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Review Article

A Review of the Effectiveness of Neurofeedback on Learning Disorders

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ABSTRACT

This detailed analysis examines the success of neurofeedback as a treatment for learning disorders. Learning disabilities vary widely, which manifests in different educational outcomes, as well as in the strengths and weaknesses in processing information. Neurofeedback, a technological method, is utilized for individuals requiring psychological therapy and the rehabilitation of perceptual and cognitive functions, or for those who are struggling mentally, offering significant benefits. This study compiles and assesses the current research on how neurofeedback techniques influence various learning disabilities. The findings suggest that neurofeedback therapy has been beneficial in enhancing the abilities of children with learning challenges. Likewise, this study looks into the efficacy, limitations, and future prospects of neurofeedback as a method for tackling learning difficulties. According to the results, Cognitive Rehabilitation (CR) was found to be more effective in improving Sustained Attention (SA) than neurofeedback (NFB), with significant statistical evidence ($p<0.001$). Moreover, neurofeedback interventions have shown positive effects on the performance of primary school children with learning disabilities, as measured by Wechsler's tests ($P<0.05$). The review also covers the implications for upcoming research and the possible applications in both educational and clinical environments.

Introduction

Learning disabilities (LDs) are considered as neurodevelopmental disorders affecting 5% to 20% of children and teenagers aged 5 to 16 years. As described American Academy of Psychology and Psychiatry in their 2007 and 2013 publications, and supported by Lagae in 2008, these conditions are outlined in Handbook of auxiliary diagnostic and statistical methods of psychological disorders, fifth edition, text editing (DSM-5-TR) of 2022. LD diagnosis indicates significant challenges in learning reading, writing, or math skills, with some children experiencing difficulties in all these areas. This subgroup was previously classified under a broad LD category [1]. The main treatment methods involve specialized education and evidence-based interventions in

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the problematic domains, with reading difficulties being the most common type of LD.

Neurofeedback emerges as a non-invasive and gentle method to enhance brain function and self-regulation through various mechanisms [2]. It stimulates cellular-level changes and retraining of brain wave patterns, leading to improved focus, cognitive abilities, emotional regulation, and physical coordination. This technique is grounded in the adaptability and specialization of brain waves [3]. Neurofeedback therapy (NFB), derived from EEG studies, utilizes operant conditioning to alter brain function for medical purposes or to improve its performance [7]. Despite its experimental status [12], the ongoing research highlights its potential against disorders like ADHD, anxiety, epilepsy, and LDs [4].

Recent studies, such as those by Martínez-Briones *et al.* (2023) [14], demonstrate NFB's positive impact on children with LDs, notably in self-concept and academic areas like reading and math. Comparatively, Nooripour *et al.* (2022) [17] found that neurofeedback significantly enhances working memory and processing speed in female students with LDs. Similar improvements in working memory were observed by Martínez-Briones *et al.* (2021) [15] through EEG analyses, showing changes in brain wave patterns post-treatment. Contrasting interventions, Azizi *et al.* (2018) [4] highlighted differences between cognitive rehabilitation and neurofeedback in improving sustained attention, with cognitive rehabilitation showing superior outcomes. Azadi *et al.* (2017) [5] confirmed neurofeedback's efficacy in boosting IQ test performance among students with LDs. However, Ghaemi *et al.* (2016) [9] reported mixed results in reading speed improvement, suggesting more sessions for significant progress.

In summary, neurofeedback presents a promising, non-intrusive approach to enhance brain function and address learning disabilities. This technique, which focuses on real-time feedback and brain activity training, has shown potential in various studies for improving cognitive function and academic performance in individuals with LDs, warranting further exploration and validation in the field [5].

Method

A semi-experimental research method is a valuable approach for investigating the impact of neurofeedback on learning disorders. This methodology involves selecting participants diagnosed with learning disorders, which are then systematically divided into two or more distinct groups. One of these groups is subjected to neurofeedback intervention, receiving sessions designed to enhance cognitive functions and learning capabilities. Meanwhile, the other group(s) act as a control, potentially receiving a placebo treatment or no intervention whatsoever to gauge the natural progression of learning disorders without therapeutic interference.

Evaluations are conducted before and after the intervention period to accurately assess the efficacy of neurofeedback. These assessments aim to quantify improvements in learning outcomes, focusing on areas such as reading, writing, mathematics, and overall cognitive performance. In addition, changes in the severity or characteristics of the learning disorders are meticulously recorded. This pre- and post-intervention comparison allows for a clear analysis of neurofeedback's effectiveness, distinguishing between actual therapeutic benefits and changes that may occur due to external factors or the natural evolution of the disorder.

A crucial component of this research method is the inclusion of a control group, which is essential for establishing a baseline against which the effects of neurofeedback can be measured. The control group's outcomes help researchers discern the specific impacts of neurofeedback from those that could result from placebo effects or participant expectations. Illustratively, this semi-experimental setup can be visualized as a diagram (Figure 1), highlighting the procedural flow from participant selection through the division into intervention and control groups to

the final comparative analysis of outcomes. This structured approach provides a robust framework for investigating the potential benefits of neurofeedback for individuals with learning disorders, contributing valuable insights into effective treatment strategies.

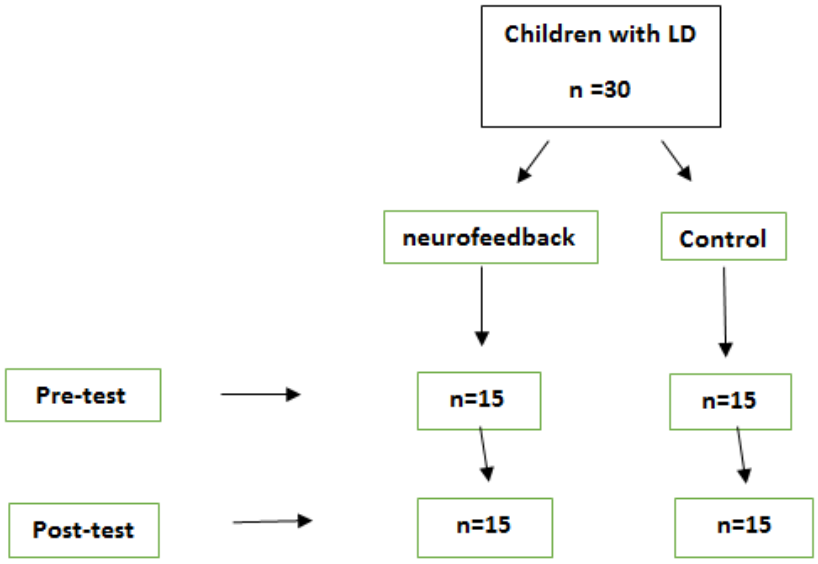

Figure 1. Disposition of the study of children with learning disorders (LD)

The neurofeedback intervention provides real-time insights into participants' brain activity, aiming to enhance and regulate neural patterns associated with learning. By comparing data from different groups, researchers assess the effectiveness of neurofeedback in treating learning disorders. This semi-experimental approach contrasts the experiences of an intervention group with that of one or more control groups, shedding light on neurofeedback's specific benefits for learning disorders. Nonetheless, it is crucial to acknowledge this method's limitations, such as potential biases and the absence of random participant assignment, which could affect result interpretation [6]. In a groundbreaking investigation, Martínez-Briones and team (2023) [14] delved into the realm of neurofeedback's influence on the self-image of youngsters grappling with learning challenges. The study harnessed the Piers-Harris Children's Self-Concept Scale to scrutinize factors within a cohort of 34 right-handed kids, aged between 8 and 11, grappling with learning disorders and delayed EEG development. Among them, twenty children underwent neurofeedback (NFB) sessions, while the rest were divided into subgroups- a sham-NFB cohort with nine participants and a waiting list group with five. The team opted for a nonparametric permutation strategy to sift through disparities in academic strides and self-perception (post-pre assessments) across the NFB and control factions. Given the limited size of the control subsets, they juxtaposed percentage alterations between the sham-NFB and waitlist members using the non-overlap of all pairs (NAP) approach. The NFB cohort exhibited noteworthy enhancements in literacy, numeracy, and the holistic self-concept domain, especially in terms of physical allure, anxiety levels, social appeal, and joyousness [7].

Nooripour *et al.* (2022) [17] embarked on a compelling investigation into the effects of neurofeedback on the cognitive domains of working memory and processing speed among female students grappling with learning impediments. Their study, designed as a quasi-experiment, entailed pre-assessments, post-assessments, and subsequent follow-ups with a control cohort. The research cohort consisted of forty young female students with learning disorders, conveniently selected from individuals referred to psychological facilities in Tehran City throughout the academic year

2020-2021. These students were split into an experimental group (n=17) and a control group. The evaluation methods encompassed structured clinical interviews based on DSM-IV criteria (SCID), n-back tasks, as well as Stroop and reverse Stroop assessments. The experimental group engaged in 20 neurofeedback sessions in conjunction with standard psychological interventions, while the control group solely received conventional treatments. Data scrutiny was executed employing repeated variance analysis, independent t-tests, and chi-square tests [8].

Martínez-Briones and their team (2021) [15] dived into a study dubbed: "*The effect of neurofeedback on the memory of children with learning disorders*" delving into various facets. The research shed light on the revelation that patterns detected in resting-state electroencephalograms (EEGs) hint at inadequate management of neural reserves. Interventions such as neurofeedback (NFB) aimed at ameliorating these EEG patterns in children grappling with learning disabilities (LDs) have exhibited the potential to enhance cognitive-behavioral results and diminish EEG irregularities. Acknowledging the prevalence of working memory (WM) deficits in children with LDs, the inquiry aimed to scrutinize the NFB repercussions on WM by scrutinizing alterations in the WM-associated EEG power spectrum. The study involved the recording of EEGs for 18 children aged 8-11 years with LDs, both prior to and following either 30 sessions of NFB therapy (10 children) or a placebo-sham therapy (8 children), amid a Sternberg-type WM exercise. Evaluations encompassed changes in Behavioral effectiveness and EEG power spectrum in relation to WM before and after interventions [9]. In a distinct exploration by Azizi *et al.* (2018) [4], entitled: "*Differences in the effect of cognitive rehabilitation and neurofeedback on sustained attention among elementary school students with specific learning difficulties: a preliminary randomized clinical trial, effects of cognitive rehabilitation (CR) and NFB on sustained attention (SA) in students with specific learning disabilities (SLD)*", this randomized controlled trial encompassed fifty-three students diagnosed with SLD in line with the DSM-5, aged between 7 and 10. They were haphazardly distributed into NFB (18 students), CR (18 students), and control cohorts (17 students). The groups underwent evaluations utilizing the continuous performance test (CPT) at the onset of the investigation and post seven weeks, subsequent to 20 sessions of either CR or NFB for the intervention clusters, while the control faction received no form of intervention. A total of 45 students, evenly distributed among the three categories, finished the study [10]. Azadi *et al.* (2017) [5] also delved into "*The Effectiveness of Neurofeedback*". This quasi-experimental inquiry with a pretest-posttest blueprint encompassed students with learning disabilities from first to fifth grade in Isfahan's primary schools who were directed to counseling and treatment centers in 2014. Fifteen students were cherry-picked through available sampling techniques and underwent 20 neurofeedback therapy sessions across 7-10 weeks. The repercussions of the therapy were gauged using the Wechsler Intelligence Test for Children (Form 4) pre and post-treatment. The outcomes were scrutinized utilizing a dependent t-test [11]. Lastly, Ghaemi and team (2016) probed into "*The Effect of Neurofeedback on the Speed and Accuracy of Reading Skill in 7–10-Year-Old Children with Learning Disabilities*". Employing a quasi-experimental setup, the research encompassed 15 children with learning disabilities aged 7-10 years, chosen through convenient sampling. The participants engaged in 15 neurofeedback sessions and were evaluated on reading and dyslexia assessments of NAMA before and after the intervention. Statistical analysis was carried out utilizing paired t-tests and the Wilcoxon test [12].

Results and Discussion

In their 2023 study, Martínez-Briones and colleagues dived into how neurofeedback (NFB) impacts the self-concept in children with learning disorders (LDs) [14]. Previous studies have revealed that neurofeedback treatments can enhance academic hurdles encountered by children with LDs, potentially boosting self-concept indirectly by addressing these

challenges. This groundbreaking research specifically investigated NFB's influence on the self-concept of children with LDs, marking a first in this realm of study. The results suggest a positive effect of NFB on the overall self-concept of these children, which could result from improved sentiments related to physical appearance, decreased anxiety, heightened popularity, and increased happiness. Martínez-Briones and team propose that future investigations should validate these findings in a more extensive cohort of children with LDs and delayed EEG maturation. When contrasting the neurofeedback (NFB) group with the control (Ctrl) group, no significant disparities were observed in age, gender, intelligence quotient (IQ), academic performance, or theta/alpha brain wave ratios. However, the control group displayed a higher overall self-concept than the NFB group, as detailed in Table 1.

Table 1. Descriptive data for the neurofeedback (NFB) and control (CTRL) groups

	NFB n=20	CTRL n=14	Statistical differences between groups	
	Mean (SD)	Mean (SD)	T	p
Age	9.05 (1.05)	9.00 (1.52)	0.11	0.91
Female/male ratio	9/11	6/8	X2 = 0.15	0.90
WISC-4: Full Scale IQ	92.55 (11.06)	93.07 (9.14)	−0.15	0.89
Reading	30.62 (20.87)	21.16(20.48)	1.36	0.26
Writing	38.68 (21.07)	28.82(17.80)	1.52	0.20
Mathematics	32.57 (20.79)	41.01(21.78)	−1.17	0.31
Global self-concept	53.15 (11.90)	59.79(8.36)	−1.96	0.04
z score (theta/alpha)	2.62 (1.001)	2.19(0.57)	1.22	0.18

There was a notable distinction between the NFB group (mean difference = −0.64, SD = 1.05) and the sham subgroup (mean difference = −0.45, SD = 0.45) in the change of theta/alpha ratio (post scores – pre scores) (t = −0.52, p = 0.34, d = −0.24). The intra-group examinations revealed a substantial reduction in the theta/alpha ratio after the treatment for both the NFB group and the sham subgroup (Table 2).

Table 2. Within groups pre vs. post *z* score (theta/alpha) differences for NFB and sham

	n	Mean pre (SD)	Mean post (SD)	t	P	Cohen's d
NFB	20	2.62 (1.01)	1.98 (1.16)	−2.70	0.00	0.58
Sham	9	2.19 (0.57)	1.74 (0.51)	−2.98	0.01	0.83

Nooripour *et al.* (2022) conducted a study on how neurofeedback affects students with learning disabilities [17]. The results indicated that neurofeedback therapy enhanced all aspects of working memory (accuracy of answers and response timing) as well as processing speed in these students, with improvements observed over a two-month follow-up period. The study suggests incorporating neurofeedback therapy's proven principles and methods into the educational and operational agendas of school counselors who work with girls with learning disabilities. Furthermore, Table 3 in the study highlighted that there was no significant difference in age, father's occupation, or birth order between the two study groups, indicating that they were comparable in terms of demographic characteristics [14].

Table 3. 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.

Descriptive statistics about analysis speed and memory in three stages (pre-test, post-test and follow-up) have been prepared for both neurofeedback and control groups, as presented in Table 4.

Table 4. Descriptive statistics for processing speed and working memory at three evaluation stages categorized by group

Variables	Groups	Pre-test	Mean±SD 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

Table 5 indicates the interaction effect and highlights the changes in processing speed, response accuracy and response time of the control and experimental (intervention) groups in the measurement steps.

Table 5. A univariate intra-subject effects test to compare the 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	-	-	-

Martínez-Briones *et al.* (2021) [15] carried out a study entitled: "*In their initial analysis comparing groups*" before treatment, they discovered no significant statistical variances across essential factors like age, gender, IQ (including a Working Memory (WM) index from the WISC-4 test), theta/alpha ratio [15], or WM behavioral performance (assessed through

correct responses and response times). This suggested that their method of randomly assigning children with Learning Disorders (LDs) effectively guaranteed comparability between groups concerning WM behavioral outcomes and power spectrum analyses post-treatment [16]. The research delved into differences within groups by examining the percentage of correct responses (as displayed in Figure 2) and response times (depicted in Figure 3) before and after the treatment. In Figure 2, the average percentages of correct responses pre-treatment are represented in blue, while post-treatment percentages are in yellow, indicating no significant statistical alterations. On the other hand, Figure 3, which displays mean response times before (in blue) and after (in yellow) treatment, emphasizes statistically noteworthy enhancements post-treatment in the Neurofeedback (NFB) group for tasks with a High-Load condition, denoted by asterisks, once more based on the Wilcoxon signed-rank test [17].

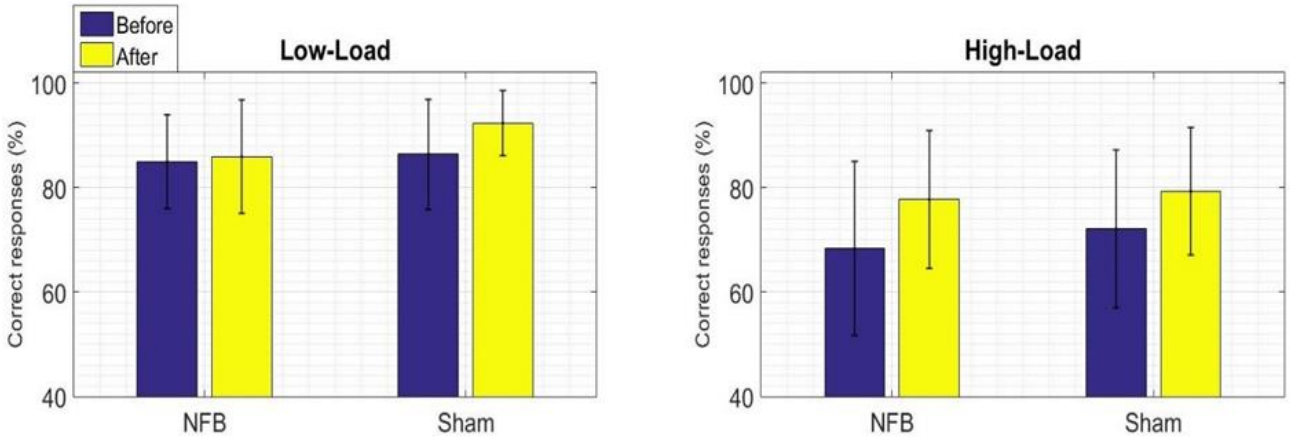

Figure 2. Within-group behavioral results for the correct responses for the WM task

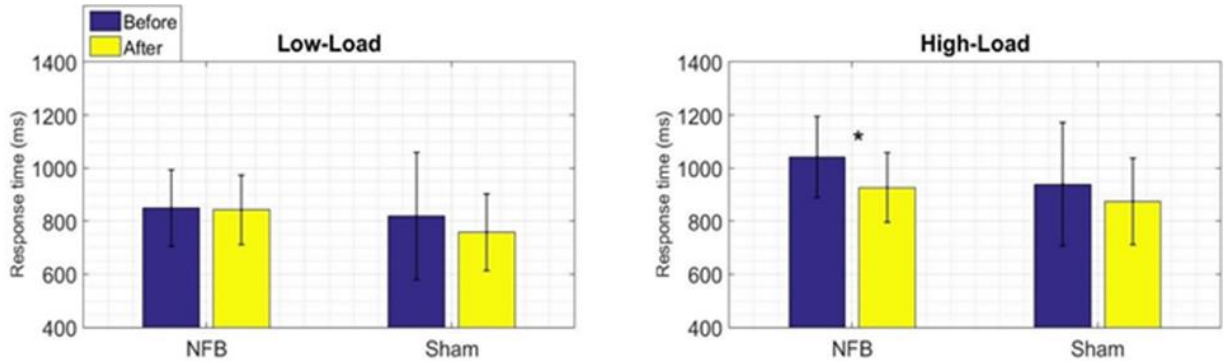

Figure 3. Within-group behavioral results for the response times to the WM task

Azizi *et al.* (2018) [4] conducted a study on the impact. They observed significant differences in the results based on (CPT) variables between the groups, with a significance level of $p<0.05$. In addition, they highlighted that the significant effects of the variables indicated that the CR group outperformed the NFB group, with a significance level of $p<0.001$. The research also showed enhancements across all metrics, such as omission errors, commission errors, and response time, from the pre-test to the post-test phases in both intervention groups, contrasting with the control group that did not receive any treatment, as outlined in Table 6 [18].

Table 6. Enhancements across all metrics

Variable	Groups	*M* ± *SD* In pre-test	*M* ± *SD* In post-test
Omissions	CR	2.05 ± 4.26	1.06 ± 1.43
	NFB	1.43 ± 3.25	0.82 ± 2.60
	Untreated	1.16 ± 3.36	1.28 ± 3.93
Commissions	CR	1.53 ± 9.73	1.42 ± 4.20
	NFB	1.35 ± 8.60	0.98 ± 5.40
	Untreated	9.06 ± 1.48	9.85 ± 1.84
Response time	CR	34.01 ± 434.56	30.98 ± 332.40
	NFB	31.55 ± 453.73	29.60 ± 347.53
	Untreated	32.23 ± 423.30	32.57 ± 436.21

Azadi *et al.* (2017) [5] conducted a study entitled: "The Effectiveness of Neurofeedback Therapy". They discovered a significant correlation between the scores before and after the treatment across all scales (P<0.05). This suggests that neurofeedback therapy significantly improves the performance of children with learning disabilities as evaluated by the Wechsler Intelligence Test for Children. Table 7 demonstrates a notable difference between the average pre-test scores and the post-test scores, showing an average increase of 4 to 5 points across all measured variables in the post-test phase [18-20].

Table 7. Descriptive indexes related to pre-test and post-test variables

Variables:	**Pre-test: Average**	**SD**	**Post-test: Average**	**SD**
Verbal comprehension:	43/4	9/341	47/07	7/676
Perceptual reasoning:	43/2	9/93	48/13	8/476
Working memory:	21/2	7/302	25/33	8/95
Processing speed:	18/87	4/642	23/07	5/65

In their study from 2016, Ghaemi *et al.* investigated the effects of neurofeedback on reading proficiency, specifically looking at speed and accuracy, in children aged 7 to 10 with learning disabilities. They found a statistically significant enhancement in reading speed, with notable variations in mean and standard deviation between the pretest and post-test (p<0.001). Nevertheless, the treatment did not lead to any significant alterations in reading accuracy. The study implies that additional therapy sessions might be necessary to bring about improvements in this aspect [21].

Conclusion

In each examined study on the impact of neurofeedback on learning disabilities, the findings revealed:

- The beneficial influence of neurofeedback on the overall self-image of affected children likely stems from enhanced self-perceptions relating to physical looks, reduced anxiety, popularity, and overall happiness.
- Neurofeedback therapy has been shown to enhance all aspects of working memory and speed analysis performance in female students with learning disabilities
- Cognitive Rehabilitation demonstrated greater efficacy in improving sustained attention compared to neurofeedback among the participants.
- It was revealed that the use of neurofeedback has a good effect on the activity of students with learning disabilities in the scale of the Wechsler test.
- By adjusting brain wave patterns, neurofeedback has been found to increase reading speed in children.

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