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Meta-Analysis of the Effectiveness of Transcranial Direct Current Stimulation on the Memory of People with Learning Disabilities

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ABSTRACT

Background and Aim: Learning disabilities, problems processing information obtained from the surrounding environment, are based on neurological disorders. These processing problems can interfere with learning basic skills such as reading, writing and/or math. The aim of the present study was to Meta-analyze the effectiveness of electrical brain stimulation on the memory of people with learning disabilities. **Methods:** This research was conducted using the meta-analysis method. The statistical population included all Persian and English researches conducted in the field of effectiveness of brain electrical stimulation intervention on memory improvement of people with learning disabilities. Among them, researches with meta-analysis criteria were reviewed by comprehensive meta-analysis software. **Results:** These studies were based on 450 samples and 26 effect sizes. The meta-analysis results showed that the effect size of brain electrical stimulation on memory improvement of people with learning disability is d=1.188. This effect size is an acceptable value according to Cohen's table. **Conclusion:** The results indicate that electrical stimulation of the brain has a great effect on improving the memory of students with learning disabilities; therefore, it was suggested that experts use these interventions to improve the memory of these students. Also, paying attention to the type of learning disorder is important in the effectiveness of the treatment.

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Introduction

Today, it is almost impossible to explain behavior without considering the function of its neural organization. With progress in understanding and the importance of information, the importance and role of information arrangement and environmental data and the role of the brain in information processing are also revealed (Mirski, 2018). Neuropsychology not only provides the possibility of understanding the relationship between behavior and the cerebral cortex, but at the same time it also acts as a tool and acts as a model and framework on the one hand and as a mechanism and working method on the other hand. (Marzi, 2020).

Neuropsychological science is the study of the relationship between the brain and behavior, and neuropsychological assessment includes the use of this field of knowledge to evaluate and intervene in human behavior as a product of normal and abnormal functioning of the central nervous system (Horovitz et al., 2020).

Neuropsychological assessment is an indirect study of the brain. In this method, instead of directly studying the structure of the brain by using neuropsychological tests, abilities and functions such as memory, abstract reasoning, problem solving, spatial abilities and emotional and personality consequences caused by brain distortion are studied. (Elling, 2019).

Learning disabilities is also a neuropsychological disorder that manifests as serious difficulties in learning and using listening, speaking, reading, writing and calculating in children with normal intelligence (Grigonko et al., 2019). So that these disorders have a neurological origin and have a developmental process that starts before elementary school and continues until adulthood (Fletcher et al., 2018). Most experts and psychologists have pointed to three main classes in this category of disorders, including reading disorders, writing disorders, and mathematics disorders (Dominguez & Caragno, 2020).

In math disorder, the affected student generally has a defect in four skills, which are: 1) language skills (such as understanding and naming mathematical terms, understanding and naming mathematical actions and concepts and converting them into symbols) (Atkinson, 2018); 2) cognitive skills (such as recognizing and reading numerical symbols or arithmetic signs and grouping figures) (Gray, 2014); 3) math skills (such as following math steps, counting and learning the multiplication table); 4) perceptual skills (such as correctly copying figures, memorizing figures) (Hacker, Kyohara, & Levine, 2019). Lerner (1993) says that about six percent of school-aged children have problems in the mathematical process. A condition that causes permanent problems in calculation and numerical process is often known as calculus failure. Arithmetic deficiency is a profound inability to learn mathematical and computational concepts that is related to the use of the brain (Soares, Evans, & Patel, 2018). Reading disorder problems are one of the most basic problems that children with learning disorders face (Halahan, Pullen, and Ward, 2014); Because a child who cannot read has very little chance to succeed in school (Swanson & Zheng, 2014). Kupitz believes that before a child learns to read, he must have reached a stage of visual-motor development, and the main part of the complex process of reading is to understand the patterns of spatial relationships and shape organization (Fletcher et al., 2014). In addition, sometimes these children's reading difficulties are accompanied by spelling problems. Sometimes, due to the environmental pressures and the inattention of those around them to the special abilities of this group of children, mental and behavioral problems are added to these problems (Kope et al., 2012).

Reading disorder is a disorder in which, despite conventional classroom experiences, a person is unable to acquire language and spelling skills that correspond to his intelligence ability (Peters & Ansari, 2019). In people with reading disorders, reading aloud is associated with distortion, substitution is associated with the omission of sounds, and reading with and without sound is characterized by slowness and inferential errors (Kang et al., 2021).

Today, attention is focused on how the brain performs reading, writing, and mathematics, and how the actions of this system, known as cognition, are related to neural substances. Over the past five decades, extensive studies have been conducted on neuropsychological factors affecting learning disabilities (Grigorenko et al., 2020).

One group considers dysfunction of the central nervous system as the main cause of learning disorders, and one group considers it to be caused by perceptual disorders and motor-perceptual coordination, memory and attention weakness, weak organization and cognitive function, and one group considers it to be a delay in information flow. (Platzer & Lemke, 2021; Munis et al., 2019; Last et al., 2022; Bharati, 2021)

In the etiology of learning disorder from the point of view of medical knowledge, the cause of this disorder is attributed to its biological origin and fields such as brain damage, brain lesion, apraxia and agnosia (Lake, Dutton and Chorkun, 2019). In this field, psychologists have looked for issues such as perceptual disorders, impulsive behavior, non-stop behavior, involuntary repetition, hyperactivity (Gabriili, Tarasch, Veliki and Ovadia-Blackman, 2020). Knowledge related to language (linguistics, language evolution, language pathology and language psychology) has paid attention to learning disorders as a new phenomenon in the realm of language disorders. In this regard, they have addressed cases such as aphasia, dyslexia, anomia (forgetting names), expressive and receptive language disorders (Muziko, 2022).

Instead of investigating the cause and psychological root of this disorder, laboratory science has focused its most emphasis on learning conditions (Mikiak & Fletcher, 2020). Since the formation of neuropsychological science, attention has been paid to cognitive functions. Cognitive disorders, as part of the problems of children with learning disabilities, is not a new concept, and basic learning disabilities are considered as neuropsychological dysfunctions (Zhang et al., 2020).

The main purpose of assessing learning disability is to identify strengths and weaknesses in order to provide an educational program; Since one of the causes of learning disorders includes neurological defects and mainly damage to the central nervous system (Torgsen, 2018). Neurocognitive deficits include problems in visual and tactile perception, psychomotor coordination, visual and tactile attention, non-verbal memory, reasoning, executive functions and special problems in aspects of language and speech (Aminlou, Daramadi, and Khalatbari, 2022). .

A review of studies shows that children who have problems in mathematics; They usually have problems with spatial perception. For example, they get confused in understanding the concepts of up, down, left, right, below, back and front, etc., and these problems cause disturbances in the mental image of the number system. It causes these children to not be able to recognize the distance between the numbers and their corresponding place (Bishara, 2018; Dergas et al., 2022; McDowell, 2018). The occurrence of these problems is caused by damage to the parietal lip (Grikorenko et al., 2018); However, damage to this area does not have a problem with oral language skills (Chakron, Quarsky, & Dutton, 2021).

Damage in the temporal lobe in addition to visual-spatial ability, short-term memory. It also impairs working memory, and left temporal-temporal damage seriously impairs the ability to remember the sequence of numbers (Mahmoud et al., 2020). These areas mainly play a role in maintaining verbal materials, and the right temporal-parietal areas play a role in maintaining non-verbal materials such as spatial status. Researches have also assigned a complementary role to the temporal and temporal lobes in memory (Fletcher et al., 2018).

Research also indicates the role of the frontal lobe in the use of memory (Horwitz et al., 2020). In a research, Patel et al showed that the temporal and temporal regions are more active in the auditory working memory test in dyslexics. A low score in calculating and reading figures is a reflection of poor attention or sequence (Patel et al., 2018). In a research, Schwartz came to the conclusion that the performance of children with learning disabilities in the Wechsler IQ scale's attention triangle (calculation, number span, coding) is weak and is correlated with their reading and mathematics scores (Schwartz, 1985). On the other hand, the results of Siu et al.'s experiment show that different brain regions are activated differently for types of accuracy and attention. For example, during spatial attention and accuracy, the parietal cortex is activated, and when attention is focused on the features of shape and color, the activity of the occipital parietal cortex increases. Bailey et al. provide another model of accuracy and attention, which is located in the frontal lobe and is closely related to short-term memory, and the degree of involvement of the frontal lobe regions depends on the level of accuracy and attention (Bailey et al., 2016).

In recent years, educational scientists began to study the brain as the main commander of the body and sought to develop memory and learning performance through the application of safe methods; A process that seems to be followed through the development of cognitive functions

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followed by memory improvement. Now the question was how the brain can limit or improve the memory enhancement process and regulate it in general (Khan et al., 2019).

In fact, according to cognitive theories, cognitive interventions are considered as effective factors in optimizing students' memory skills from two cognitive and psychological functional effectiveness systems. It affects students' cognitive and behavioral reactions (Beck & Beck, 2011; Porchaska & Norcross, 2018). So far, several studies have shown the essential role of the brain in determining memory enhancement and improvement; Therefore, the development of innovative methods to aid memory performance is of great interest.

One of these methods is the use of direct current stimulation through the skull (tDCS). tDCS is a non-invasive technique that creates a weak electric current through the depolarization of the resting membrane potential (anode stimulation, a-tDCS) or cortical inhibition (cathode stimulation, c-tDCS). It is capable of stimulating the brain by increasing the polarization of the resting potential of the membrane; That is, increasing or decreasing the spontaneous firing rate of nerve cells is affected by the electric current (Flimer, Mattingly, and Dax, 2020; Thayer et al., 2017).

Adolescence is an important period of social, psychological and physical development. Adolescents make important choices about health, developing attitudes and health behaviours that affect their adulthood (Brovar et al., 2021). In recent years, overweight and obesity have spread among many societies and countries (Novak et al., 2021).

Overweight is a public health problem in developed and developing societies, affecting one-third to fifty per cent of adults (Waden et al., 2021). Overweight is defined as a state in which the body weight is 10 to 19% higher than the ideal weight (the ideal weight is determined both according to the body mass index and according to the ratio of weight to height). When the body weight is 20% more than the ideal weight, it is called obese (Sanderson, 2013).

Overweight and obesity are worrisome because they significantly impact health and longevity. In addition to health-related problems, the psychological consequences of being overweight and obese include low self-esteem, inappropriate body image, low quality of life, and high scores in anxiety and depression symptoms. (Sarafino, 2007). Some studies also indicate that rumination is related to restricted eating behaviours, emotional eating and external eating in overweight and obese people. (Hirsch, Klausner, and Brandt, 2014, cited in Tabrizi, Qamari, Farahbakhsh, and Bezazian, 2019).

In recent years, the examination of thinking patterns and thoughts in people involved with inappropriate body mass index and their role in the continuation of a sedentary lifestyle and inappropriate nutrition has attracted the attention of experts and clinical researchers; One type of these patterns is rumination (Verenko et al., 2020). Rumination is an abnormal emotional cognitive regulation method that people show in response to experiencing a negative mood. They are a set of passive thoughts that have a repetitive aspect, are focused on the causes and results of symptoms, and lead to an increase in negative thoughts (Rood, 2015, quoted by Dereshian, Salehi, Gharibdoost, and Mahmoudi, 2020). It is a class of conscious thoughts that is defined around an axis. These thoughts are frequently repeated without the need to request an environment related to them (Cohen, Moore, & Henick, 2015).

Research results indicate that a high score in rumination is associated with inappropriate nutritional behaviours and adolescent body image dissatisfaction (Marco et al., 2021). People with a higher level of rumination face problems in cognitive functions and experience a higher level of avoidance (Zamani & Gurban Jahrami, 2019).

On the other hand, some studies have shown a negative and significant correlation between distress tolerance, experiential avoidance and rumination (Sadighi et al., 2021). Individuals with low distress tolerance usually perceive stress and anxiety more, and anxiety symptoms may lead to avoidance responses or laboured performance (Geller et al., 2021).

In fact, distress tolerance is a personality variable that has shown itself in many ways in contemporary psychological literature through various inferences. It refers to how a person processes information in an ambiguous situation and responds to it with cognitive, emotional and behavioural reactions (Radmehr & Karmi, 2019). Tolerating distress is accepting uncertainty as a part of life, the ability to continue living with incomplete knowledge, and the willingness to start an activity without knowing whether one will succeed. (Antonik, 2009 quoted by Malikpour Lepari & Bakhtiari Renani, 2021).

A review of previous studies shows that distress tolerance appears in two ways in adolescents. One form of it refers to a person's ability to tolerate negative emotions. Another form of behavioural manifestation is the tolerance of unpleasant internal states that are called by various stressful situations (Zegel et al., 2021). Therefore, when adolescents with a high body mass index face stressful situations, they respond more strongly. By thinking about it, they try to reduce these negative emotional states by avoiding them and using emotion-oriented methods to eliminate stressful situation. (Rezapour Mirsaleh & Ismail Beigi, 2017).

Erkan and Yariari (2014) showed that stimulating the brain through the skull using direct electric current (TDCS) affects executive functions. Arjamandania et al. (2016) also showed that the intervention of electrical stimulation of the brain effectively improves the working memory of students with math disorders. What is clear is that tDCS can enhance learning functions by improving memory functions. Despite such specified advantages for using tDCS, there is still another challenge: the license to use this device on students with learning disabilities. In the meantime, it seems that tDCS is still not welcomed by parents of students with learning disabilities, and this attitude change requires advertising programs and of course receiving scientific approvals; Therefore, what is certain is that extensive research is needed for the application of tDCS, and its use in the educational community should be done with caution. Therefore, this study was conducted to investigate this research question, whether transcranial direct electrical stimulation techniques lead to the optimization of memory performance of students with learning disabilities or not.

Method

In this research, compound meta-analysis has been used to collect, combine and summarize research findings related to the effect of transcranial electrical stimulation on the memory performance of people with learning disabilities. In meta-analysis, the basic principle is to calculate the effect size for individual studies and return them to a common matrix and then combine them to achieve the average effect. The statistical population of this research in the systematic review stage was all the articles related to the topic and indexed in the databases of Pop Mod, Google Scholar, Science Direct, Scopus, Cochran Database, PsychInfo, Jihad Dhanshi, Mag Iran. The time range considered for searching articles is from 2011 to 2021. The keywords used included transcranial electrical stimulation, learning disorder, memory function. The sources of the selected articles were screened and the relevant reviews were carried out by the authors of the article independently. The criteria for selection and exclusion of articles was defined in such a way that the studies were included in the research if the subject of the research was transcranial electrical stimulation in the field of improving memory and working memory of students with learning disabilities; had the necessary conditions in terms of methodology (hypothesis formulation, research method, population, sample size and sampling method, measurement tool, statistical assumptions, statistical analysis method and correctness of calculation); The results of the research can be accessed through the reliable sites investigated in this research. Exclusion criteria also include items such as 1) the article is a research summary; 2) the article is done in a review and correlational form; 3) their full text is not available; 4) Articles that have received zero points based on the evaluation list; (Having the minimum criterion for meta-analysis (1) and not having the minimum criterion for meta-analysis (0) were considered). To extract the data, using the research selection checklist, the data of each study was extracted independently. The recorded characteristics of the study included the name of the year of publication of the article, sample size, age and gender of the participant, intervention protocol, type of feedback, type of control, type of electrode used, duration of intervention, location of electrode placement, and type of learning disorder of the students. For meta-analysis, the results summary, mean, standard deviation (SD) and number of people in each group before and after the intervention were used. For data analysis, after extracting the desired data, the average of the experimental and control groups, the standard deviation of the groups and the number of samples in each group) were analyzed by the CMA program and using the meta-analysis method. The statistical tests used in the hypotheses were analyzed after converting to the effect size using the formula provided by Wolff, by combining the effect size using the Schmidt and Hunter method. It should be mentioned that the SMD index was used to calculate the effect size. The implementation steps were as follows: first, the method of calculating the discriminative effect size for each research, the summary effect size with the random effects model was used for all studies and heterogeneity diagnostic tests. Cochran's Q test was used to detect the significance of heterogeneity and I-squared index was used to determine the level of heterogeneity. The I-squared index is suitable for determining heterogeneity in meta-analysis, because it shows the amount of heterogeneity without the influence of the sample size. In addition to examining heterogeneity in meta-analysis, it is necessary to examine publication bias; Therefore, first the publication bias was checked with a funnel plot, then to eliminate possible publication bias and heterogeneity, outlier or extreme effect sizes were identified and removed through sensitivity analysis.

Results

In terms of demographic characteristics, the statistical sample of the present study was homogeneous in terms of gender (all participants were girls) and age (the same level of education). The following table shows the descriptive findings obtained from the data collected by the questionnaire.

Identification	**Identified articles....................................450** Google scholar ……………….........….115 Pub-Med……………………........…..…76 Psych info………………..……………..….30 Science direct ……………………..….124 Cochrane database……………………...………...13 Scopus…………………………...………27 Magiran…………………………...…….46 SID………………………..……….....…..19	
		Delete duplicates...…......................141
Screening	**Preliminary screening results..309**	
		Deletion of articles based on lack of full text.................. 105
Choosing	**Selecting items related to checking the main text............... 204**	
		Removal of articles based on the review of the text.................................. 148
Selection	**Final articles for review...................................56**	
		Removal of articles based on research results...................................30
Selection	**Final meta-analysis articles...26**	

Figure 1. Search and data collection process

Table (1) examines the results of the systematic review.

Table 1. Characters of articles published by researchers in the field of tDCS on the memory of people with learning disabilities

researcher	Year	Electrode place	Electrode type	Protocol	Sessions	Length (Weeks)	Control group	Sample Size	Age	Gender	Variable	Disorder
Miron et al	2021	DLPFC	Andal and reference	Right posterolateral frontal cortex anodic electrode	10	20	Yes	51	10	Male	active memory	Math
Grandprem et al	2020	C4/DLPFC	Andal and reference	Left posterolateral frontal cortex anodic electrode/right motor cortex anodic electrode	3	50	Yes	50	12	Male	Visual-spatial memory	dictation
Maskuta et al	2019	C3/C4/DLPFC	Andal and reference	Anodic electrode of the primary motor cortex and cathodic	1	15	Yes	19	11-9	Male & Female	Memory	Reading

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				electrode of the posterolateral frontal cortex								
Seidel et al	2019	C3/C4	Andal and reference	Bilateral primary motor cortex anodic electrode and opposite electrode pair on ipsilateral shoulders	1	20	Yes	46	12.2	Male	active memory	Math
Lotari et al	2019	DLPFC	Andal and reference	Anodic electrode of posterolateral frontal cortex	1	20	Yes	15	14.5	Male & Female	active memory	Math
Fraser et al	2019	C3	Andal and reference	Anodic electrode of the left primary motor cortex	1	20	Yes	13	14-10	Male	active memory	Reading
Halgado et al	2019	DLPFC	Andal and Catdal	Anodic electrode of the posterolateral frontal cortex and cathodic electrode above the shoulder	3	20	Yes	36	12.3	Male	active memory	Math
Park et al	2019	C3/C4/Cz	Andal and reference	Anodic electrode of primary motor cortex	1	20	No	10	26	Male & Female	active memory	Math
Cicone et al	2019	T3	Andal and reference	Left temporal cortex anodic electrode	5	15	Yes	20	7	Male	Spatial executive function	Reading
Ota et al	2019	DLPFC	Andal and Catdal	Anodic electrode of right posterior lateral frontal cortex and cathode electrode of left posterior lateral frontal cortex / Anodic electrode of left posterior lateral frontal cortex and cathode electrode of right posterior lateral cortex	2	20	Yes	30	2	Male	short term memory	Reading
Angius et al	2019	DLPFC/Fp2	Andal and reference	Anodic electrode of posterolateral prefrontal cortex and cathodic electrode of left posterolateral prefrontal cortex	1	20	Yes	12	21	Male & Female	Memory	Write
Kamali et al	2019	DLPFC	Andal and Catdal	Anodic electrode of right posterior lateral prefrontal cortex and cathode electrode of left posterior lateral prefrontal cortex	2	20	Yes	16	20.6	Male & Female	Memory	Math
Kamali et al	2019	C3/C4/T3	Andal and reference	Anodic electrode of primary motor cortex / Anodic electrode of left temporal cortex	2	12	Yes	12	6	Male & Female	Memory	Math
Huang et al	2019	C3/C4/T3	Andal and reference	Anodic electrode of primary motor cortex / Anodic electrode of left temporal cortex	5	20	بدونگروه کنترل	9	12.3	Female وMale	active memory	Reading

Angius et al	2018	C3/C4	Andal and Catdal	Bilateral primary motor cortex anodic electrode and opposite electrode pair on ipsilateral shoulders	6	10	Yes	12	10.6	Male	Memory	Math
Waltzalula et al	2018	C3/C4	Andal and reference	Bilateral primary motor cortex anodic electrode and pair of opposite electrodes on the shoulders of the same side	1	20	No	8	14.2	Male	working memory	Math
Vargas et al	2018	C3/C3	Andal and reference	Anodic electrode of primary motor cortex	4	15	Yes	20	12	Male & Female	Memory	Math
Halgoda et al	2018	DLPFC	Andal and Catdal	Cathode electrode of the left posterior lateral prefrontal cortex	3	20	Yes	36	13.1	Male	Memory	Reading
Hazim et al	2018	C3/C4/DLPFC	Andal and reference	Anodic electrode of the primary motor cortex and cathodic electrode of the posterolateral prefrontal cortex	2	20	Yes	16	12.2	Female	Memory	Math
Lotari et al	2018	DLPFC	Andal and reference	Anodic electrode of posterolateral prefrontal cortex	1	20	Yes	11	13	Male	short term memory	Reading
Okano et al	2017	C3/C4	Andal and reference	Bilateral primary motor cortex anodic electrode and opposite electrode pair on ipsilateral shoulders	1	20	No	13	11	Female	working memory	Math
Mizuo et al	2017	Cz	Andal and reference	Anodic electrode of the primary sensory-motor cortex	1	10	No	8	14.3	Male	Memory	Reading
Lotari et al	2017	DLPFC	Andal and reference	Cathode electrode of the posterolateral prefrontal cortex	2	20	Yes	15	10.3	Female	Memory	Math
Rudel et al	2017	C3/C4/DLPFC	Andal and reference	Anodic electrode of the primary motor cortex and cathodic electrode of the posterolateral prefrontal cortex	1	20	Yes	44	12	Male	Memory	Reading
Pixel et al	2017	C3/C4	Andal and reference	Anodic electrode of primary motor cortex	1	15	Yes	31	11	Female	Memory	Math
Flood et al	2017	C3/C4/Cz	Andal and reference	Anodic electrode of primary motor cortex	1	20	Yes	12	11.2	Female	Memory	Math
Abdulmolla et al	2016	C3	Andal and reference	Anodic electrode of the primary motor cortex and cathodic electrode above the shoulder	2	10	Yes	22	12	Male & Female	Memory	Math
Lotari et al	2016	C3/C4	Andal and reference	Bilateral primary motor cortex anodic electrode and opposite electrode pair on	3	20	Yes	10	10	Female	active memory	Math

				ipsilateral shoulders								
Lotari et al	2016	C3/C4	Andal and reference	Bilateral primary motor cortex anodic electrode and pair of opposite electrodes on the shoulders of the same side	3	20	No	10	12	Female	working memory	Reading
Brawood et al	2016	C3	Andal and reference	Anodic electrode of the left primary motor cortex	2	20	No	6	14	Male	working memory	Math
Angios et al	2016	C3/Fp2	Andal and reference	Anodic electrode of the left primary motor cortex and cathode electrode of the right prefrontal cortex / Anodic electrode of the left primary motor cortex and cathode electrode above the shoulder	2	10	Yes	9	12	Female	Executive-spatial function	Reading
Magalhas et al	2016	T3	Andal and reference	Anodic electrode of the left temporal cortex	5	20	Yes	19	12	Female	active memory	Math
Chu et al	2016	C3/DLPFC	Andal and reference	Anodic electrode of right posterior lateral prefrontal cortex and left motor cortex	4	20	Yes	32	14	Male	working memory	Math
Iris Montenegro et al	2015	T3	Andal and reference	Anodic electrode of the left temporal cortex	2	20	No	10	15	Male	Memory	Math
Hoda et al	2015	C3/C4/DLPFC	Andal and reference	Anodic electrode of the primary motor cortex and cathodic electrode of the posterolateral prefrontal cortex	6	15	Yes	24	14	Female	Memory	learning
Vinor Costa et al	2015	C3/C4	Andal and reference	Anodic electrode of primary motor cortex	2	12	Yes	11	12	Female	Executive-spatial function	learning
Montenegro et al	2015	C3/C4	Andal and reference	Anodic electrode of primary motor cortex	1	20	Yes	14	12	Female	working memory	Math
Okana et al	2015	C3	Andal and reference	Anodic electrode of the left primary motor cortex	1	15	Yes	13	15	Female	working memory	Math
Angios et al	2015	C3/Fp2	Andal and reference	Right prefrontal cathode electrode/ left motor cortex anodic electrode and above shoulder cathode electrode	2	15	Yes	9	14	Male	working memory	Math
Indian et al	2013	C3/Fp2	Andal and reference	/ Anodic electrode of left frontal cortex and cathodic electrode of right frontal cortex	3	20	Yes	30	16	Male & Female	working memory	Math
Kahn et al	2013	C4	Andal and reference	Anodic electrode of the right primary motor	1	10	Yes	30	16	Male	Memory	Math

				cortex and cathode electrode on the right shoulder								
Monhleib et al	2013	DLPFC	Andal and reference	Anodic electrode of posterolateral frontal cortex	1	10	Yes	15	14	Male	Memory	Math
Williams et al	2013	C3/T3	Andal and reference	Primary motor cortex anodic electrode/ left temporal lobe anodic electrode	1	20	Yes	18	12	Male	working memory	Math
Lampropoulou et al	2013	C3	Andal and reference	Anodic electrode of the left primary motor cortex	1	10	Yes	12	11	Male	Executive-spatial function	Math
Shabahang et al	1399	C4/FP1	Andal and reference	Anodic electrode of the right primary motor cortex and cathode electrode of the left prefrontal cortex	3	20	Yes	24	14	Male & Female	active memory	Math
Arefanian and colleagues	1399	C4/FP1	Andal and reference	Anodic electrode of the right primary motor cortex and cathode electrode of the left prefrontal cortex	3	20	Yes	45	15	Female	working memory	learning
Bahrami et al	1399	C3-FP2/Qz-Cz	Andal and reference	left primary motor cortex anodic electrode, right prefrontal cortex cathodic electrode/ visual cortex anodic electrode and primary motor cortex cathodic electrode	6	15	Yes	45	14	Male & Female	working memory	Math
Jahanian et al	1398	F4-P4	Andal and reference	Anodic electrode of the right frontal cortex and cathodic electrode of the right parietal cortex	1	15	Yes	54	14	Male	Mental rotation of hand images and visuospatial memory	Math
Nozari et al	1398	C4-FP1	Andal and reference	Anodic electrode of the right primary motor cortex and cathode electrode of the left prefrontal cortex	3	20	Yes	24	12.5	Male	Executive-spatial function	Math
Nazari Pirdosti et al	1398	C3/C4/FP2	Andal and reference	Anodic electrode of the primary motor cortex and cathodic electrode of the right prefrontal cortex	2	15	No	10	13	Female	working memory	Math
Yavari Katab et al	1397	F4/P4	Andal and reference	Cathodic electrode of left frontal cortex / anodic electrode of right parietal cortex and cathode	5	15	Yes	60	15	Male & Female	working memory	learning

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				electrode of left parietal cortex								
Mohabbat Bahar et al	1397	C4/FP1	Andal and reference	Anodic electrode of the primary motor cortex and cathode electrode of the left prefrontal cortex	3	15	Yes	20	14	Female	working memory	Math
Nazeri et al	1397	F3/FP2	Andal and reference	Anodic electrode of the left posterior lateral prefrontal cortex and cathodic electrode of the right prefrontal cortex	3	15	Yes	24	15	Male	working memory	Math
Fathi Azar and colleagues	1396	DLPFC	Andal and reference	Anodic electrode of posterolateral prefrontal cortex	1	20	Yes	28	12	Female	selective attention	learning
Ghadiri Surmanabadi and colleagues	1396	C4/FP2	Andal and reference	Anodic electrode of the right primary motor cortex and cathodic electrode of the right prefrontal cortex	2	20	Yes	30	14	Male	Working memory and reaction time	learning

The main characteristics of the 56 reviewed studies are summarized in Table (1). These studies were published between 2011 and 2021. A total of 1225 people participated in the interventions with an average of 22.94 people in a sample size of 6 to 60. The number of students and children by gender was such that 12.74% were girls, 48.1% were boys, and the rest were a combination of girls and boys. The number of internal tDCS sessions for people was reported from 1 to 6 sessions, the average number of sessions was 2.37 and the duration of the sessions was calculated as 18.05 minutes on average. The locations of electrodes were mainly C3/C4/Cz/DLPEC/Fp2/P4/FP1/T3/F3/F4 points. Memory evaluation indicators included evaluation of working memory, visual-spatial memory, accuracy, memory span. 79.16% of the control group was used in the research. Table (2) shows the final meta-analysis of studies on the effect of tDCS interventions on the memory of people with learning disabilities.

Table 2: The size of the effect of tDCS on the memory of people with learning disabilities

researcher	Year	tDCs		Control		Weight	Effect size
		Mean	SD	Mean	SD		
Miron et al	2021	5509	58.16	54144	62.19	4.178	[0.499.0.599-] 0.179
		0.72	0.13	0.7	0.12	4.166	[0.49-0.71] 0.569
Kamali et al	2019	17.4	5.6	35.5	1.5	0.486	[50293 , 2.074] 4.487
		11.8	3.1	14.5	2.3	1.169	[2.027 , -0.049] 1.867
		3244	652.4	2466	432.5	0.9	[2.047 , -0.22] 1.431
		15.6	4.2	19.1	3.5	0.892	[2.094 , 0.282-]1.492
Park et al	2019	52.24	4.24	16.23	3.5	1.054	[3.2 , 1.014] 3.778
Huang et al	2019	565.35	39.73	568.39	28.7	1.474	[1.012 , 0.837-]0.186
		0.92	0.05	0.88	0.06	1.385	[1.678 , 0.229-]1.488
		0.96	0.02	0.95	0.02	1.448	[1.225 , 0.541-]0.844
Ota et al	2019	2345	25.6	2276	32.1	2.152	[1.823 , -0.202] 2.736
		164.21	5.6	149.12	11.9	1.442	[3.31 , 1.441] 4.981
Halgado et al	2019	238.05	38.9	229.4	42.5	1.956	[1.015 , 0.59-0.519].
Angius et al	2019	14.3	2.6	11.1	3.1	0.851	[2.335 , -0.098] 1.802
Lotari et al	2017	8	0.3	8.4	1.6	1.777	[-0.19 , 0.495] -0.809
		199.5	97.2	137.1	73.1	1.692	[1.588 , -0.137] 1.648
		2340.2	458.9	1541.8	287.6	1.642	[2.569 , 1.118] 4.463
		1519.4	235	1541.8	287.6	2.458	[0.788 , 0.644-]0.196
		4.8	1.01	4.93	1.96	2.457	[0.799 , 0.623-]0.228
		6.33	1.29	4.93	1.96	2.258	[1.591 , -0.097] 2.214

Flood et al	2017	24.48	1.73	22.92	2.71	1.953	[1.05 , 0.557-]0.601
		17.25	4.09	15.22	3.2	1.902	[1.227 , 0.291-]1.259
		1.23	1.21	0.26	0.99	1.786	[1.742 , -0.063] 2.106
		93.07	32.73	100.27	44.25	1.959	[0.985 , 0.619-]0.447
Angios et al	2016	191	124	173	114	1.471	[1.076 , 0.774-]0.32
		219	136	173	114	1.451	[1.298 , 0.565-]0.771
Abdulmolla et al	2016	162.4	52.8	146.6	42.7	1.779	[1.17 , 0.512-]0.776
Brawood et al	2016	825	25.5	745	62.5	0.853	[2.782 , -0.352] 4.140
		253	14.5	238.5	20.5	1.432	[1.762 , 0.112-]1.723
Okana et al	2015	311.2	29.9	301	19.8	1.593	[1.27 , 0.408-]1.061
		751.4	71.5	722.7	45	1.597	[1.352 , 0.425-]1.023
		147.5	53.2	125	35.4	1.59	[1.387 , 0.392-]1.095
Vinor Costa et al	2015	485	35.2	415	26.5	1.106	[3.314 , 1.129] 4.126
		450	25.7	415	26.5	1.472	[1.266 , 0.416] 02.841
Angios et al	2015	11.5	1.3	7.6	1.5	0.751	[4.074 , 1.483] 4.205
Kahn et al	2013	322.8	122.4	354.5	144.8	2.442	[0.955 , 0.482-]0.645
Monhleib et al	2013	333	119	252	146	2.458	[1.867 , 0.567-]0.411
Williams et al	2013	1551	82.67	1491	101.640	1.475	[0.989 , 0.854-]0.138
Lampropoulou et al	2013	1.2	0.2	1.8	0.6	1.606	[2.227 , 0.456] 2.969
Shabahang et al	1399	26.91	2.99	32.41	3.75	1.481	[2.544 , 0.699] 2.446
		34.66	5.02	39.01	4.01	1.765	[1.801 , 0.112] 2.219
Arefanian and colleagues	1399	40.47	22.2	33.4	18.5	1.421	[1.077 , 0.266-]0.967
		60.7	19	93	17.5	1.768	[2.612 , 0.924] 4.106
Jahanian et al	1398	1030.21	70.29	1601.04	351.38	0.988	[4.276 , 2.018] 5.464
		98.13	2.31	95.23	5.29	2.074	[1.505 , -0.054] 1.835
		1326.49	214.77	1747.63	302.48	1.667	[2.485 , 0.747] 2.644
		59.22	4.46	92.05	4.46	2.146	[1.255 , 0.277-]1.251
		6.5	0.94	5.54	0.77	1.914	[1.934 , 0.302] 1.689
		2034.72	121.86	25.5.84	155.23	0.942	[4.436 , 2.135] 5.564
Nozari et al	1398	294.5	37.96	342.75	342.75	1.627	[2.174 , 0.414] 2.882
		508.25	76.32	76.33	577.75	1.752	[1.84 , 0.144] 2.293
Nazari Pirdosti et al	1398	29.4	4.37	4.37	21.4	1.227	[2.653 , 0.626] 3.172
		858.3	276.86	276.86	611.2	1.511	[1.737 , -0.089] 1.77
		173	32.24	32.24	176.66	1.636	[0.75 , -1.003] -0.281
		41.9	11.29	11.29	46.1	1.614	[0.529 , -1.238] -0.776
Nazeri et al	1397	81.66	9.56	9.56	59.16	0.986	[3.951 , 1.499] 4.892
Fathi Azar et al	1396	1437.69	146.64	146.64	1737.16	1.686	[2.564 , 1.499-]3.855
		1281.07	161.49	161.49	1603.76	1.695	[2.544 , 1.499-]2.821
		1622.3	72.48	72.48	190092	1.121	[3.294 , 1.499] 5.229
total (fixed size)							=۰/۰۰۰P=۰/۹۴۵ M
total (random size)							=۰/۰۰۰P=۱۸۸/۱ M

Based on the results presented in Table (2), the number of tDCS studies and the average effect size are shown. The results indicate that electrical stimulation of the brain with an average total effect size (fixed size) of 0.945 and a random size of 1.188 is considered as an effective intervention method on people's memory in studies. Table (3) summarizes the results.

Table 3: Fixed and random effect size statistics of tDCS effect on people's memory

Model	Effect size and confidence interval 0.95						H0		heterogeneity			
Effect	N	IE	STD Err.	Var.	Lower bound	Higher bound	z	Sig	Q	df	Sig	I^2
Constant	26	83/0	056/0	004/0	716/0	945/0	478/14	001/0	71/211	25	1	394/71
Random	26	96/0	112/0	015/0	764/0	188/1	765/7	001/0				

The average effect size of the studies conducted on the effect of tDCS interventions on people's memory for the fixed effects model has a z-statistic of 14.478 and a significance of less than 0.001. For random effects, this value was reported as 7.765, which is less than 0.001 at the significance level. The results show that there is heterogeneity of studies; Therefore, the null

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hypothesis that the overall average effect size does not differ is rejected. According to Cohen's theory, the higher the value of M, the greater the effect; Therefore, the mean of M=0.945 shows that the effect of tDCS interventions on people's memory is high. According to the results of table (2), the highest effectiveness is related to the study of Jahanian et al. (2019). In examining the heterogeneity with the help of the Q index, the results show that this index is 211.71 at a significant level of less than 0.001 with a degree of freedom of 25; Therefore, the assumption of homogeneity of the studies is rejected and it is concluded that the studies are heterogeneous. The square I statistic is 7.394, another confirmation of the heterogeneity of the studies. Hence, the reviewed studies share a true effect size, and the difference in the observed effect size is due to sampling error. To check the printing and publishing bias, a funnel plot was drawn by comprehensive meta-analysis software, and the safe N test of classical error was used. As can be seen in the diagram (2), the research in question has a tendency to print and publish to some extent. This issue can be caused by the number of samples in the research. The safe N test of the classical error also shows that the difference between the studies used in the number of 26 cases and the total number of studies in the amount of 450 cases is significant.

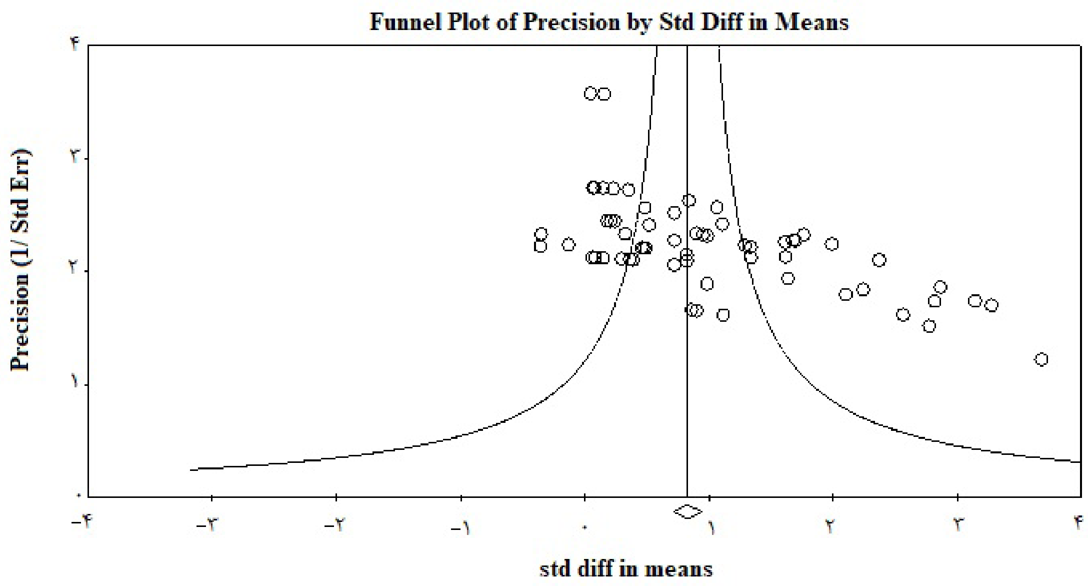

Figure 2. Study effect size, standard error of the mean in the model of the effects of tDCS on people's memory

Conclusion

The present meta-analysis investigated one of the non-invasive psychological interventions of the brain called transcranial electrical stimulation tDCS on the memory of people with learning disabilities. The results of applying the meta-analysis method using the effect size combination method by the Schmidt and Hunter method showed that tDCS has the necessary ability to optimize the memory performance of people with learning disabilities. This result was in line with studies (Grand Perrin et al., 2020; Latari et al., 2019; Monis et al., 2019). In recent years, researchers have investigated the effects of electrical stimulation of the brain on psychological functions. Their results have shown that tDCS can be used as a source of neuromodulation for people to improve people's memory performance. These changes were evident both in healthy people and in people with learning disabilities who used electrical stimulation during their educational programs; The results of the present meta-analysis showed that, in none of the reviewed studies, the negative side effects of electrical stimulation of the brain were mentioned. The results of examining the differences between studies showed that tDCS was effective in improving the memory function of people with learning disabilities. The electrical stimulation protocol of the brain is implemented through two electrodes connected to the skin under the title: The anode on the left posterior lateral prefrontal cortex (F3) and the other as the cathode on the right posterior lateral prefrontal cortex (F4), have an electric current of one to two milliamps and a cross-sectional area

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of 35 square centimeters. In anodic TDCS, by depolarizing neurons, they have a stimulating effect on nerve cells, while its cathodic type, by hyperpolarizing neurons, leads to the inhibition and shutdown of nervous tissue (Prosta-Rubix et al., 2018).

The type of brain electrical stimulation on executive functions is as follows: The dorsal-lateral prefrontal cortex, which has a high capacity in special cognitive tasks in working memory, planning, goal-based behavior, concentration and inhibitory control, is targeted. It leads to an increase in the excitability of the cortex in the left posterior lateral prefrontal cortex because the electrical stimulation of the brain, especially the anodic stimulation by depolarizing the neuron, causes a change in the neuronal resting system and leads to an increase in the excitability of this area. An increase in surface excitability in the frontal cortex leads to an increase in the release of dopamine, which contributes to the improvement of problem solving skills. As a result, the electrical stimulation of the brain increases the response by improving the stimulating effects such as the level of glutamate, amino acids related to working memory, memory recovery and recognition, and learning. On the other hand, stimulation of the posterior lateral occipital cortex area, due to the passage of electric current and changes in local ion concentration and changes in membrane passage and changes: Positive hydrogen ion is effective in: It is effective in improving short-term memory, visual-spatial skills, executive function, attention, accuracy, working memory, awareness of time and place, and problem solving ability. Finally, it can be said that familiarity with the functioning of the brain and nervous system is very important because learning issues cannot be understood without this familiarity. It is clear that education is also influenced by the results of neuropsychological studies. Because awareness of neuropsychological functions helps clarify the learning process. In addition, it can reveal some factors that cause learning problems and for researchers who research about academic failure. At the very least, the impact of research results in neuropsychology is that it provides a new look at research and teaching methods. From the point of view of the topic, the research that is carried out today in the prestigious universities of the world is mostly about the functions of the brain. It is hoped that human achievements in the field of brain knowledge can be useful in more and better exploitation of the brain, growth and development of the mind, treatment of mental disorders and production of patterns created from the brain.

In general, transcranial electrical stimulation can be used to change memory function in people with learning disabilities. However, the effect of tDCS on memory performance is moderated by the design and use of the control group, that is, when the analysis was restricted to active controls, the effect of transcranial electrical stimulation on memory improvement may be reduced. Future research should pay attention to the following: Replication and extension of the effect size of tDCS with larger sample sizes; adopting a fully controlled design of an active group; providing evidence for changes in trained frequency bands; Identification of the most appropriate intervention protocol based on the direct correlation of the results in memory improvement and the use of transcranial electrical stimulation in real activities and in the educational field.

The methods of existing studies limit the value and validity of a systematic study or meta-analysis; Therefore, the results of the present meta-analysis review may reflect the weaknesses of the study method rather than the strengths or weaknesses of the effect of tDCS on memory performance of people with learning disabilities. In fact, the studies that were examined in the present systematic review and meta-analysis had some limitations in the methodological part, such as not using a control group during the study. Another limitation of the current research is related to the heterogeneity and small number of studies that studied and analyzed the effect size of tDCS in the field of people with learning disabilities, because the range of studies in the field of children with autism was more than that of learning disorders. Studies that have been conducted as randomized controlled trials have mostly included small sample sizes, which may overestimate the effect size compared to trials with larger sample sizes; Therefore, future research should focus on replicating and developing the effect size of tDCS with a larger sample size. Another limitation of the research is that some studies did not report in their results whether tDCS actually led to learning and improved memory performance as indicated by

lesson changes. This is a key point because if electrical stimulation of the brain fails to produce the expected changes in the EEG level, then the size of the training effect is likely to be related to other factors; Therefore, future research should not only consider changes in people's memory, but also determine specific changes in EEG power. Considering the rapid increase in the volume of tDCS studies regarding the improvement of memory ability, important methodological limitations need to be revised. Regarding the methodology of these interventions, it is necessary to be careful in interpreting the results related to the effectiveness of tDCS as an autogenic.
Also, it is necessary to standardize methodological variables such as assembly of electrodes, current intensity, time of intervention sessions and other details to provide a better attitude and knowledge about the real effects of transcranial electrical stimulation on people's memory. In addition, the mechanisms related to improving the memory ability of people with learning disabilities are not yet clear. In this regard, the interesting question is, what factors cause temporary improvement in the memory performance of people with learning disabilities? Modulation of corticospinal excitability or other targeted brain regions following tDCS seems to be responsible for this improvement. However, few studies have examined corticospinal or brain activity following or during tDCS. Another technical characteristic of transcranial electrical stimulation is the low spatial separation of the electric field caused by the brain compared to the magnetic stimulation of the skull, which can affect the function of some brain areas beyond the desired areas. The smallness of the samples in the research can justify the falsity of the results; Therefore, it is necessary to pay special attention to this issue in future research. Finally, the lack of suitable single-blind and double-blind methods in most studies should be considered, because specific methods can lead to unexpected and confusing psychological effects and make it difficult to interpret the results.

Conflict of Interest

According to the authors, this article has no financial sponsor or conflict of interest.

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