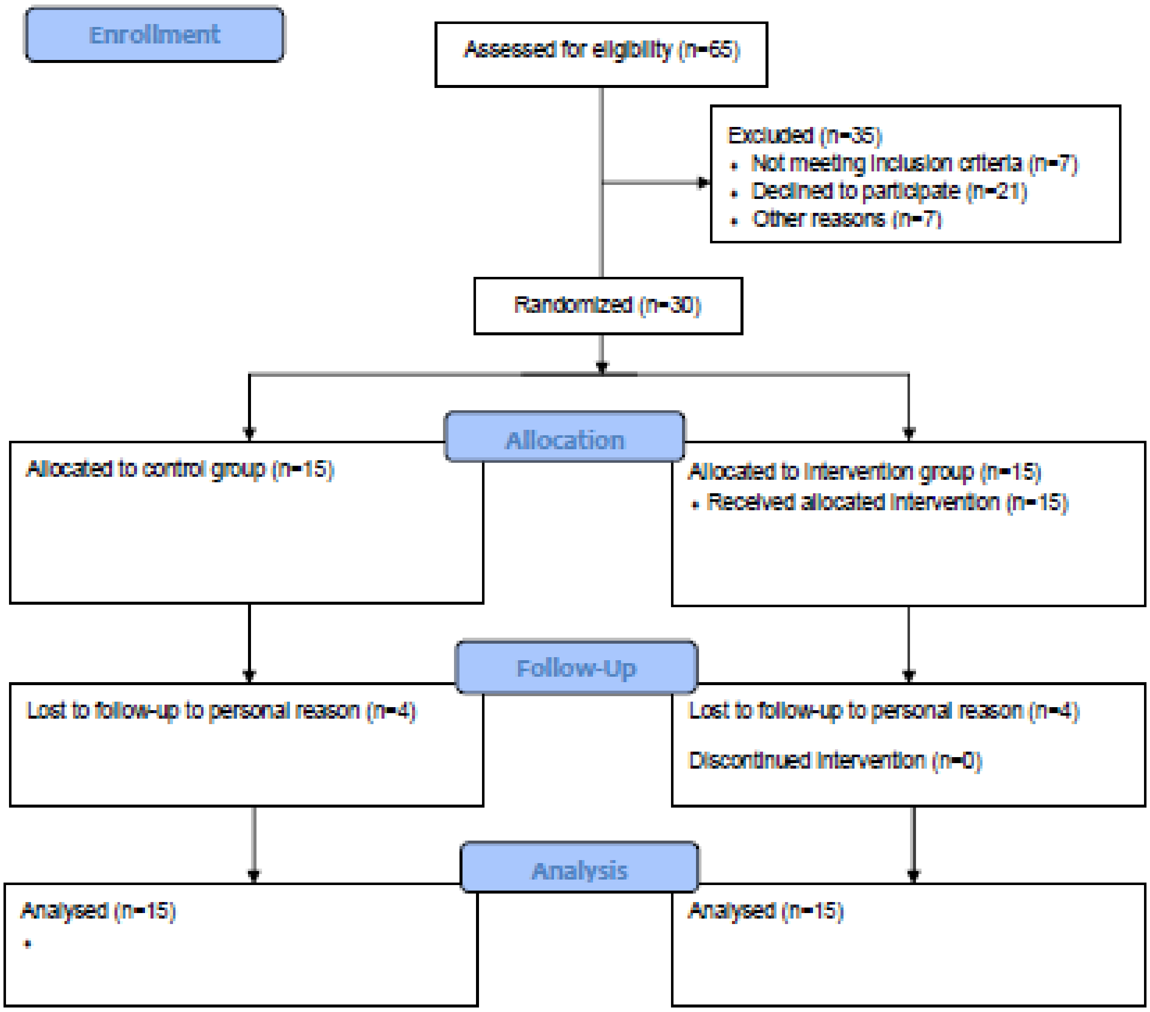


**Figure 1.** CONSORT trial flow diagram of study participants

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sessions (mean difference=1.67, P<0.001) in the intervention group. Analysis of the science grades revealed the interaction effect of group×time (P<0.005, $\eta$=0.17) in the science grades. Figure 2-D shows the significant differences between follow-up and pre-test sessions (mean difference=0.6, P=0.042) only in the intervention group.

Analysis of the literature grades revealed the main effect of time (P<0.01, $\eta$=0.15) in the literature grades. There was neither the main effect of the group nor the interaction effect of group×time on the literature scores in both groups.

## 4. Discussion

This report is part of a study intended to develop the combined memory training program and investigate its efficacy on children with SLD based on a clinical trial study. So, the present pilot study (second stage) was conducted to address the effectiveness of the combined WM training program with the Caillou program [21] and Working Memory Training Program (WMTP) [19] in increasing the working memory capacity. This assessment was done in terms of digit span, letter-number sequencing as a primary outcome, and school achievement as a secondary outcome during 20 sessions in 10 weeks. This improvement lasted until follow-up in the children with SLD. The comparison of effect size showed the large effect of the current program on verbal memory and the small effect on the mathematics and science grades.

One of the advantages of this program was the enthusiastic participation of the children in the intervention sessions. Vernucci et al. found environment and motivation in the intervention to determine the outcome of working memory training [17]. So, in this program, a wide variety of tasks considering all domains of working memory were deliberately designed to make an acceptable situation for memory training. Another finding of the current

**Table 1.** Demographic and clinical characteristic of study participants

| Variables | | Mean±SD/No. | | P |
|---|---|---|---|---|
| | | Intervention | Control | |
| | Age (y) | 9.07±0.96 | 8.93±0.88 | 0.7 |
| | Digit span | 4.9±1.6 | 6.3±2.6 | 0.09 |
| | Letter-number sequencing | 3.9±1.1 | 6.1±2.4 | 0.003 |
| | Mathematics | 1.5±0.8 | 2.1±1.2 | 0.2 |
| | Literature | 2.5±1.2 | 2.4±1.2 | 0.2 |
| | Science | 2.3±1.1 | 2.9±1.2 | 0.9 |
| Gender | Boys | 7 | 8 | 0.5 |
| | Girls | 8 | 7 | |
| Type of learning disorder | Mathematics | 6 | 3 | 0.6 |
| | Writing | 3 | 5 | |
| | Mathematics+Writing + Reading | 5 | 6 | |
| | Mathematics + Reading | 1 | 1 | |

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**Table 2.** Mean and standard deviation of primary and secondary outcomes measures

| Variables | Groups | Mean±SD | | |
|---|---|---|---|---|
| | | Pre-test | Post-test | Follow-up |
| Digit span | Intervention | 4.9±1.6 | 13.3±3.2 | 13±3.7 |
| | Control | 6.3±2.6 | 6±2.1 | 6.4±2.2 |
| Letter-number sequencing | Intervention | 3.9±1.1 | 12.4±1.3 | 12.3±1.2 |
| | Control | 6.1±2.4 | 6.1±2.1 | 6.2±1.9 |
| Mathematics grade | Intervention | 1.5±0.8 | 2.3±0.9 | 2.6±0.3 |
| | Control | 2.1±1.2 | 2.3±1.2 | 2.4±1.1 |
| Literature grade | Intervention | 2.5±1.2 | 2.7±1.0 | 3±0.9 |
| | Control | 2.4±1.2 | 2.4±1.2 | 2.5±1.1 |
| Science grade | Intervention | 2.3±1.1 | 2.6±0.9 | 3±0.7 |
| | Control | 2.9±1.2 | 2.8±1.1 | 2.8±1.1 |

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**Table 3.** Repeated measures ANOVA to determine the effects of combined memory programs on study outcomes at pre-test, post-test, and follow-up between two groups

| Variables | Main Effect | | | | | | Interaction Effect | | |
|---|---|---|---|---|---|---|---|---|---|
| | Time | | | Group | | | Time×Group | | |
| | F | P | ηp² | F | P | ηp² | F | P | ηp² |
| Digit span | 109.75 | <0.001 | 0.8 | 21.1 | <0.001 | 0.43 | 117.7 | <0.001 | 0.81 |
| Letter-number sequencing | 143.8 | <0.001 | 0.84 | 39.64 | <0.001 | 0.57 | 137.2 | <0.001 | 0.83 |
| Mathematics grade | 16.99 | <0.001 | 0.38 | 0.017 | 0.897 | 0.01 | 7.51 | 0.01 | 0.21 |
| Literature grade | 4.85 | 0.01 | 0.15 | 0.65 | 0.43 | 0.02 | 2.94 | 0.06 | 0.09 |
| Science grade | 2.48 | 0.09 | 0.08 | 0.39 | 0.54 | 0.02 | 5.79 | 0.005 | 0.17 |

ηp²: Partial Eta-squared

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program was the durability of the effect of the intervention after two months. It has been reported in the brain mapping literature that long-term WM training could help reorganize the cortex and improve neural function or reorganize cortical maps [25, 26]. The present study results are consistent with the previous studies that have examined the effects of WM training on different aspects of WM [8, 9, 16, 17]. However, there are some disparities between these two studies regarding different intervention protocols (computer WM training), the populations, the number of training sessions (more than 20 sessions), and longer intervention periods.

Because children with SLD suffer from severe difficulties in the digit span task [27], we assessed the quality of the current training program and compared it with other

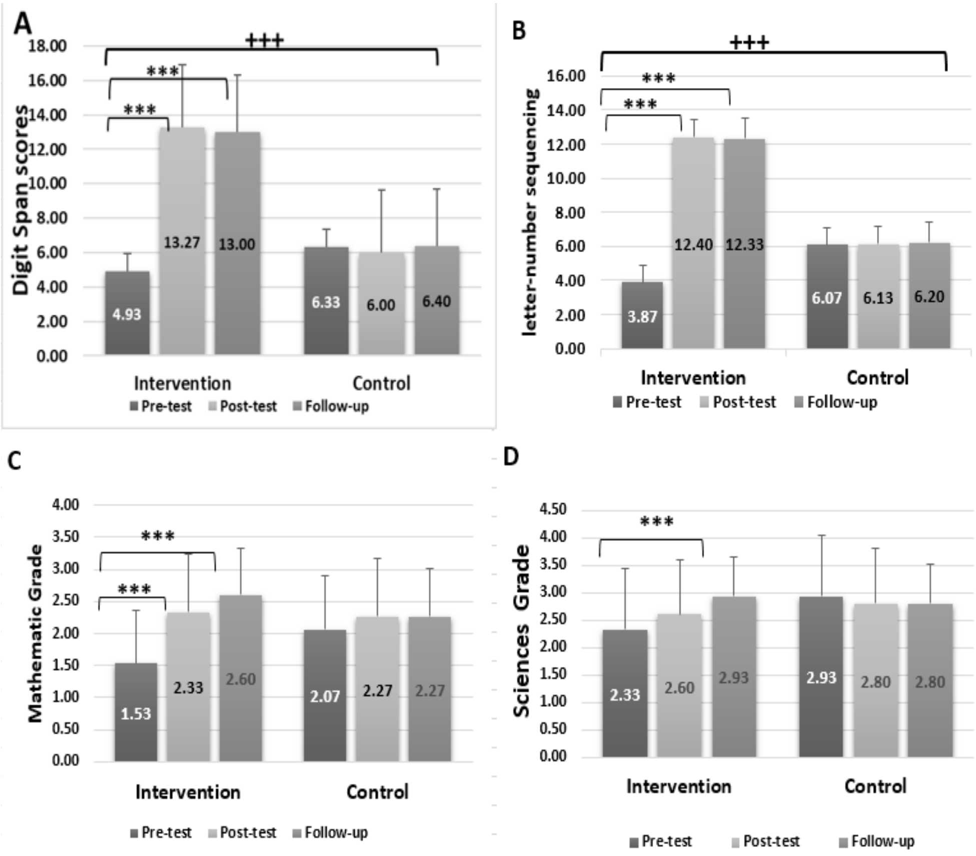


**Figure 2.** The plot of main and interaction effect within and between groups

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**Supplementary 1.** Working Memory Training Program (WMTP)

| Level of Difficulty | Exercises: Verbal-Auditory |
|---|---|
| Easy to moderate | Forward digit span (the examiner repeat the numbers from 2 to 7 digits and within 5 seconds) |
| | Mention 3-7 words that start with a certain letter (for example, 3 words that start with B or A). |
| | We tell 3-5 numbers, letters, names of animals, or whatever to the child and ask him or her to tell us again. |
| Moderate | Listen to the words, remove the first letter and say the new word. (e.g., Table able) |
| | Throwing a ball into specific objectives (e.g., After hearing the number 1, hit the ball to the ground and hear 2, hit it to the wall). |
| | Find a specific device in the room, according to the details we have gotten the child (e.g., next to the chair, inside the closet, and in green color) |
| Moderate to hard | Backward digit span: (Repetition of the numbers was told by the examiner, in a reverse way, from 2 to 7 digits and within 5 seconds) |
| | We read the words, and the child tells us the opposite words (e.g., dark, pretty, bright, moonlight). |
| | Types of orders from simple to difficult (e.g., draw a large circle and a small square inside it) |
| | Categorize cubes with verbal commands, first, vary in number and then in color and number. |
| Hard | To give a contrary answer quickly. Start with 2-word sentences (e.g., are you a boy?) and little by little become more difficult (e.g., Is the moon in the sky at night?) |

| Level of Difficulty | Exercises: Visual-Spatial |
|---|---|
| Easy to moderate | Show several things to the child, and then while his or her eyes are closed, cover one of them, he or she says what the one we covered was. First, use identical pictures (e.g., fruits) and different things in harder stages. |
| | Certain sequences of numbers are written on a card and show the child for 10-15 seconds; then the child should choose the card showing that sequence, among other cards. |
| | Using the objects and animals, jobs, etc., cards: Show 2-7 images of the animals or fruits for 15-10 seconds, then the child should mention them in the same way that has already been seen. |
| | Finding peers: find the similar one or more cards or devices that we have shown before. |
| Moderate | Rey-Osterrieth complex figure: Immediate retrieval, delayed retrieval (Show a figure to the child for 30-15 seconds, then draw it and again draw after a few minutes). |
| | Using the objects and animals, jobs, etc., cards: Picking up a few cards on the table and ask the child to look at them for a few seconds and then close his eyes. We will change their location or cover them with other forms of leaves, and after opening the eyes, he or she tells us the changes. |
| | Show the child a picture for a few seconds (15-30 s) and then ask the child: what was in the pictures. |
| | Show the child a certain letter of the alphabet; then, we grant him a few words. He must identify the words that contain that specific letter. |
| Moderate to hard | Using the cards, using the objects and animals, jobs, etc., cards: We put a few cards and, for example, ask the child that put up the airplane on the machine and orange on the apple. From 1 to 5, orders increases. |
| | Show a few cards quickly, and turn them over, and the child should find similar cards. Start from 4 cards. |
| | Corsi block: Creating shapes using 2-9 cubes by the examiner and then performing by a child. |
| Hard | Show the child 6 cards containing the images of the face, animal, or fruit for a few seconds (10-15), and then show cards that contain only one image of the face, animal, or fruit. The child should recognize which of the second images exists in the cards he or she had seen before. |
| | Some numbers should be written above the cards containing images of animals or fruits and give the child 30 seconds to memorize them. Then, the examiner tells the given number, and the child tells him the name of that image associated with that number. |
| | Prepare a few paper cards with dimensions of 10 x 7 cm and write a word on each one. Give the cards to the child to memorize the words. Then, take the cards out of his or her sight and remove 1 or 2 cards, and then give the child the other cards. Then, the child should mention the cards we removed. |
| | Show him 6 cards containing the images of the face, animal, or fruit for a few seconds (10-15 s), and then show cards that contain only one image of the face, animal, or fruit. The child should recognize which of the second images exists in the cards he had seen at first. |
| | Some numbers should be written above the cards containing images of animals or fruits and give the child 30 seconds to memorize them. Then the examiner tells the given number, and the child tells him the name of that image associated with that number. |
| | Prepare a few paper cards with dimensions of 10 x 7 cm and write a word on each one. Give the cards to the child to memorize the words. Then, take the cards out of his or her sight and remove 1 or 2 cards, and then give the child the other cards. Then, the child should mention the cards we removed. |

studies by the digit-span part of WISC-IV. Although the visuospatial working memory training was included to present the program, one of the major weaknesses of this study was the lack of visuospatial working memory evaluation. So, further research is recommended to assess this part too.

As secondary outcomes, despite the significant improvement in mathematics and science scores, literature scores were not improved. The trend of improvement in the intervention group in science and mathematics differed from that in the control group (Figure 2). These findings were debated in several respects. Our results agree with other studies such as Redick TS et al., further supporting the hypothesis that WM training has a near-transfer effect. On the other hand, it is known that MW training is imperative for academic achievement, but we cannot expect the immediate effects of training on academic skills. The reports show that good improvement in academic performance should be more than two years [28]. Moreover, academic achievement requires various skills and capabilities such as attention, executive function, and problem-solving [7]. Further research is suggested to control these factors.

Memory deficit is a common problem in neurologic patients such as stroke [29, 30], so it is suggested to study the effectiveness of combined memory training on memory skills of these patients in occupational based intervention method [31].

However, some limitations should be considered in future studies. These limitations include assessing the visuospatial working memory, using standard tools for academic achievement, and lack of a long-term follow-up to assess the far-transfer effect.

## Ethical Considerations

### Compliance with ethical guidelines

This study was approved by the Ethics Committee of the Iran University of Medical Sciences (Code: IR.IUMS.REC.1394.9311355012).

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### Authors' contributions

All authors equally contributed to preparing this article.

### Conflict of interest

All authors declared no conflict of interest.

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