Research Paper

The Effectiveness of Neurofeedback on Working Memory and Processing Speed Among Girl Students With Learning Disabilities

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ABSTRACT

Background: Learning disorders (LDs) are diagnosed in children impaired in the academic skills of reading, writing, and/or mathematics. Children with LDs usually exhibit a slower resting-state electroencephalogram (EEG), corresponding to a neurodevelopmental lag. The present study aimed to investigate the effectiveness of neurofeedback treatment on working memory and processing speed among girl students with learning disabilities.

Methods: The design used in the current study was a quasi-experimental design, including pretest, post-test, and follow-up with a control group. Using the convenience sampling method, 40 girl students with LDs were selected from among all students referred to the psychological clinics in Tehran City, Iran, in the 2020-2021 academic year. Therefore, samples were assigned to two control and experimental groups (n=17). Samples were assessed for structured clinical interviews for DSM-IV (SCID), n-back task, and Stroop and reverse-Stroop tests. The experimental group received 20 sessions of neurofeedback and standard psychological intervention treatment, while the control group received only standard interventions. Mixed repeated analysis of variance, independent t tests, and chi-square were used for data analysis.

Results: The findings showed that neurofeedback treatment improved all the components of working memory (correct answer and correct response time) and processing speed in girl students with LDs during a two-month follow-up ($P<0.0001$).

Conclusion: It is recommended that the principles and concepts of neurofeedback treatment, confirmed in the current study, be considered an educational mission and executive task for school counselors for girls with learning disabilities.

Keywords: Learning disabilities, Working memory, Neurofeedback, Student

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1. Introduction

Learning disabilities (LDs) are neurodevelopmental impairments that are found in 5%-20% of children and adolescents between 5 and 16 years [1]. A child diagnosed with a specific LD has significant difficulties in learning the academic skills of reading, writing, or mathematics. A child with a combined deficiency in two or three of these skills belongs to a subtype of LD formerly known as LD [2]. Coupled with the lagged development of academic skills, students with an LD usually endure a heterogeneous frame of cognitive impairments in processes such as phonological awareness, attentional control, processing speed, and working memory [3].

Working memory is the part of the memory that is a commonly affected cognitive domain in children with an LD [4] and adequately predicts current and future academic difficulties [5]. Working memory performance is more severely affected in children with an LD that co-occurs with other intellectual impairments [3]. A defective working memory implies a diminished capacity for access, maintenance, and/or retrieval of information, usually phonological. School-age children require adequate working memory to develop their basic academic skills properly. Children with LDs are also at an increased risk of suffering from processing speed. A meta-analysis study conducted by Peng and Fuchs [6] on working memory in different learning disabilities showed a significant deficiency in children's verbal and numerical working memory. In Tolar et al.'s study [7], working memory was the only cognitive variable that significantly differed in children's LDs. In this regard, Callinan et al. [8] showed that phonological processing, automatic naming speed, and verbal memory can predict the precise grouping of 77% to 82% of students with LDs and the group of normal children.

Research evidence also indicates the weakness of students with LD processing speed [9]. Processing speed is one of the 16 broad cognitive abilities in the Cattell-Horn-Carroll theory which includes five micro-cognitive abilities (comprehension speed, test response speed, numerical skills, speed, and fluency in reading and writing). Processing speed is also the ability to automate and fluid simple and repetitive cognitive tasks, especially when high mental efficiency (sustained attention and concentration) is required [10]. Research evidence shows that children with LDs score well on some Wechsler intelligence scale for children indicators, including verbal comprehension and perceptual reasoning, which constitute the general ability index. At the same time, these students have many problems with working memory and processing speed indicators, which comprise the index of cognitive dominance [11]. The findings of various studies indicate that students with LDs score higher in the general ability index but show significant deficiencies in the index of working memory and processing speed [12].

Students with LDs usually exhibit slower resting-state electroencephalogram (EEG), corresponding to neurodevelopmental lag [13]. Frequently, children with LDs show working memory impairment, associated with an abnormal task-related EEG with slower EEG activity (more delta and theta power and less gamma activity in posterior sites) [14]. Special education classes and evidence-based reading, writing, or mathematics programs are the primary interventions used to treat LDs. Neurofeedback treatment is a relevant therapeutic approach that has resulted from the EEG field of research [1, 15].

Neurofeedback treatment still has experimental treatment status [1, 16], with ongoing research on its effects on many disorders such as attention-deficit/hyperactivity disorder, anxiety disorders, epilepsy, and LDs [17, 18]. The research about neurofeedback effects on LDs in children has shown that a protocol aimed at normalizing their altered EEG resting state by reducing the theta/alpha ratio is capable of boosting cognitive-behavioral performance and improving resting-state EEG patterns. The treatment effects are reported to last for at least two years [19, 20].

These positive effects suggest the facilitation of EEG maturation due to this neurofeedback treatment. Two other works have also found that neurofeedback benefits in children with LDs include improved spelling, increased EEG connectivity of the alpha-band with a measure of coherence [21], improved reading and phonological awareness standards, and normalization of EEG coherence measures [22, 23].

Special education classes and evidence-based reading, writing, or mathematics programs are the primary interventions used to treat LDs. A follow-up study performed on children with LDs showed that neurofeedback is an effective treatment for LDs whose beneficial effects are not only after neurofeedback but also over a more extended period and patients generally had a reduction in LD symptoms [24]. Research has shown that neurofeedback treatment in beta and theta brainwave patterns and beta-enhancing theta can correct cognitive impairments associated with attention-deficit/hyperactivity disorder and LDs [25, 26]. Neurofeedback treatment still has experimental treatment status [27], with ongoing research on its effects on many disorders such as attention-deficit/hyperactivity disorder, anxiety disorders [28], epilepsy [29], and LDs [26]. Neurofeedback benefits in children with LDs include improved spelling, increased EEG connectivity of the alpha-band with a measure of coherence [16], improved reading and phonological awareness measures, and normalization of EEG coherence measures [17].

On the one hand, the research results, especially in neurofeedback, are contradictory. It is essential to review these studies because there are LDs due to the underlying disease. Therefore, knowing that neurofeedback has a specific effect on LDs or its impact on other variables such as working memory and processing speed increases the importance of researching the effects of neurofeedback on learning disorders. Students with LDs in everyday life have many problems, especially in education. The academic issues of these students are generally due to working memory and processing speed. Improving these characteristics is one of the most important goals of treatment for these students, which is one of the most challenging clinical issues.

Given these inconclusive findings regarding the effects of neurofeedback, processing speed, and working memory on cognitive functioning in students with LDs, more comparative and ecologically valid research is needed to evaluate the clinical usefulness of neurocognitive training for children and adolescents with LDs. So, the present study aimed to investigate neurofeedback's efficacy on working memory and processing speed among girl students with LDs.

2. Methods

Patients

In this quasi-experimental study, one experimental and one control group were considered. The study population consisted of all second, third, and fourth-grade girl students referring to special centers for LDs in Tehran in the academic year 2020-2021. The samples were tested in the pretest (before neurofeedback treatment), posttest (after neurofeedback treatment), and follow-up (two months after the intervention) using the scales. The independent variable in this study was the 20-week intervention of neurofeedback, and the dependent variable was the working memory and processing speed.

Sampling

Convenience sampling was performed among the patients referred to the psychological clinic in Tehran. Forty girls aged 11 to 14 years diagnosed with LDs were selected from a larger sample of female students referred by clinical psychologists. Before the survey, informed consent was obtained from samples and their parents or legal guardians. All girl students fulfilled the following inclusion criteria: (1) normal neurological and psychiatric assessment (except for the LD diagnostic requirements as stated below); (2) intelligence quotient of at least 75 assessed via the Wechsler intelligence scale for children, 4th edition, to exclude students with an intellectual disability; (3) mother (or tutor, in her absence) with at least a completed elementary school education and a per capita income greater than 50 percent of the minimum wage; (4) an abnormally high EEG theta/alpha ratio compared to a normative database; (5) presenting no sign of psychotic and bipolar disorders; and (6) having no limiting severe physical illness, such as cancer or kidney problems, as well as having minimum physical and cognitive ability to participate in the intervention sessions.

The reason for considering the final inclusion criterion was that the EEG of girl students with an LD is characterized by having more theta and less alpha power than the EEG of girl students with typical development. Exclusion criteria included being absent in two sessions of the treatment, dissatisfaction with participation in research, facing severe stressful events or illness, and withdrawal of the individual.

The LD diagnosis was established based on the following two criteria: (a) poor academic achievement reported by teachers and parents; (b) the diagnosis of the LD performed by a psychologist according to the DSM-IV criteria for LDs [30].

According to the above criteria and willingness to cooperate, 40 girl students with LDs participated in the study. So, the study's sample (N=40) was randomly assigned to one of two groups: The neurofeedback group (n=20) received a neurofeedback treatment that reinforced the reduction of the theta/alpha ratio, and the control group (n=20). Three students from the neurofeedback treatment group and three students from the control group dropped out before the study was completed. Therefore, the final analysis was performed on seventeen samples in the neurofeedback group (n=17) and seventeen samples in the control group (n=17).

Procedure

All samples were asked to complete the instruments (structured clinical interview for DSM-IV (SCID) and Beck anxiety inventory) before, after the intervention, and two-month follow-up. The neurofeedback treatment group received the treatment protocol for two and a half months. The protocol consisted of 20 sessions, two sessions per week.

Neurofeedback treatment is based on the alpha/theta protocol and osmosis 10-20 using a ProCamp 5 device with a sampling sensitivity of 256 Hz. The neurofeedback protocols in each session were based on Sensory Motor Rhythm (SMR), Cz area (central cortex) [31], and Pz area (parietal cortex) alpha-theta [32], performed in 20-25 minutes using the Thought Technology Procomp2 system [31].

The purpose of the Alpha/theta protocol performed in a state of relaxation with eyes closed is to increase theta waves ratio (4 to 8 Hz) in central and frontal areas of the brain relative to alpha waves (8 to 12 Hz) (it is considered increasing in both waves). Alpha wave activity in the brain is usually higher than the theta. This protocol is widely used to upgrade personal performance in different fields [33]. Because of the time of theta waves predominance, the person is more distortable and more relaxed in emotion. This would be the proper step for the person to reconstruct the cognitive structure in a more favorable method. It should be noted that the American Society of Psychology approved neuro-feedback as one of the treatment methods for LDs after the successful results of this treatment protocol [34].

The participant obtained a situation of maximum relaxation during performing protocol; after the installation of electrodes, according to the treatment mentioned protocol and based on international system 10-20, on the head skin and earlobes. Before commencement, they were asked to be seated calmly, relax their muscles, regulate and calm their breath, and close their eyes. The mental image helps participants increase their cerebral theta waves. Thus, they were required to recall positive memory, after which feedback was presented to them in audio. This feedback was the combination of the sound of river waves, waves in the ocean, and background sound. Once alpha waves rise in the cerebral cortex area, the sound of river waves reaches high, while theta waves dominate, and the sound of ocean waves is boosted. The participants were asked to listen to the sounds of waves from rivers and oceans periodically; every time they heard the sound of river waves (associated with alpha waves), they tried to boost their theta waves by mental image construction so that they were able to hear the sound of the ocean more clearly and loudly and then try to hear the sound of river waves again. After the initial assessment was referred to the treatment of asylum and after group specification, n-back task, Stroop, and reverse-Stroop tests were performed as the pretest. Finally, participants were informed about the time of their presence and procedure. To initiate the evaluation, active, reference, and ground electrodes were positioned at the Pz point, right ear, and left ear, respectively. Ninety seconds with open eyes and 90 seconds with closed eyes were registered per electrode. The active electrode was similarly positioned on four other points (p3, p4, o1, o2) and recorded data. After removing artifacts, the next step was calculating each participant's alpha frequency. Before treatment initiation, relaxation was instructed to the participants through progressive muscle relaxation and diaphragm breathing. After ensuring proper implementation, the treatment session was started by choosing the alpha/theta window. The corresponding setting was carried out with a window including delta domain determination which warns to prevent participants from falling asleep. Room lighting was adjusted, and the sound played in the environment was maintained steady. It should be mentioned that follow-up time was defined as sixty days. For motivational purposes, a learning-curve plot was updated each session, showing the last successful theta/alpha ratio.

A structural clinical interview for DSM-IV (SCID) was used. The interview assessed the first axis I disorders in SCID-I including seven groups characterized by mood disorders, psychiatric issues, substance dependence, anxiety, eating complications, and compatibility problems. The instrument's reliability and validity are 0.81 to 0.84, respectively [35].

The n-back task was used for working memory. Verbal, spatial, and standard object versions of the n-back working memory task required samples to decide about the stimulus they saw as "2-back" as each new stimulus was presented. The verbal n-back task consisted of letters shown in the center of the screen. The letters were lowercase and presented in Courier New font of size 72. All 20 consonants were used (vowels were excluded). To increase similarity to the verbal version, the spatial version consisted of a black circle (3 cm diameter) that moved around in 20 different locations (i.e., in a 4 row by 5 column array). The common objects version of the n-back task included 20 objects similar to the images used [36]. The images were taken from the International Picture Naming Project at the Centre for Reading and Language, University of California San Diego website [37]. The images are similar to the Snodgrass and Vanderwart images for naming agreement, familiarity, complexity, imagery judgments, and naming latencies [38]. The objects were chosen to ensure an equal number of semantic categories (e.g., fruit, vegetables, furniture, and transportation) and an equal number of typically male, female, and neutral objects [39]. Dependent measures for the n-back included several correct answers and average reaction time.

The Stroop and reverse-Stroop tests [40, 41] were used as the manual response task, comprising four conditions as did the oral response task namely the Stroop condition, the reverse-Stroop condition, and the control conditions for each. In the Stroop condition, samples were asked to check the word corresponding to the ink color of an incongruent stimulus with a pen from a list of five words (red, blue, yellow, green, and black) written in black in Farsi. In the reverse-Stroop condition, samples were asked to check the color patch corresponding to the meaning of an incongruent stimulus with a pen from a list of five color patches in red, blue, yellow, green, and black. For both the Stroop condition and the reverse-Stroop condition, the incongruent stimuli were five words red, blue, yellow, green, and black in Farsi) printed in a nonmatching color (from among the same five colors). In contrast, color patches in the same five colors were used for stimuli in the control condition of the Stroop, and the words for the same five colors were printed in black for the control condition of the reverse Stroop [40]. For each condition, the number of correct responses out of 100 stimuli arranged randomly on a sheet of paper was measured with a time limit of 60 seconds, which was used for the calculation of the interference scores. Data were analyzed by the mixed repeated analysis of variance, independent t-test, and chi-square, using the statistical SPSS software, version 26.

3. Results

Chi-square and t test were used for independent groups to evaluate the status of control and experimental groups regarding age, father occupation, and birth order. The results are shown in Table 1. Table 1 showed no significant difference between the two groups regarding age, father's job, and birth order, and the groups are homogeneous in terms of anthropological characteristics. Descriptive indices of mean

Table 1. Comparison of demographic indices by control group and neurofeedback group

Variables	Neurofeedback (n=17)	Control (n=17)	Statistical Analysis
Father's job (unemployed/part-time/permanent)	0/7/10	1/5/11	$\chi^2(2)$=1.38, n.s.
Birth order (1st/2nd/3rd)	13/4/0	1/5/11	$\chi^2(2)$=1.27, n.s.
Age (Mean±SD)	32.14±9.1	87.14±32.1	t(32)=1.32, n.s.

ns: statistically insignificant.

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Table 2. Descriptive statistics of processing speed and working memory in three stages of evaluation by group

Variables	Groups	Mean±SD		
		Pre-test	Post-test	Follow-up
Processing speed	Control	41.70±3.273	42.09±3.088	41.72±2.926
	Experiment	44.80±3.001	47.17±3.473	46.93±3.737
Correct answer	Control	57.24±5.783	57.76±5.166	57.41±5.328
	Experiment	58.59±7.009	62.76±6.815	63.12±7.140
Correct response time	Control	2.30±0.515	2.18±0.380	2.25±0.411
	Experiment	2.47±0.492	1.97±0.385	2.00±0.354

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Table 3. Univariate intra-subject effects test for comparison of control and experimental groups

Variables	Sources	Sum of Square	df	Mean of Square	F	Sig.	Effect Size
Processing speed	Time	24.623	2	12.311	9.681	0.001	0.232
	Time×Group	34.463	2	17.231	13.550	0.001	0.297
	Error	81.386	64	1.272	-	-	-
Correct Answer	Time	125.490	2	62.745	26.010	0.001	0.448
	Time×Group	92.784	2	46.392	19.231	0.001	0.375
	Error	154.392	64	2.412	-	-	-
Correct Response Time	Time	1.854	2	0.927	22.127	0.001	0.409
	Time×Group	0.918	2	0.459	10.951	0.001	0.255
	Error	2.681	64	0.042	-	-	-

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and standard deviation related to processing speed and working memory in three stages of pretest, posttest, and follow-up by neurofeedback and control groups are presented in Table 2.

The present study is an experimental design with pretest, posttest, and follow-up with a control group to investigate the effect of neurofeedback on working memory and processing speed. Repeated measures mixed statistical test was used to analyze results. Analysis of variance with repeated measures requires establishing assumptions that must be tested before using this statistical test.

The results of Box's M test for processing speed ($F_{(6,7419.17)}$=2.08, P=0.052), correct answer ($F_{(6,7419.17)}$=1.35, P=0.23), and for correct response time ($F_{(6,7419.17)}$=0.69, P=0.65) were not significant in the research variables. Hence, the null hypothesis that the covariance matrix is homogeneous in the variables is confirmed. Levine's test results for processing speed ($F_{(1,32)}$=0.077, P=0.78), correct answer $F_{(1,32)}$=0.31, P=0.31), and for correct response time ($F_{(1,32)}$=0.01, P=0.99) were not significant. Therefore, the null hypothesis that the variance is homogeneous with the variables is confirmed. The findings demonstrated Mauchly's test sphericity for processing speed ($\chi^2(2)$=0.559, P=0.75), the correct answer ($\chi^2(2)$=4.56, P=0.102), and correct response time ($\chi^2(2)$=4.12, P=0.093) were not statistically significant, indicating that the sphericity assumption is not violated.

Table 3 shows the significance of the interactive effect indicating the difference between the process of changes in processing speed, correct response, and correct response time of control and experimental groups (intervention) during the measurement steps. The Bonferroni post hoc test compared the mean scores in pairs during

Table 4. Bonferroni post hoc test for difference between mean processing speeds in three evaluation rounds

Groups	Stages	Stages	Mean Difference	SE	Sig.
Control	Pre-test	Post-test	0.346	0.361	1
		Follow-up	-0.019	0.404	1
	Post-test	Follow-up	-0.365	0.394	1
Experiment (intervention)	Pre-test	Post-test	-2.366	0.361	0.001
		Follow-up	-2.125	0.404	0.001
	Post-test	Follow-up	0.242	0.394	1

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Table 5. Bonferroni post hoc test for adjusted score or main test score and correct response index

Groups		Stages	Stages	Mean Difference	Standard Error	Sig.
Correct response	Control	Pre-test	Post-test	-0.529	0.498	0.886
		Post-test	Follow-up	-0.176	0.622	1
			Follow-up	0.353	0.465	1
	Experiment (intervention)	-	Post-test	-4.176	0.498	0.001
		Pre-test	Follow-up	-4.529	0.622	0.001
		Post-test	Follow-up	-0.353	0.465	1
Correct response time	Control	Pre-test	Post-test	0.115	0.082	0.517
		Post-test	Follow-up	0.051	0.085	1
		-	Follow-up	-0.064	0.029	0.096
	Experiment (intervention)	-	Post-test	0.498	0.082	0.001
		Pre-test	Follow-up	0.470	0.085	0.001
		Post-test	Follow-up	-0.028	0.029	1

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the measurement steps (pre-test, post-test, and follow-up). The results are presented in Table 4.

According to Table 4, mean processing speed scores in the post-test and follow-up compared to the pretest stage have increased significantly. There is no significant difference between post-test scores and follow-up scores. In the control group, the difference between scores in the pretest, post-test, and follow-up stages and between scores in the post-test stage and follow-up scores were insignificant (P<0.05).

According to Table 5, mean scores of correct response in the post-test and follow-up compared to the pretest stage have increased significantly. There is no significant difference between post-test scores and follow-up scores. In the control group, the difference between the pretest, post-test, and follow-up stage scores and between the post-test and the follow-up scores were insignificant (P<0.05). Also, mean scores of correct response time in the post-test and follow-up compared to the pretest stage have increased significantly. There is no significant difference between post-test scores and follow-up scores. In the control group, the difference between scores in the pre-test, post-test, and follow-up stages and between scores in the post-test and follow-up were insignificant (P<0.05).

4. Discussion

The present study aimed to investigate the effectiveness of neurofeedback treatment on working memory and processing speed among girl students with LDs. Those findings showed a two-month follow-up neurofeedback treatment improved all the components of working memory (correct answer and correct response time) and processing speed in girl students with LDs.

This finding is consistent with previous research results such as [42, 43]. The theta/alpha ratio is a helpful scale for identifying EEG abnormalities in children. Many researchers, such as [42], have shown that the EEG pattern of LD children is characterized by slow brain wave activity. These children are characterized by higher theta and lower alpha than normal children. Studies on alpha/theta waves in groups with poor education, reading and writing disabilities, and dementia support this view [44].

This means that various neurological capabilities have been associated with high levels of theta and delta power and low alpha power. The theta/alpha treatment protocol at CZ points was used for the subjects' progress in the present study. The rationale for the treatment used is based on the following: (a) compared to the EEG of normal children, the highest age or frequency of EEG abnormalities observed in LD children is increased theta activity and (b) a minimum amount of silent alpha activity is required for the proper functioning of mental tasks in the areas involved in homework for both typical children and normal adults. These facts suggest that amplifying the reduction of the theta/alpha coefficient for LD children with EEG abnormalities may lead to a trend toward EEG normalization and consequently, behavioral and cognitive abilities [45].

The results obtained on the effectiveness of neurofeedback on working memory showed that neurofeedback treatment improves working memory. These findings are consistent with the results of previous research such as [46, 47]. It can be said that neurofeedback treatment in CZ simultaneously affects three sensory-motor cortices, motor, and cellulitis. The sensory-motor cortex is the boundary between the parietal and frontal lobes. Given the widespread effects of the sensorimotor cortex, it is understandable that early pioneers in neurotherapy began the treatment process along the sensorimotor cortex.

The sensory-motor cortex also helps the cortex to encode physical and cognitive tasks. The circuits in the brain that are used to organize, sequence, and schedule a mental activity are the same as those used to regulate, sequence, and schedule a physical activity. This means that the sensory-motor cortex is shared in the leadership of both physical and mental processes. Therefore, therapists who have difficulty understanding the logical sequence of cognitive tasks can benefit from neurofeedback treatment in the left hemisphere (C3) sensory-motor cortex.

Training in the sensory-motor cortex of the right hemisphere (C4) can evoke emotions, thrills, or relaxation. Intermediate point training (CZ) facilitates a mixed response. Neurofeedback treatment in CZ simultaneously affects the three sensory-motor cortices, motor, and cingulitis. In cingulate, systems that deal with emotion/feeling, attention, and working memory interact closely with each other in such a way that they form the energy source of external actions (movement and internal activities of reasoning and thinking) [18, 46].

The results of this part of the study align with the findings of [48] in connection with neurofeedback treatment with the high alpha band on working memory. In another explanation for the results of this study, it can be said that increasing SMR in the CZ region activates neurons involved in working memory. Previous research has shown that working memory is based on neuronal orbit, which results from an interaction between the attention control system located in the peripheral cortex and the storage of sensory information in the posterior communication cortex.

The theory of factor conditioning may explain the underlying mechanism of this change so that if the stimulus change (amplitude of the brain waves based on a predetermined contract with the desired outcome) is accompanied by the movement of video images or sound production, the stimulus will be learned. This learning will be most effective when it uses simpler stimuli (such as neurofeedback treatment) to receive reinforcement. Thus, as a method, neurofeedback is concerned with providing information to the individual after expressing the desired behavior until this information leads to the recurrence of that behavior in the future.

As a result of this information, the student learns to change their behaviors in a more favorable direction. Finally, in explaining the results, it can be said that the changes in the level of behavior reflect the changes in the status of the brain. Neurofeedback, as a therapeutic method, has focused its work directly on brain waves. Changes in the level of behavior can be considered a consequence of changes in brain waves. However, this does not always happen; sometimes, behavioral changes can be seen without changes in the level of measured brain waves. It can be noted that trying to change brain waves through methods such as neurofeedback leads to changes in the level of the brain.

The main limitation of this study was finding girl students with LDs who were willing to collaborate in the research, and finding such participants was a big challenge for the researcher. Given the limitations of a particular segment of society (girl students with learning disabilities), care should be taken in generalizing the results to different and larger communities.

The current study is cross-sectional to confirm the research results and a more detailed survey of longitudinal research relationships in this field is needed. This research has been done in Tehran, therefore, the results should be generalized to other statistical communities and cities cautiously. Finally, we can point to the limitations of the response set which refers to the psychological readiness and motivations of the respondents. In the questionnaire studies, the participants' tendency to answer in a specific way and the possible confirmation of the experimenter's opinion are among the issues related to the preparation of the answer. Although the researcher considered this issue during the implementation of the questionnaires and steps were taken to neutralize this tendency by presenting research objectives and establishing a good relationship with participants, there is a possibility of deviation in response sensitivity that becomes inevitable to the researcher as a necessity. In this case, too, a degree of variation is reminded so that readers can be considered in analyzing and interpreting the results.

It is recommended that the principles and concepts of neurofeedback treatment, confirmed in the current study, be considered an educational mission and an executive task for school counselors for girls with LDs. It can help girl students with LDs and their families. It is suggested that the necessary knowledge of LDs in the lives of children and adolescents be provided to counselors and school officials to take the measures needed to prevent their emotional, social, and behavioral problems. In future research, it is suggested to select samples from other age groups of society to compare the results with the present study. Unlike previous studies, which have been done on a case-by-case basis and with limited generalization, the present study has been conducted experimentally on many samples. As a result, these results are more generalizable.

5. Conclusion

Neurofeedback treatment improved all the components of working memory (correct answer and correct response time) and processing speed in girl students with LDs during a two-month follow-up. This is the first study to investigate the effects of neurofeedback on working memory and processing speed among girl students with LDs. We obtained promising positive results, including improved processing speed, correct answers, and correct response time post-treatment.

Ethical Considerations

Compliance with ethical guidelines

This research was approved by the Ethics Committee of Shahid Beheshti University (Code: IR.SBU.REC.1400.265). The applied method is consistent with the National Research Committee's ethical standards, the Helsinki Declaration of 1964, subsequent revisions, or equivalent ethical norms. All samples and their parents/legal guardians signed the informed consent to participate in the study. The researchers fully maintain the confidentiality of information. In none of the research stages, no cost was imposed on the participants.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declare no conflicts of interest.

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