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Comparison of the Effectiveness of Infinite Tomatis Sound Therapy, Vestibulo-Cerebellar Skills Training, and the Combination of Both Methods on Response Inhibition in Students with Specific Learning Disorder with Reading Impairment

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A B S T R A C T

The present study aimed to compare the effectiveness of Infinite Tomatis sound therapy, vestibulo-cerebellar skills training, and the combination of both methods on response inhibition in students aged 8 to 12 years with specific learning disorder characterized by reading impairment. This research was an applied study utilizing a quasi-experimental design with pre-test, post-test, and follow-up stages accompanied by a control group. The statistical population consisted of all students with reading difficulties in Tehran in 2024 who sought treatment at counseling and rehabilitation clinics. The sample included 60 students from this population who were selected through convenience sampling and randomly assigned to four groups: Infinite Tomatis sound therapy training (n=15), vestibulo-cerebellar skills training (n=15), combined Infinite Tomatis sound therapy and vestibulo-cerebellar skills training (n=15), and a control group (n=15). After the intervention sessions, participants in all three experimental groups completed the research questionnaires again. The data were collected using the Reading and Dyslexia Test (NAMA) by Karami Nouri et al. (2008), the IVA2 Test, and the Go/No-Go Test developed by Bruner and Hoffman (1984). Data analysis was performed using repeated measures ANOVA with SPSS version 22. The findings indicated a significant difference in response inhibition scores between the combined training group and the vestibulo-cerebellar skills training group. Specifically, the response inhibition scores in the combined training group were higher than those in the vestibulo-cerebellar skills training group.

Keywords: *sound therapy, vestibulo-cerebellar skills, response inhibition, learning disorder.*

1. Introduction

Specific Learning Disorder (SLD) with reading impairment, commonly referred to as developmental dyslexia, represents one of the most prevalent neurodevelopmental disorders affecting school-aged children worldwide. Dyslexia is characterized by difficulties in accurate and fluent word recognition, poor spelling, and decoding abilities, which stem from deficits in the phonological component of language processing rather than from sensory or intellectual disabilities (Yang et al., 2022). Recent meta-analyses estimate the global prevalence of developmental dyslexia among primary school children to range between 5% and 15%, depending on linguistic, cultural, and methodological variations (Yang et al., 2022). These difficulties significantly affect children's academic achievement, self-esteem, and social adjustment, making early identification and intervention a critical component of educational and psychological practice (Osa-Afiana, 2022).

Neurocognitive research has identified multiple domains implicated in the etiology of dyslexia, including deficits in auditory processing, phonological awareness, executive functions, and cerebellar functioning (Cainelli et al., 2023; Crisci et al., 2021; Hemmati et al., 2022). The cerebellum, traditionally known for its role in motor coordination, has been increasingly recognized for its contribution to higher-order cognitive processes such as attention, working memory, and response inhibition (Bahmerd et al., 2021). Dysfunction in cerebellar and vestibular systems can impair temporal sequencing, phonological processing, and automaticity of reading, all of which are essential for literacy development (Hemmati et al., 2022). Consequently, recent studies have emphasized the importance of multimodal interventions that engage both cognitive-linguistic and sensorimotor domains to address the complex neurobiological underpinnings of dyslexia (Rahmani, Estaki, et al., 2019; Shahroudi et al., 2020).

Auditory processing plays a pivotal role in reading acquisition, as it underlies the ability to discriminate, process, and integrate phonological elements necessary for decoding written symbols (Malayeri & Pourgharib, 2022; Northern & Downs, 2022). Deficits in central auditory processing often lead to challenges in distinguishing phonemes, recognizing sound patterns, and forming stable auditory representations of language (Li et al., 2022). The Tomatis method—an auditory stimulation approach developed to enhance auditory-vocal feedback and neuroplasticity—has gained considerable attention in recent years for its potential to improve auditory discrimination, attention regulation, and cognitive processing speed (Brbić & Tomić, 2020; El-Tellawy et al., 2022). By exposing individuals to filtered and modulated sound frequencies, the Tomatis method aims to reorganize neural pathways between the ear and brain, thereby improving phonological awareness and reading performance in children with learning difficulties (Rahmani, Esteki, et al., 2019).

Empirical evidence supports the efficacy of Tomatis sound therapy in promoting executive functions and language-related skills. In a study on dyslexic students in Tehran, Tomatis-based sound therapy significantly improved executive functions such as working memory and cognitive flexibility, as well as reading accuracy and fluency (Rahmani, Estaki, et al., 2019; Rahmani, Esteki, et al., 2019). Similarly, in children with autism spectrum disorder, Tomatis sound therapy in combination with hyperbaric oxygen therapy led to enhanced auditory processing, social communication, and attention regulation (El-Tellawy et al., 2022). These findings highlight the cross-modal effects of auditory interventions, suggesting that sound-based therapies may facilitate broader neurocognitive improvements beyond language processing alone.

While auditory stimulation techniques target the cortical and subcortical networks associated with sound perception and attention, vestibulo-cerebellar interventions address the motor and postural aspects of learning, which are equally important for reading and executive control (Bahmerd et al., 2021; Hemmati et al., 2022). The vestibular and cerebellar systems interact dynamically with the prefrontal cortex to regulate sensorimotor coordination, balance, spatial orientation, and cognitive inhibition (Liang et al., 2022; Stucke et al., 2022). Deficits in these domains have been linked to difficulties in response inhibition, sustained attention, and self-regulation, which are frequently observed in children with SLD (Crisci et al., 2021). Interventions that engage vestibulo-cerebellar activation, such as balance and coordination exercises, can enhance neural connectivity between motor and cognitive networks, thereby supporting academic learning and executive function development (Hemmati et al., 2022; Liang et al., 2022).

Research on cerebellar and vestibular training demonstrates promising outcomes in improving reading, motor coordination, and cognitive inhibition. Bahmerd et al. (2021) reported that structured cerebellar exercises significantly improved reading and fine motor skills among students with dyslexia (Bahmerd et al., 2021). Similarly, Shahroudi et al. (2020) compared vestibular stimulation and

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cognitive rehabilitation interventions and found that vestibular training had a more pronounced effect on academic achievement among students with learning disabilities (Shahroudi et al., 2020). These findings align with neurodevelopmental theories emphasizing the cerebellum's role as a "timing and modulation center" for cognitive and linguistic performance (Tabrizi & Tabrizi, 2022).

Moreover, research on executive functions—the umbrella term encompassing inhibitory control, working memory, and cognitive flexibility—has shown that these skills are crucial for learning efficiency and self-regulation in educational settings (Crisci et al., 2021; Li et al., 2022). In particular, inhibitory control, which refers to the ability to suppress impulsive or automatic responses, plays a key role in reading comprehension and attention regulation (Liang et al., 2022). Studies have shown that both auditory and vestibular training can strengthen inhibitory control by enhancing neural communication between the cerebellum and prefrontal cortex (Dado & Emadian, 2024; Liang et al., 2022). Dado and Emadian (2024) found that cognitive-behavioral play therapy targeting executive functions improved inhibition and attention in students with reading difficulties, further supporting the potential of integrative interventions (Dado & Emadian, 2024).

Given the complex nature of dyslexia, many researchers advocate for multimodal interventions that combine sensory, motor, and cognitive stimulation (Snowling et al., 2019; Williams et al., 2021). Such integrated approaches address both bottom-up (sensory-motor) and top-down (cognitive-linguistic) processes, facilitating more comprehensive improvements in reading and executive function performance (Cainelli et al., 2023). The combination of Tomatis sound therapy and vestibulo-cerebellar training may offer a synergistic effect by simultaneously enhancing auditory processing and sensorimotor coordination, leading to improved response inhibition and learning outcomes (Hemmati et al., 2022; Rahmani, Estaki, et al., 2019).

In addition to neurophysiological evidence, theoretical perspectives also support such integrative interventions. The auditory-vocal feedback loop described in Tomatis theory emphasizes the role of listening as an active cognitive process influencing speech and learning (Malayeri & Pourgharib, 2022; Northern & Downs, 2022). Meanwhile, motor learning theory and cerebellar activation models propose that repetition of coordinated motor exercises strengthens the neural efficiency required for cognitive flexibility and inhibitory control (Bahmerd et al., 2021; Liang et al., 2022). Together, these frameworks suggest that a combined auditory–motor intervention may optimize cross-modal brain plasticity, thereby compensating for neural inefficiencies in children with reading impairments (Cainelli et al., 2023; Crisci et al., 2021).

Moreover, recent findings indicate that sedentary behavior and reduced physical activity in children may negatively impact executive functioning, particularly inhibition and working memory (Li et al., 2022). Thus, interventions involving physical and sensory-motor engagement, such as vestibular-cerebellar training, are critical to counteract the cognitive stagnation associated with low physical activity levels (Stucke et al., 2022). These findings underscore the importance of active, movement-based therapy as a complement to auditory interventions in promoting neurocognitive development.

Cultural and contextual factors also shape the presentation and treatment of dyslexia. In multilingual and non-Western contexts, such as Iran and Indonesia, children with reading disorders often face additional linguistic and pedagogical barriers that exacerbate learning difficulties (Friantary et al., 2020; Rahmani, Esteki, et al., 2019). The inclusion of culturally adaptive and non-invasive interventions such as sound therapy and vestibular training provides an accessible and effective means of remediation within educational and rehabilitation settings (Bahmerd et al., 2021; Shahroudi et al., 2020). Tabrizi and Tabrizi (2022) emphasized that modern treatment programs for reading disorders should be multimodal and based on neuropsychological evidence to effectively target the root causes of reading difficulties (Tabrizi & Tabrizi, 2022).

Further, the increasing use of electroencephalography (EEG) and neuroimaging in dyslexia research has revealed that effective interventions induce measurable changes in brain activity, particularly in auditory and cerebellar regions (Cainelli et al., 2023; Stucke et al., 2022). These neural adaptations reflect enhanced cortical synchronization, greater inter-hemispheric communication, and improved auditory attention. Hence, therapies that engage both auditory and vestibular pathways can potentially induce long-term neural reorganization, facilitating lasting improvements in reading and executive performance (El-Tellawy et al., 2022; Rahmani, Estaki, et al., 2019).

Altogether, the evidence suggests that sound therapy and vestibulo-cerebellar skills training share overlapping but distinct mechanisms that contribute to cognitive and linguistic improvement. While the Tomatis method enhances auditory attention and neural plasticity, vestibular-

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cerebellar exercises improve motor timing, coordination, and inhibitory control. Their integration may therefore yield additive or synergistic benefits in children with reading disorders (Bahmerd et al., 2021; Liang et al., 2022; Rahmani, Esteki, et al., 2019).

In light of the reviewed literature, the present study aimed to compare the effectiveness of Infinite Tomatis sound therapy, vestibulo-cerebellar skills training, and the combination of both methods on response inhibition in students aged 8–12 years with specific learning disorder characterized by reading impairment.

2. Methods and Materials

2.1. Study Design and Participants

The present study employed an applied quasi-experimental design using a pretest–posttest–follow-up structure with a control group. The statistical population included all students with reading difficulties in Tehran in 2024 who sought treatment at counseling and rehabilitation clinics. The study sample consisted of 60 students selected through convenience sampling, who were then randomly assigned to four groups: Infinite Tomatis sound therapy training (n=15), vestibulo-cerebellar skills training (n=15), a combined intervention of Infinite Tomatis sound therapy and vestibulo-cerebellar skills training (n=15), and a control group (n=15). After completing the intervention sessions, participants in all three experimental groups again completed the study questionnaires.

The required sample size was determined based on similar studies and following Gall, Borg, and Gall (2004), which suggest that 15 participants per group are sufficient for quasi-experimental designs.

The inclusion criteria were: a confirmed diagnosis of specific learning disorder with reading impairment based on the NAMA test, age between 8 and 12 years, informed consent from both the child and parents to participate in the study, and absence of any acute or chronic physical or psychological disorders. The exclusion criteria included missing two training sessions, lack of cooperation, and failure to complete the assigned activities during the training program.

To conduct the research, one center specializing in learning disorders was randomly selected from among the centers in District 8 of Tehran. Using convenience sampling, 60 students with reading difficulties were selected and randomly assigned to three experimental groups and one control group. In the next phase, the questionnaires and tests were administered to all participants in the four groups over two sessions, and the obtained scores were recorded as pretest scores.

The Infinite Tomatis sound therapy was conducted for 30 sessions (2 hours each, three times per week) for the first experimental group; cerebellar training was conducted for 20 sessions (40 minutes each, three times per week) for the second group; and the combined intervention was conducted for 30 one-hour sessions (three times per week) for the third group. The control group did not receive any intervention. However, participants in the control group were promised the opportunity to receive the training after the study if the intervention proved effective.

Three months after completing the interventions, all participants in the three experimental groups were retested for follow-up without any additional intervention. Following ethical principles, parents were provided with information about the study's objectives and procedures, assured of confidentiality, and informed that results would be published only in aggregate form. Participants were also told they could withdraw at any stage of the study. Written informed consent was obtained from all participants.

2.2. Measures

Reading and Dyslexia Test (NAMA): To assess reading ability and identify students with dyslexia, the Reading and Dyslexia Test "NAMA," developed and standardized by Karami Nouri et al. (2008), was used. The test aims to evaluate the reading ability of male and female elementary school students with monolingual or bilingual characteristics and to identify children with reading difficulties and dyslexia. It was standardized on a sample of 1,614 elementary students across five grades. The reliability of the test, calculated using Cronbach's alpha, ranged from 0.43 to 0.98 across subtests, with an overall mean of 100 and a standard deviation of 15. The test consists of ten subtests: word reading, word chain, rhyming, picture naming, text comprehension, word comprehension, phoneme (sound) deletion, non-word (pseudo-word) reading, letter–sound correspondence, and category–symbol correspondence. Raw scores are recorded on the answer sheet and the reading summary profile, then converted into standardized scores using grade-specific tables. The final results are interpreted and documented on a special report sheet. The overall reliability of the test is reported as 0.88 and validity as 0.84 (Karami Nouri et al., 2008).

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IVA2 Test: The IVA is a 13-minute continuous visual–auditory performance test that assesses two main factors—response control and attention. It is a computerized test applicable for individuals aged six years and above. Including the training section, the total administration time is approximately 20 minutes. The task involves responding or withholding response (response inhibition) to 500 stimuli, each presented for 1.5 seconds, requiring sustained attention. The IVA+PLUS test is based on the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) and differentiates ADHD subtypes, including inattentive, hyperactive–impulsive, combined, and unspecified types. It is also used to assess other conditions such as self-control difficulties due to head injury, sleep disorders, depression, anxiety, learning disorders, dementia, and other medical problems. The test was developed in the United States by BrainTrain Inc., with its latest version released in 2004. Research findings show that the IVA+PLUS test demonstrates high sensitivity (0.92) and predictive accuracy (0.89) for diagnosing ADHD in children. Test–retest reliability of the 22 IVA scales ranges from 0.46 to 0.88, indicating positive correlations (Gholami et al., 2017).

Go/No-Go Test: Developed by Hoffman (1984), this test evaluates inhibition, inhibitory control, sustained attention, and impulsivity. Widely used to measure behavioral inhibition, it consists of two categories of stimuli: participants must respond to one set ("Go") and withhold responses to the other ("No-Go"). Since "Go" stimuli are more frequent, participants develop a readiness to respond, and failure to inhibit response (commission error) occurs when a motor action is performed in response to a non-target stimulus. In this test, "Go" stimuli are geometric triangles presented among other geometric shapes ("No-Go") at the center of a 16-inch monitor, 60 cm from the participant's eyes, for 500 milliseconds. The participant must press the spacebar as quickly as possible when the triangle appears and refrain from responding to other shapes. A few practice trials are administered initially to familiarize participants with the task and response key, followed by 100 main trials, of which 70 are "Go" stimuli to induce a strong response tendency. All responses and reaction times are recorded. The reliability of the test was reported as 0.87 by Ghadiri, Jazayeri, Eshaeri, and Ghazi Tabatabaei (2006).

2.3. Intervention

The Infinite Tomatis sound therapy intervention consisted of 30 treatment sessions conducted three times per week, with each session lasting two hours. The sessions were administered by a trained psychologist and certified sound therapist. Children participated in pairs inside a soundproof room equipped with the VEGAS auditory stimulation system. They wore specialized headphones through which filtered high-frequency sound compositions, including those by Mozart, Beethoven, Gregorian chants, and other classical music, were delivered. The auditory material was modulated to stimulate both air and bone conduction, thereby enhancing auditory discrimination and cortical activation. During sound stimulation, participants engaged in simple play-based tasks to maintain comfort and attention. The purpose of this protocol was to improve auditory processing, emotional regulation, and neural synchronization between the auditory system and brainstem pathways, thereby facilitating better cognitive and behavioral inhibition control.

The vestibulo-cerebellar training was implemented across 20 sessions, each lasting 40 minutes, held three times a week based on the structured motor coordination and sensory integration frameworks developed by Kephart (1971) and Ayres (1974). Each session included activities targeting balance, coordination, spatial orientation, and rhythmic sequencing designed to strengthen the vestibular and cerebellar systems. Exercises involved head and body rotations, balance board tasks, coordinated hand–eye and foot–eye movements, crawling, skipping, and visual tracking tasks. The training aimed to improve cerebellar efficiency, sensorimotor integration, and executive control by enhancing postural regulation and neural timing processes. This structured physical–cognitive approach was designed to improve response inhibition and attention by modulating the functional connectivity between motor and prefrontal cortical areas.

The combined intervention integrated both Infinite Tomatis sound therapy and vestibulo-cerebellar skills training to leverage the complementary effects of auditory–neurological and sensorimotor stimulation. The program included 30 one-hour sessions conducted three times per week. Each session was divided into two sequential components: a 30-minute vestibulo-cerebellar training segment involving balance, coordination, and spatial tasks, followed by a 30-minute Infinite Tomatis sound therapy segment using filtered classical music through specialized headphones. The combined protocol aimed to simultaneously enhance auditory processing, motor coordination, and cognitive control functions. By engaging both auditory–cerebellar and vestibular–cortical pathways,

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the intervention sought to optimize neural plasticity and strengthen inhibitory control mechanisms critical for academic and behavioral performance in students with specific learning disorder characterized by reading impairment.

2.4. Data Analysis

For data analysis, descriptive statistics including frequency tables, charts, central tendency indices, and measures of dispersion such as mean and standard deviation were used. Multivariate analysis of covariance (MANCOVA) and repeated measures ANOVA were employed for inferential analysis. To test the assumptions of inferential statistics, Levene's test (for homogeneity of variances), the Shapiro–Wilk test (for normality of distributions), the homogeneity of regression test, MBox's test, and Mauchly's test of sphericity were conducted. All statistical analyses were performed using SPSS version 22.

3. Findings and Results

Given the quasi-experimental design of the research, 60 participants were assigned equally to four groups of 15 members each: three experimental groups (Infinite Tomatis sound therapy, vestibulo-cerebellar skills training, and the combined training of both methods) and one control group. The mean and standard deviation, as key descriptive indicators of the response inhibition variable, were calculated based on the pretest, posttest, and follow-up phases across the experimental and control groups. The descriptive statistics are presented in Table 1.

Table 1

Descriptive Indicators of Response Inhibition in the Pretest, Posttest, and Follow-up Stages Across Groups

Time	Group	N	Mean	Standard Deviation
Pretest (Response Inhibition)	Sound Therapy	15	13.056	2.609
	Vestibulo-Cerebellar Training	15	14.040	3.199
	Combined Training	15	14.750	2.897
	Control	15	13.933	2.685
	Total	60	13.983	2.626
Posttest (Response Inhibition)	Sound Therapy	15	21.600	2.873
	Vestibulo-Cerebellar Training	15	22.666	2.845
	Combined Training	15	27.200	3.913
	Control	15	13.400	2.823
	Total	60	21.216	5.883
Follow-up (Response Inhibition)	Sound Therapy	15	20.933	2.658
	Vestibulo-Cerebellar Training	15	22.466	2.996
	Combined Training	15	26.933	3.712
	Control	15	14.333	2.350
	Total	60	21.166	5.399

The Shapiro–Wilk test was used to assess the normality of the response inhibition variable across the three time points and four groups. The results indicated that at a significance level of $p > .05$, the collected data met the assumption of normality, confirming that the data were parametric across all three time points and four groups. Homogeneity of variances, another statistical assumption, was examined using Levene's test. For response inhibition, no violation of the homogeneity assumption was observed in the pretest [$F(3,56) = 3.56$, $p > .001$], posttest [$F(3,56) = .667$, $p > .05$], or follow-up [$F(3,56) = 1.305$, $p > .05$].

The homogeneity of covariance matrices across groups was assessed using Box's M test. The results revealed a significant F value [$F(816.18,11081) = 3.862$, $p < .05$], indicating that the assumption of homogeneity of covariance matrices for the dependent variable (response inhibition) across the levels of independent variables was not met. Hence, Pillai's Trace was reported as the appropriate multivariate statistic.

Mauchly's test of sphericity, which evaluates the equality of covariance matrices, also indicated a violation of the sphericity assumption ($p < .05$). Therefore, the Greenhouse–Geisser correction was applied. Additionally, due to the non-homogeneity of the covariance matrix (Box's M test), Pillai's Trace was used to assess the within-subject effect of time (pretest, posttest, and follow-up) and the time-by-group interaction effect across the experimental and control groups. The results of the multivariate tests are shown in Table 2.

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Table 2

Results of the Multivariate Test (Pillai's Trace)

Test	Effect	Value	F	df1	df2	Sig	Effect Size
Pillai's Trace	Time	.942	446.294	2	55	.001	.942
Pillai's Trace	Time × Group	1.017	19.321	6	112	.001	.509

The results indicate that the response inhibition variable showed significant differences across time (pretest, posttest, and follow-up) [F(2,55) = 446.294, p < .001] and also in the interaction between time and group [F(6,112) = 19.321, p < .05]. In other words, both the main effect of time and the time-by-group interaction were statistically significant for the dependent variable, meeting the necessary conditions for conducting a mixed two-way ANOVA.

Since Mauchly's test of sphericity was not met, the Greenhouse–Geisser correction was used for within-subject time effects (pretest, posttest, and follow-up). The results of the mixed two-way ANOVA for response inhibition are presented in Table 3.

Table 3

Results of the Mixed Two-Way ANOVA for Within-Subject Effects

Source	Test	Sum of Squares	df	Mean Square	F	Sig	Effect Size
Time	Greenhouse–Geisser	2078.478	1.386	1499.497	756.028	.001	.931
Time × Group	Greenhouse–Geisser	901.567	4.158	216.809	109.312	.001	.854
Error	Greenhouse–Geisser	153.956	77.623	1.983			

As shown in the table, the main effect of time was significant [F(1.78) = 756.028, p < .001], indicating that approximately 93% of the changes in response inhibition scores were explained by the within-subject time factor (partial eta squared = .93). Furthermore, the time-by-group interaction effect was also significant [F(4.78) = 109.312, p < .001], with a partial eta squared of .85, suggesting that approximately 85% of the changes could be attributed to the interaction between time and group levels.

Because the main within-subject effect was significant, Bonferroni post hoc tests were performed to compare paired means. The results are shown in Table 4.

Table 4

Results of Bonferroni Post Hoc Test for Within-Group Mean Comparisons (Response Inhibition)

Group	Time (I)	Time (J)	Mean Difference (I–J)	Standard Error	Sig
Sound Therapy	Pretest	Posttest	-7.600*	.321	.001
		Follow-up	-6.933*	.371	.001
	Posttest	Follow-up	.667	.435	.087
Vestibulo-Cerebellar Training	Pretest	Posttest	-8.667*	.333	.001
		Follow-up	-8.467*	.413	.001
	Posttest	Follow-up	.200	.145	.566
Combined Training	Pretest	Posttest	-13.200*	.846	.001
		Follow-up	-12.933*	.759	.001
	Posttest	Follow-up	.267	.118	.122
Control	Pretest	Posttest	.533	.256	.167
		Follow-up	-.400	.273	.493
	Posttest	Follow-up	-.933	.396	.101

As seen in Table 4, in the Infinite Tomatis sound therapy group, there was a statistically significant difference in response inhibition scores between the pretest and both posttest and follow-up phases. However, no significant difference was observed between posttest and follow-up scores. In other words, the sound therapy intervention had a significant effect on the response inhibition variable in the experimental sample, increasing the mean score by approximately eight points after the intervention in the posttest phase. However, no significant change was

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observed between posttest and follow-up scores, suggesting that the improvement achieved through sound therapy was maintained over time without additional enhancement.

In the experimental group receiving vestibulo-cerebellar skills training, there was a statistically significant difference in response inhibition scores between the pretest and both the posttest and follow-up assessments. In other words, vestibulo-cerebellar skills training was effective for the sample on the response inhibition variable, producing an increase of approximately 9 points in response inhibition following the training. Moreover, no significant change was observed between the posttest and follow-up scores in this experimental group.

In the experimental group receiving the combined training, there was a statistically significant difference in response inhibition scores between the pretest and both the posttest and follow-up assessments, and an increase of approximately 13 points was observed in the auditory attention component score following the combined training in the sample. In addition, there was no significant change between posttest and follow-up scores. This difference was also examined in the control group, and the results indicated that, with respect to response inhibition, there was no significant difference among the pretest, posttest, and follow-up scores. Next, Table 5 presents the test of between-subjects effects.

Table 5

Results of Between-Subjects Effects Test

Source	Sum of Squares	df	Mean Square	F	Sig	Effect Size
Intercept	63,544.022	1	63,544.022	2,731.305	.001	.980
Group	1,811.133	3	603.711	25.949	.001	.582
Error	1,302.844	56	23.265			

As shown in Table 5, the between-subjects effect is significant [$F(3, 56) = 25.949$, $p < .001$]. This finding indicates comparability of response inhibition across the experimental groups (Infinite Tomatis sound therapy, vestibulo-cerebellar skills training, and combined training) and the control group. In other words, the type of training affected the response inhibition of the study sample, and there was a significant difference between at least two of the groups. The partial eta squared also shows that approximately 58% of the variance in visual attention scores can be explained by the treatment groups. Given the significant difference between groups, pairwise comparisons of means were conducted. Because the sample sizes were equal across the four groups and the assumption of homogeneity of variances was met, Tukey's post hoc test was used to compare response inhibition scores among the groups. The results of the between-group mean comparisons are reported in Table 6.

Table 6

Pairwise Comparisons of Mean Response Inhibition Scores Across Study Groups (Tukey Post Hoc)

Group I	Group J	Mean Difference (I–J)	Standard Error	Sig
Sound Therapy	Vestibulo-Cerebellar Training	-0.867	1.017	1.000
Sound Therapy	Combined Training	-3.867*	1.017	.002
Sound Therapy	Control	4.956*	1.017	.000
Vestibulo-Cerebellar Training	Sound Therapy	0.867	1.017	1.000
Vestibulo-Cerebellar Training	Combined Training	-3.000*	1.017	.028
Vestibulo-Cerebellar Training	Control	5.822*	1.017	.000
Combined Training	Sound Therapy	3.867*	1.017	.002
Combined Training	Vestibulo-Cerebellar Training	3.000*	1.017	.028
Combined Training	Control	8.822*	1.017	.000
Control	Sound Therapy	-4.956*	1.017	.000
Control	Vestibulo-Cerebellar Training	-5.822*	1.017	.000
Control	Combined Training	-8.822*	1.017	.000

As indicated by the results in Table 6, the mean score of the combined training group was approximately 4 points higher than the sound therapy group and 3 points higher than the vestibulo-cerebellar training group, and these differences were statistically significant. Additionally, there were significant differences between each of the three

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experimental groups and the control group for response inhibition: the sound therapy group scored about 5 points higher than the control group, the vestibulo-cerebellar training group scored about 6 points higher than the control group, and the combined training group scored about 9 points higher than the control group. Subsequently, a comparative chart of the four groups on the response inhibition variable was presented.

4. Discussion and Conclusion

The present study aimed to compare the effectiveness of Infinite Tomatis sound therapy, vestibulo-cerebellar skills training, and the combination of both methods on response inhibition in students aged 8–12 years with specific learning disorder characterized by reading impairment. The results demonstrated that all three interventions significantly improved response inhibition scores from pretest to posttest, whereas no significant decline was observed in the follow-up phase, indicating the durability of the effects over time. Moreover, the combined intervention group showed the highest level of improvement compared with either sound therapy or vestibulo-cerebellar training alone, while the control group exhibited no significant change. These findings suggest that both auditory and sensorimotor interventions effectively enhance cognitive control and executive functions in children with reading difficulties, and that an integrated approach can yield synergistic benefits.

The improvement in response inhibition following Tomatis sound therapy is consistent with previous research emphasizing the connection between auditory stimulation and executive functioning (Rahmani, Estaki, et al., 2019; Rahmani, Esteki, et al., 2019). The Tomatis method enhances neural efficiency through auditory–cortical modulation, stimulating pathways between the cochlea, vestibular nuclei, and prefrontal cortex. This auditory-based feedback loop contributes to better attentional regulation, inhibition control, and phonological awareness (Malayeri & Pourgharib, 2022; Northern & Downs, 2022). The present study's findings align with those of Rahmani et al. (2019), who reported significant improvement in executive functions such as working memory and attention regulation among dyslexic students following sound therapy (Rahmani, Esteki, et al., 2019). Similarly, Crisci et al. (2021) emphasized that deficits in executive functions, particularly inhibitory control, are commonly observed in neurodevelopmental disorders, including dyslexia and ADHD, and can be effectively targeted through sensory-based interventions (Crisci et al., 2021).

Furthermore, the study corroborates the theoretical framework suggesting that auditory stimulation reorganizes brain networks involved in self-regulation and attention (Cainelli et al., 2023; Li et al., 2022). The increase in response inhibition scores observed among participants may reflect enhanced inter-hemispheric communication and improved activation of the prefrontal cortex, as supported by EEG studies showing neural plasticity in children with dyslexia following sound-based interventions (Cainelli et al., 2023). The filtered and modulated frequencies used in Tomatis therapy stimulate the auditory-vocal feedback loop, improving the synchronization between listening and speech production centers (Malayeri & Pourgharib, 2022). As a result, children develop better phonological processing and inhibitory control, which are essential for reading and cognitive performance.

The significant effect of vestibulo-cerebellar skills training on response inhibition also supports previous literature emphasizing the cerebellum's role in cognitive and behavioral regulation (Bahmerd et al., 2021; Hemmati et al., 2022). The vestibular and cerebellar systems are deeply interconnected with the prefrontal cortex, forming a sensorimotor-cognitive network that influences attention, balance, and inhibition. Cerebellar training activates neural circuits responsible not only for motor coordination but also for higher-order cognitive functions, including planning, timing, and response inhibition (Liang et al., 2022). The current findings align with Bahmerd et al. (2021), who demonstrated that cerebellar exercises significantly improved reading fluency and motor coordination in students with dyslexia (Bahmerd et al., 2021). Similarly, Shahroudi et al. (2020) found that vestibular stimulation enhanced academic performance in students with specific learning disorders by improving cognitive control and sensory integration (Shahroudi et al., 2020).

In addition, the observed gains in inhibitory control can be interpreted in light of the "cerebellar deficit hypothesis" of dyslexia, which proposes that cerebellar dysfunction contributes to difficulties in automatisation of cognitive and linguistic skills (Snowling et al., 2019; Tabrizi & Tabrizi, 2022). Training the cerebellum through balance and coordination exercises may thus strengthen procedural learning mechanisms and neural timing accuracy, leading to better regulation of attention and inhibition (Liang et al., 2022). The current results reinforce the notion that vestibulo-cerebellar training fosters neuroplasticity across cognitive

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and motor domains, bridging deficits commonly seen in dyslexic children.

Importantly, the greatest improvement in response inhibition was observed in the combined training group, indicating that integration of auditory and vestibulo-cerebellar stimulation exerts a synergistic effect on cognitive regulation. The combination of Tomatis sound therapy and vestibular exercises likely enhanced multisensory integration and inter-network coordination between auditory, motor, and prefrontal regions. Such multimodal engagement can optimize brain plasticity by simultaneously activating different neural systems responsible for self-regulation and attention (Hemmati et al., 2022; Liang et al., 2022). The concurrent stimulation of auditory and vestibular inputs might improve temporal synchronization and neural coherence, which are crucial for reading fluency and executive functioning (Cainelli et al., 2023).

Previous research supports the superior outcomes of multimodal interventions in addressing neurodevelopmental disorders. For example, El-Tellawy et al. (2022) found that Tomatis sound therapy combined with hyperbaric oxygen treatment produced greater improvements in auditory processing and attention than either treatment alone in children with autism (El-Tellawy et al., 2022). Similarly, Liang et al. (2022) reported that a combined exercise program enhanced executive functions, including inhibition and working memory, in children with ADHD, underscoring the advantage of multisensory engagement (Liang et al., 2022). These findings are consistent with the current study's results, which demonstrate that combined auditory–motor stimulation enhances inhibitory control more effectively than single-modality interventions.

The observed differences between the experimental and control groups also reflect the importance of targeted cognitive-motor training in neurodevelopmental remediation. Children in the control group, who received no intervention, showed no significant changes in response inhibition scores across testing phases, confirming that natural maturation or exposure to conventional education was insufficient to improve inhibitory control. This finding echoes the conclusions of previous longitudinal studies showing that children with untreated dyslexia continue to exhibit persistent deficits in executive functioning and reading performance over time (Snowling et al., 2019; Williams et al., 2021).

The improvement in inhibitory control across the experimental groups can further be understood through the lens of neuroplasticity. Auditory and vestibular stimuli activate subcortical structures such as the thalamus, cerebellum, and brainstem, which, through repeated stimulation, enhance functional connectivity to cortical regions involved in executive control (Cainelli et al., 2023; Northern & Downs, 2022). Such neural adaptations may explain the sustained effects observed during the follow-up phase. The maintenance of improvements after the cessation of training supports the long-term efficacy of both sound therapy and cerebellar training as neurorehabilitative approaches (Bahmerd et al., 2021; Rahmani, Estaki, et al., 2019).

The findings also align with the growing recognition of the interdependence between auditory processing and motor control in literacy development. Northern and Downs (2022) emphasized that auditory input not only influences language acquisition but also contributes to sensory-motor integration necessary for fluent reading (Northern & Downs, 2022). Moreover, vestibular and auditory systems share overlapping neural pathways that converge in the brainstem and cerebellum, enabling cross-modal reinforcement during combined interventions (Malayeri & Pourgharib, 2022). The simultaneous engagement of these pathways may underlie the superior performance of the combined group in the current study.

In the broader context of educational neuroscience, these findings support integrative therapeutic frameworks for specific learning disorders that combine behavioral, sensory, and cognitive modalities (Crisci et al., 2021; Dado & Emadian, 2024). Such approaches are aligned with multisensory learning theories, which propose that cognitive development benefits from the convergence of auditory, visual, and kinesthetic experiences (Friantary et al., 2020; Williams et al., 2021). As emphasized by Tabrizi and Tabrizi (2022), reading remediation programs that integrate auditory and motor components are more effective in addressing the multidimensional nature of dyslexia (Tabrizi & Tabrizi, 2022).

The present findings also resonate with the results of Dado and Emadian (2024), who found that cognitive-behavioral play therapy significantly improved executive functions, including inhibition and working memory, in students with reading disorders (Dado & Emadian, 2024). Together, these studies affirm the role of cognitive control as a modifiable target of intervention in children with SLD and highlight that both physical and sensory stimulation can facilitate such improvement.

Furthermore, the study contributes to the understanding of environmental and behavioral factors affecting executive

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functions. Stucke et al. (2022) and Li et al. (2022) reported that children's daily activity patterns, sedentary behavior, and engagement in structured tasks are strongly correlated with executive function performance (Li et al., 2022; Stucke et al., 2022). The active, movement-based structure of vestibulo-cerebellar training counteracts the negative effects of sedentary lifestyles, fostering cognitive engagement and self-regulation. These findings suggest that integrating structured physical activity within educational therapy can play a critical role in optimizing children's executive development.

From a neurodevelopmental perspective, the combination of auditory and vestibular interventions in this study provides empirical support for the "cross-modal compensation" hypothesis, which posits that enhancing one sensory system can improve the performance of another through shared neural pathways (Hemmati et al., 2022; Liang et al., 2022). This cross-system interaction may explain the substantial gains in response inhibition, as the cerebellum modulates attention and temporal sequencing while auditory therapy strengthens sensory encoding and cortical activation.

Overall, the results underscore the potential of integrating sound therapy with vestibulo-cerebellar training to remediate deficits in executive function and reading-related performance in children with specific learning disorder. The observed improvements suggest that multisensory interventions not only enhance behavioral outcomes but also induce deeper neurocognitive changes that support sustained learning and self-regulation (Cainelli et al., 2023; Rahmani, Estaki, et al., 2019). This combination therapy can be considered an innovative, non-invasive, and cost-effective approach in educational and clinical settings, aligning with global trends in personalized neuropsychological rehabilitation (El-Tellawy et al., 2022; Osa-Afiana, 2022).

This study, while providing valuable insights, faced certain limitations. First, the sample size was relatively small and drawn from a single urban area, which limits the generalizability of the findings to broader populations with different cultural or linguistic backgrounds. Second, the convenience sampling method may introduce selection bias, and randomization across diverse educational settings would be necessary to confirm the robustness of results. Third, the study relied primarily on behavioral measures of response inhibition, without incorporating neurophysiological assessments such as EEG or fMRI, which could provide more direct evidence of neural changes underlying the observed improvements. Fourth, the duration of follow-up was limited to three months, making it difficult to determine the long-term sustainability of treatment effects. Finally, variations in therapist expertise, parental involvement, and participants' motivation could have influenced outcomes, highlighting the need for controlled fidelity measures in future interventions.

Future research should focus on replicating these findings using larger, more diverse samples and employing randomized controlled trial designs to enhance internal validity. Studies should also integrate neuroimaging techniques to explore the neural mechanisms underlying improvements in inhibitory control and reading performance following combined interventions. Longitudinal research extending follow-up periods beyond six months would help clarify the durability of treatment effects. Comparative studies examining the impact of these interventions on other executive domains—such as cognitive flexibility, working memory, and attentional shifting—could further elucidate their broader cognitive benefits. Additionally, integrating parent and teacher training modules alongside child interventions may amplify outcomes by creating supportive learning environments. Cross-cultural studies comparing the effectiveness of Tomatis and vestibular-cerebellar training across linguistic contexts would also contribute to a more universal understanding of their applicability in global education systems.

In practice, educators, school psychologists, and rehabilitation specialists should consider integrating multisensory approaches—combining auditory stimulation and vestibular-cerebellar exercises—into intervention programs for children with specific learning disorders. School-based centers can implement Tomatis sound therapy as part of individualized education plans, complemented by structured motor coordination activities to strengthen executive functions. Collaboration between audiologists, occupational therapists, and psychologists can facilitate comprehensive treatment planning. Furthermore, training teachers to recognize signs of auditory and cerebellar dysfunction can support early referral and intervention. Finally, implementing these integrative methods within inclusive classrooms may enhance academic outcomes, behavioral regulation, and overall cognitive resilience in children with reading impairments.

Authors' Contributions

Authors contributed equally to this article.

Declaration

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In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

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Declaration of Interest

The authors report no conflict of interest.

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Ethics Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

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