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# The effect of computerized cognitive rehabilitation on visual-spatial ability and processing speed of students with a specific mathematical learning disorder

**Azadeh Esmailzadeh Roosbahani\***

Ph.D Educational psychology, faculty of education and psychology, Shahid chamran University of Ahvaz, Ahvaz, Iran.

Corresponding author, email: [az.sm90@gmail.com](mailto:az.sm90@gmail.com)

**Marjan Esmaeilzadeh Rouzbhani**

Master of science in General psychology, Department of Health Psychology, Khorramshahr-Persian Golf International Branch, Islamic Azad University, Khorramshahr, Iran.

**Abstract**--This study aimed to investigate the effectiveness of computer-based cognitive rehabilitation on visual-spatial ability and processing speed of students with a specific mathematical learning disorder. The research design was quasi-experimental, pretest-posttest with the control group, and a two-month follow-up. Among the fourth-grade male students with a specific mathematical learning disorder in Karaj, 40 people were selected by a convenience random sampling method, and with random replacement, they were divided into experimental and control groups. The subjects in the experimental group received the Captain's Log cognitive rehabilitation program individually for 12 sessions of 50-60 minutes. Data were collected by The Advanced Reaction Time Test, The Rey-Osterrieth Complex Figure Test, and the Iran KeyMath Diagnostic Tests. Covariance analysis was used to analyze the data. Computerized cognitive rehabilitation caused the experimental group to show shorter reaction time and more visual-spatial ability in the post-test and follow-up stages than the control group ( $p < 0.05$ ). Therefore, computerized cognitive rehabilitation programs can improve students' visual-spatial ability and processing speed with a specific mathematical learning disorder.

**Keywords**--*Computerized Cognitive Rehabilitation, Visual-Spatial Ability, Processing Speed, Specific Mathematical Learning Disorder.*

## Introduction

One of these disorders is a mathematical learning disorder, which may be determined through academic performance assessments and screening at the age of 8 by numerical magnitude perception, arithmetic fact, accurate and fluent, and correctness in mathematical reasoning (American Psychiatric Association, 2013). According to Net News, LDA of Minnesota (Lemberg, 2011), 6% of students have a learning disability in mathematics. According to another research, between 5% and 8% of children aged 6-14 suffer from a math disorder (Tangsujarijtkol, Luterno, and Bonchudwang, 2020). A mathematical learning disorder is a severe difficulty to acquire mathematical ideas and arithmetic that is often accompanied by brain malfunction (Moghaddam, Esteki, Saadat, and Kooshaki, 2011). One of these children's traits is that they often struggle with spatial connections, visual recall, and sense of form stability (Zaidel, 2015; Esteki, Ashayeri, Borjali, Tabrizi, and Delavar, 2007; Lerner & Johns, 2014). Children with math disorders have problems with visual-spatial processing, motor-psychological organization, visual perception, and idea creation, according to Geary (2010).

One of the most significant cognitive talents in schooling is the visuospatial ability, which comprises high-level neurological capabilities (Possin, 2010; Бровко, K. A., et. al., 2020; Hanawi, S. A., et. al., 2020). Visual dysfunction may restrict the breadth of abilities needed for everyday living, such as reading, writing, and walking; as a consequence, problems with this function can raise anxiety, sadness, and lower self-efficacy and quality of life (Moschos, 2018). In their study of the impact of visual-spatial skills on solving spatial problems, Buckley, Seery, and Canty (2019) discovered a link between higher levels of spatial ability and mathematical performance, and students with higher levels of visual-spatial abilities use more problem-solving strategies. Wright, Thompson, Ganis, Newcombe, and Kosslyn (2008) found that processing speed and visual-spatial skills have a role in mathematical development beyond IQ. Moreover, children who struggle with math have less spatial-visual abilities than children who struggle with reading or spelling (Lambert & Spinath, 2017). Other neuropsychological investigations show that many of these children have functional deficits in the occipital lobe of the right hemisphere, which is critical for visual information processing and, in particular, the sense of spatial connections (Goswami, 2019).

Defects in the information processing system, including attention, memory, organization, and other cognitive functions, are the source of learning difficulties in this disorder (Swanson, 2015). The rate at which information is processed is a perceptual-cognitive capacity (Swanson, H. L., Harris, K. R., & Graham, 2013). "Processing speed" refers to the time it takes to complete a task while maintaining accuracy (Jacobson, Ryan, Martin, Ewen, Mostofsky, Denckla & Mahone, 2011). Children with math disorders process information much quicker than typical children (Bartelet, Ansari, Vaessen & Blomert, 2014). In their study, Moll, Göbel, Gooch, Landerl, and Snowling (2016) discovered three cognitive abilities linked to attention problems in children with reading and math disorders that may be shared by both disorders: speed information processing, temporal processing, and working memory. The temporal processing is the capacity to estimate, reconstruct, and detect time (Castlanoz and Tannock, 2002; Toplak, Dockstader

& Tannock, 2006). According to Kibby, Vadnais, and Jagger-Rickels (2018), processing speed problems are mostly connected to negligent issues, and processing speed is not a single process but a comprehensive system.

Learning programs based on cognitive rehabilitation are one of the most effective therapies for easing impairments (Narimani, Soleimani, and Tabrizchi, 2015; Finn & McDonald, 2011). Through successive arousal, computerized cognitive rehabilitation, based on brain plasticity and self-healing, generates stable synaptic modifications in the brain's less active regions (O'Connell, Belgro, & Robertson, 2007). These programs may alter the task complexity from easy to challenging depending on individual characteristics and provide continual cognitive challenges for the user (Gaitán, Garolera, Cerulla, Chico, Rodriguez Querol, & Canela Soler, 2013). In this respect, Svaerke, Niemeijer, Mogensen, & Christensen (2019), Svaerke, Omkvist, Havsteen, & Christensen (2019), Celeste, Muratori, Mapelli, & Pepi (2017), Azizi et al. (2017), and Arjmandnia, Sharifi, & Rostami (2014) have demonstrated that computerized cognitive rehabilitation is effective in visual-spatial empowerment of patients with hemianopia, stroke, hyperactivity and learning disabilities. Numerous empirical studies have also shown that computer programs and cognitive rehabilitation based on continuous training improve memory function, information processing speed, and hence the ability to learn new information (Chiaravalloti, Goverover, Costa & DeLuca, 2018; Kesler, Lacayo & Jo, 2011; Chisholm, Hickey, Theeuwes & Kingstone, 2010; Ojeda et al., 2010; Akbarifard, Ahmadi, Fatehabadi and Salehi, 2019; Soleimani et al., 2018).

Captain's log software is one of the most extensively utilized applications for cognitive rehabilitation and enhancement. It is possible to strengthen and increase people's mental capacities in various professions by using this software. This program contains over 2000 unique exercises targeting 20 cognitive skills intended to help individuals with attention deficit hyperactivity disorder (ADHD), learning disabilities, brain injuries, mental retardation, and psychiatric disorders such as schizophrenia and mood disorders improve their performance. This program concurrently enhances and upgrades both fundamental and superior cognitive processes; as a result, one's talents and capacities to learn and succeed in a variety of everyday, academic, and professional life may be enhanced (Fine, A. H., & Kotkin, 2003). The study topic was, in general, whether the cognitive rehabilitation program had an effect on children with particular math deficiencies' visual-spatial skills and processing speed.

## **Method**

The study used a quasi-experimental design with a pre-test-post-test design, a control group, and a follow-up period.

### **Society, sample, and sampling method:**

Among the fourth-grade male students with a specific mathematical learning disorder in Karaj, 40 people were selected by a convenience random sampling method, and with random replacement, they were divided into experimental and control groups.

Data were gathered using the following questionnaires:

**Reaction Time Test (RT):** This instrument was used to determine the reaction rate in this investigation. This test is utilized for people of various ages. The Sina Cognitive Behavioral Science Research Institute developed the program, which measures two types of reaction time: Simple Reaction Time (response to a simple stimulus with the right index finger) and Choice Reaction Time (response to two stimuli with two right and left index fingers). Using Cronbach's alpha coefficients of 0.71 and 0.75, Narimani and Soleimani reported the test's reliability in two different trials in 2012 and 2011. (Oraki, Shetab Bushehri, and Abedanzadeh, 2016). For simple and choice response times, Oraki et al. (2016) obtained a reliability value of 0.85. The reliability of this test was determined in this study using three methods: Cronbach's alpha, Spearman-Brown, and Guttman halving for simple reaction speeds of 0.90, 0.79, and 0.82, respectively; diagnostic reaction speeds of 0.86, 0.77, and 0.70; selective reaction rates of 0.76, 0.66, and 0.76; and complete test reliability of 0.87, 0.71, and 0.80. In addition, the content validity ratio of the Advanced Reaction Time Test for Simple Reaction Speed 0.92, Diagnostic Reaction Speed 0.96, and Choice Reaction Speed 0.93 was achieved in this research, which was reviewed by 10 experts from Learning Disorders Training Centers in Karaj.

**Rey Complex Figure Test:** This test was designed to analyze and evaluate visual memory and spatial perceptual organization. Andre Rey devised this test in the 1930s, and Street (1944), one of Rey's students, subsequently modified it. The test comprises two cards, A and B, and is administered in two phases, each of which is chosen and administered independently and on occasion. The first step is to duplicate the form. At this stage, examining the subject's sketching pattern demonstrates how perceptual activity occurs. The second stage is memorization production, which reveals the depth and precision of visual memory (Bahrami, 2004). According to Ahadi and Mirhashemi (2003), this test has a validity coefficient of 0.77 in the copy stage, 0.51 in the reminder stage, and a validity coefficient of 0.624 in the validity stage. Mirhashemi (1992) determined the reliability of the Wechsler Memory Scale subtest using the retest technique to be 0.62, which indicates satisfactory reliability. The correlation coefficient between age and participants' ability to organize their visual-spatial information was substantial in this research ( $r = 0.41$ ,  $p < 0.01$ ), indicating the validity of the test's structures. The reliability of this scale was 0.88, 0.80, and 0.82 for visual perception, 0.81, 0.68, and 0.70 for visual memory, and 0.89, 0.74, and 0.77 for the overall test, respectively, using Cronbach's alpha, Spearman-Brown, and Guttman methods. Furthermore, the current research found that the Andre Rey complex figure test had a content validity ratio of 0.89 for visual perception and 0.91 for visual memory when reviewed by ten specialists from the Learning Disorders Training Centers in Karaj.

**Wechsler Intelligence Scale for Children - Fifth Edition (WISC-V):** The Wechsler Intelligence Scale for Children, Fifth Edition (WISC-V) is a thorough clinical instrument for testing the intelligence of children aged 6 to 16 years and 11 months and one of the most comprehensive tests for measuring multiple IQ scales. In 2014, the fifth edition was released. The WISC-V comprises ten primary subtests, six secondary subtests, and five complementary subtests. Canivez,

Watkins, and Dombrowski (2017) graded the omega-hierarchical coefficients of ten key subtests and the overall intelligence quotient as high and adequate while analyzing the construct validity of the Wechsler Intelligence Scale for Children - Fifth Edition (0.82). Sadeghi, Rabiee, and Abedi (2015) used semi-quantification and retest techniques to compute the validity of the four-Persian Wechsler intelligence test and reported the retest validity coefficients for all subscales except the subscale of visual ideas, which ranged from adequate to outstanding. Mousavi Sadati and Jirsarai Bazargard also modified and standardized this test on a sample of Iranian children (2019). The halve validity coefficients of this test ranged from 0.71 to 0.86, while the validity of the subtests in the retest ranged from 0.65 to 0.95. The Wechsler Intelligence Scale for Children - Fifth Edition was used in this research to measure the IQ and associated cognitive processes of children with learning difficulties (sample). WISC-V validity was determined by content and predictive validity scores ranging from 0.61 to 0.79, as well as cross-correlation between Wechsler subtests (WISC-V) values ranging from 0.56 to 0.84. The reliability of this test was also studied in this research, with reliability coefficients of 0.81, 0.89, and 0.88, respectively, using Cronbach's alpha, Spearman-Brown, and Guttman halving techniques.

**Procedure:** Following the completion of the Wechsler Intelligence test, students' adaptation to the diagnostic criteria for learning disabilities based on DSM5 and definitive diagnosis, as well as the consent of students and their parents to participate in the study, 40 people were randomly selected and divided into two groups of 20 people each (20 in the experimental group and 20 in the control group). Because it was their time to establish a training class, the 20 control groups received no additional intervention or instruction, except the standard training offered by the school instructor in the classroom. The experimental group got 50 minutes of therapeutic education and 50 minutes of cognitive rehabilitation utilizing the Captain's Log approach.

Brain Train originally debuted the Captain's Log rehabilitation program in the United States in 2000. These sessions included step-by-step computer activities that tested spatial-visual ability and processing speed (if progress is made in one stage, permission to enter another stage, which is more difficult exercises). Table 1 of the Captain's Log Cognitive Rehabilitation Intervention Program (2018 version) lists the sessions' aims and instructional material.

Table 1  
Objectives and Content of Captain's Log Cognitive Rehabilitation Training Program (2018 Edition)

Sessions	Target	Content
First	Introducing the software and familiarizing subjects with it and how to use it	The participants were instructed on the software environment and how to use it. Additionally, during this session, the user IDs for each subject were created, the software identified the first levels of references as a pre-test, and the appropriate diagrams and information were presented to the therapist.
Second	Visual-spatial ability	Happy Trails?

		Max's Match?
Third	Visual-spatial ability	Hide & Seek Concentration
Fourth	Visual-spatial ability	What's Next? Tower power?
Fifth	General Attention Skills	My story messages The great hunt detective Smart
Sixth	Processing speed	Where is my car? Bingo discovery
Seventh	Processing speed	Lost and found Pick quick Birds of a feather
Eighth	Processing speed	Touchdown! A day at the races The topic was done concurrently and one after the other at the start of the session, with cognitive exercises from previous stages being given sequentially from the last stored level.
Ninth	Consecutive and integrated performance of visual-spatial exercises and processing speed and reviewing sessions	The therapist showed the diagram relating to the subject's performance in the previous session, and the subject was monitored; the therapist then summarized and administered post-tests and offered explanations for the outcomes. Finally, participants and their parents were acknowledged for their participation in the study.
Tenth	Post-test	

## Results

Table 2 displays descriptive markers of visual-spatial skills and response times by experimental and control groups in the pre-test, post-test, and follow-up stages. Table 2. Mean and standard deviation of research variables by experimental and control groups in three measurement stages

Variable	Measuring Stage		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
	Posttest	Follow-up						
Visual-spatial abilities	Reaction times							
Visual perception		Experimental	28.50	0.89	30.10	1.21	29.70	0.73
Visual memory		Control	30.00	1.12	29.70	1.17	29.90	1.37
		Experimental	15.20	0.41	16.50	0.69	16.55	0.76

	Simple Reaction Time	Control	15.60	0.88	15.60	0.60	15.40	0.75
	Diagnostic Reaction Time	Experimental	121.10	18.47	108.05	18.38	108.75	17.32
	Choice Reaction Time	Control	111.70	12.75	113.00	13.03	113.00	13.10
		Experimental	190.85	37.52	146.70	22.82	147.00	23.24
		Control	183.95	22.90	184.35	22.12	185.05	21.17
		Experimental	197.55	26.71	135.60	23.95	146.30	28.80
		Control	195.00	25.71	200.75	27.15	197.45	26.83

The Kolmogorov–Smirnov test was used to assess the normality of the distribution of scores between the two groups in the research variables, Levene's test was used to determine the equal variances of research variables in the community, and Box's M test was used to assess the homogeneity of variance-covariance matrices before performing the multivariate analysis of covariance. These tests returned non-significant findings ( $p > 0.05$ ), and an examination of the homogeneity of the regression line slope confirmed the non-significant interaction between conditions and pre-test ( $p > 0.05$ ). Moreover, Bartlett's Test of Sphericity was performed to determine the default value for the normal correlation between covariate variables or pre-tests. With the significance of the KMO index and the estimated chi-square value for the Bartlett sphericity test ( $p < 0.05$ ), it is possible to conclude that there are no multiple correlations between covariate variables and that the correlation between covariates is normal. As a result, the results did not cast doubt on the assumptions behind the use of covariance analysis. So, based on the assumptions, the analysis of covariance can be used.

After controlling the influence of the pre-tests, a multivariate analysis of covariance was done on the data to compare the experimental and control groups based on post-test results and to track the visual-spatial skills and response times. In the post-test stage with pre-test control, significance levels of all multivariate tests for visual-spatial abilities ( $p < 0.01$  and  $F = 10.66$ ) and reaction times ( $p < 0.01$  and  $F = 138.60$ ) were obtained, while in the follow-up phase with pre-test control less than 0.01 significance levels of all multivariate tests for visual-spatial abilities ( $p < 0.01$  and  $F = 13.67$ ) and reaction times ( $p < 0.01$  and  $F = 54.88$ ) were obtained. Consequently, the null hypothesis is rejected, and it is determined that there is a significant difference between the experimental and control groups' visual-spatial skills and response times at post-test and follow-up. The inter-subject effects test was performed to determine the differences between the experimental and control groups in the visual-spatial skills and response times. The findings are provided in Table 3.

Table 3  
Experimental effects of post-test comparison and tracking of visual-spatial abilities and reaction times with pre-test control

size	Variable	Posttest		Follow-up			
		F-ratio	P-Value	F-ratio	P-Value	Effect size	Effect
Visual-spatial abilities	Visual perception	7.99	0.008	0.18	0.18	0.678	0.01
Reaction times	Visual memory	16.25	0.001	0.31	20.33	0.001	0.36
	Simple Reaction Time	55.49	0.001	0.61	46.34	0.001	0.57
	Diagnostic Reaction Time	90.07	0.001	0.72	74.32	0.001	0.68
	Choice Reaction Time	113.11	0.001	0.76	41.40	0.001	0.54

According to the data reported in Table 3, there is a significant difference in post-test visual-spatial skills and response times between the experimental and control groups ( $p < 0.01$ ). As a result, the null rejection hypothesis and the study hypothesis that computer cognitive rehabilitation may help students with particular arithmetic learning difficulties improve their visual-spatial ability and processing speed have been validated.

Furthermore, Table 3 shows that controlling the pre-test revealed a significant difference between the experimental and control groups in visual memory tracking and response times ( $p < 0.01$ ). However, this difference was not significant ( $p > 0.05$ ) in the case of visual perception.

### Conclusion and discussion

This research aimed to investigate the impact of computerized cognitive rehabilitation on children with particular learning disabilities in mathematics in terms of visual-spatial ability and processing speed. According to the first part of the study findings, computerized cognitive rehabilitation increased the visual-spatial capacity of children with particular arithmetic learning difficulties in the dimensions of visual perception and visual memory. This finding is consistent with the results of Svaerke et al. (2019), Celeste et al. (2017), Azizi et al. (2017), and Arjmandnia et al. (2014), which demonstrated that computerized cognitive rehabilitation is effective and consistent in visual empowerment patients with impaired cognitive and visual memory impairments caused by hemoptysis, stroke, hyperactivity, and learning disabilities. Cognitive rehabilitation, which involves the development of neural pathways and the creation of new ones, results in sustained structural and chemical changes in the visual-spatial perception of students with special math learning disabilities, such as increased brain-derived neurotrophic factor (BDNF) levels (Churchill, Gallows, Calcombe, Sweeney,



Kramer and Greenaw, 2002). Consequently, in learning impairments, cognitive rehabilitation with proper and regular stimulation of distorted brain areas may result in long-term modifications in those regions, as changes in the structure of brain neurons occur and stay constant (Azami, Moghadas, Hemmati, and Ahmadi, 2013). The tools used in the Captain's log software training program are unique for each activity, preventing repetition and practice in kids and ensuring that the tools used are uniform for children. The appealing look of these games encourages the child to do these exercises with more enthusiasm and without exhaustion, and having a time limit enables the child to exert more effort and raise the speed of action in the visual-spatial processing of stimuli. Each activity is completed quickly, avoiding tiredness (Gaiten et al., 2013). Another factor to consider when enhancing the visual-spatial ability of students with special learning disabilities is that Captain's log cognitive rehabilitation software, inverted reminder, conceptual discrimination, and numerical composition programs all require attention and focus; otherwise, the subject will be unable to complete the task. As a result, the adoption of these programs strengthens the subject's visual-spatial abilities.

The second section of the study revealed that computer cognitive rehabilitation improved the processing speed of students with unique difficulties of mathematics learning in the dimensions of basic response time, diagnosis, and selection. This finding is consistent with the results of several studies demonstrating that computer programs and cognitive rehabilitation based on continuous training have increased the speed of information processing and hence the capacity for new learning (Chiaravalloti, Goverover, Costa & DeLuca 2018; Kesler, Lacayo & Jo, 2011; Chisholm, Hickey, Theeuwes & Kingstone, 2010; Ojeda et al., 2010; Akbari Fard, Ahmadi, Fathabadi and Salehi, 2019; Soleimani et al., 2018). The speed with which information is processed is a cognitive function that may be increased by cognitive, educational interventions. In this line, Kessler et al. (2011) showed that increasing frontal brain activity increases information processing speed and cognitive flexibility. This observation is also consistent with the PASS theory. According to this theory, when cognitive rehabilitation therapies are delivered through a computer, they may help the brain concentrate on the primary stimulus and avoid reacting to irrelevant stimuli over time (Ghamrani and Samadi, 2017). This is evident in the performance of the period of psychological unresponsiveness, in which two stimuli are generally presented at very short intervals, one of which is unrelated and the other of which is the primary stimulus, and one must avoid responding to both the irrelevant stimulus and the main stimulus. According to PASS theory, the task presentation during psychological unresponsiveness is a continuous process with distinct periods during which the individual must resist reacting to extraneous stimuli. Thus, computerized cognitive rehabilitation, while enhancing information processing and individual response time, may also affect the process of remembering and learning for children with unique learning problems, according to a recent psychological perspective. Overall, given the brain pathways involved in cognitive computer assignments (Ciesielski, Lesnik, Savoy, Grant & Ahlfors, 2006), computerized cognitive rehabilitation seems to be well involved in the processing speed of students with disabilities learning math for the following reasons; Existence of different visual and audio stimuli, with simultaneous involvement of sensory areas (for processing sensory data input), prefrontal cortex (for processing

task complexities and choosing the appropriate strategy for responding to the task) and movement areas (for providing movement feedback), areas the brain related to working memory, i.e., visual-spatial ability. Involvement and activation of working memory brain regions are highly effective when the activity has an emotional component to it (instant reward) or failure (immediate punishment) (failure to progress to the next level).

The current research has many limitations, including a drop in subject enrollment owing to coronavirus illness and the closing of educational institutes. Other limitations of this research were the unavailability of the Persian language in the captain's log program and certain pupils' lack of mouse abilities. The purpose of this study is to investigate spatial-visual skills in general. It is advised that in future research, all sub-components of this variable be studied and quantified.

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