SIN-CHN SCIENTIFIC PRESS PTE.LTD.

Molecular & Cellular Biomechanics 2025, 22(4), 1019.
https://doi.org/10.62617/mcb1019

Article

Enhancing prefrontal cortex activity and attention distribution in children with ADHD-I/C: TOMATIS and PASS training effectiveness

Xu Zhang[1,2], Guanjie Shang[3], Shufang Huang[4], Yong Wang[5,*]

[1] Institute of Psychology, Chinese Academy of Sciences, Beijing 100000, China
[2] Department of Psychology, University of Chinese Academy of Sciences, Beijing 100049, China
[3] Fujian Aiken Education Technology Co., LTD, Fuzhou 350000, China
[4] Zhongke Jiuzhan Institute of Science and Technology, Xiamen 361000, China
[5] Department of Psychology, University of International Relations, Beijing 100000, China
*** Corresponding author:** Yong Wang, wangy@uir.edu.cn

CITATION

Zhang X, Shang G, Huang S, Wang Y. Enhancing prefrontal cortex activity and attention distribution in children with ADHD-I/C: TOMATIS and PASS training effectiveness. Molecular & Cellular Biomechanics. 2025; 22(4): 1019. https://doi.org/10.62617/mcb1019

ARTICLE INFO

Received: 5 December 2024
Accepted: 8 January 2025
Available online: 28 February 2025

Abstract: This study introduces three methodological innovations in enhancing children's prefrontal cortex activity and executive functions using TOMATIS filtered audio therapy and PASS theory training. The interventions synergize to improve cognitive processing and neural plasticity. Divided into two stages, the initial focuses on physical and emotional adaptation, while the latter targets cognitive enhancement. After five weeks, significant improvements in attention and executive functions were observed in the treatment group compared to controls ($P < 0.05$). The study also explores AI exoskeletons and near-infrared technology to optimize therapy, offering new insights into ADHD treatment.

Keywords: TOMATIS therapy; PASS theory; prefrontal cortex; ADHD; cognitive enhancement

1. Introduction

1.1. Three kinds of inhibition defects lead to ADHD children's behavioral abnormalities

Attention Deficit/Hyperactivity Disorder (ADHD) is a prevalent emotional and behavioral disorder that typically emerges before age 12 and may persist into adulthood [1]. The prevalence estimates of ADHD in Mainland China, Hong Kong, and Taiwan were 6.5%, 6.4%, and 4.2%, respectively, with a pooled estimate of 6.3% [2]. These children grapple with uncontrollable executive behavior, impulsive hyperactivity, concentration difficulties, emotional disorders, and social communication challenges, severely impeding their learning, daily life, and social development. Therefore, there is an urgent need to explore effective, convenient, and comprehensive treatments that surpass single therapy approaches.

The theory of executive dysfunction in ADHD children posits behavioral inhibition as the core defect [3]. The neural mechanisms underlying executive function impairments in ADHD are intricately linked to the development and dysfunction of the prefrontal cortex [4]. Jones and Graff-Radford [5]. summarizes the cognitive and behavioral functions of the prefrontal cortex, with a particular emphasis on executive cognitive functions and their associated clinical consequences. It mentions that executive functions, which encompass working memory, cognitive flexibility, and inhibition, rely on the top-down (i.e., goal-driven) control of distributed processes in the brain. The prefrontal cortex regions are crucial for key cognitive functions related to social, emotional, and motivational behaviors [5]. Furthermore, other brain regions such as the cingulo-frontal-parietal (CFP) cognitive-attention network, which is relevant to cognitive processes affected in ADHD [6].

The theory of executive dysfunction in children with ADHD regards behavioral inhibition as the most fundamental defect in these children [3]. The neural mechanism of executive function deficits in ADHD children is mainly related to the development and dysfunction of the prefrontal cortex [4]. The prefrontal cortex is the primary brain region associated with executive function and is responsible for advanced cognitive functions such as planning, decision making, and inhibitory control. ADHD children develop their prefrontal cortex much more slowly than their peers, leading to widespread executive dysfunction [5]. Additionally, the ventral medial prefrontal cortex related to complex decision making and strategic planning, the parietal cortex related to attention orientation, and the ventral anterior cingulate cortex and dorsal anterior cingulate cortex related to the emotional and cognitive components of executive control are also abnormal in structure and function. The resulting inhibition deficits are mainly manifested as working memory deficits, attentional blinks, and emotional and behavioral problems [6].

From a biomechanics perspective, the mechanical behavior of neural tissues and the mechanical coupling within neural networks play a pivotal role in regulating cognitive functions. Mechanical forces and deformations can influence the conformational changes, binding/reaction kinetics, and transport processes of biomolecules within the neural system. For instance, alterations in the mechanical stiffness of DNA, RNA, and proteins due to stretching, twisting, bending, and shearing could impact processes such as DNA condensation, gene replication and transcription, DNA-protein/RNA-protein interactions, protein folding, and receptor-ligand binding, which are critical for normal brain function.

The lack of working memory significantly impacts children's school life and daily life. Studies have shown that ADHD children have obvious deficiencies in processing visual graphics and visual spatial working memory [7]. Attentional blink refers to the phenomenon that when two target stimuli are presented rapidly and continuously, the report rate of the second stimulus is reduced within a few hundred milliseconds after the first target stimulus appears, reflecting the time limitation of ADHD children in attention allocation. Studies have found a significant correlation between attention deficit and the lack of inhibitory control function in ADHD children [8]. Emotional disorders are also more common in ADHD children [9], who often exhibit emotional instability, impulsivity, stubbornness, irritability, and other personality characteristics, accompanied by more social withdrawal and worse selfcontrol ability [10].

Moreover, the mechanical behavior of cells and tissues, including neurons and glial cells, can affect signaling pathways and cellular responses. Mechanical stimuli can alter chemical potentials and cell morphologies, activating signaling cascades and modifying cell phenotypes. In the context of ADHD, mechanical forces might influence the mechanical biochemistry of neural cells, affecting their ability to respond to external or internal stresses, leading to conformational changes in intracellular binding affinities, cell proliferation, apoptosis, migration, and wound healing.

1.2. Subtype classification, assessment and intervention strategy determination of ADHD children

According to the internationally accepted IVA audiovisual integration continuous test report, ADHD children can be divided into three subtypes: attention deficit type (ADHDI), hyperactivity type (ADHDH), and mixed type (ADHDC) [11]. Based on the Plan Attention Simultaneous Successive Processing Model (PASS model), the DN: CAS (Cognitive Assessment System) cognitive assessment system can effectively assess the working memory deficit and attentional blink in the inhibition deficit of ADHD children and evaluate the cognitive, processing, and execution processes of the brain. It can also classify the executive function of the large and basic subtypes of ADHD, providing a strong basis for the precise intervention treatment of children with different clinical subtypes of ADHD and offering potential value for further understanding the pathogenesis of ADHD [12].

The results of the study showed significant differences between the three groups of ADHD children with different clinical subtypes and the healthy control group in planning, simultaneous processing, attention subscales, and total scores. This indicates that children with ADHDI and ADHDC are weaker than healthy children in planning ability, simultaneous processing ability, sequential processing ability, and attention ability in the DN: CAS cognitive assessment scale. Therefore, this experiment selected children with ADHD attention deficit problem (ADHDI) or mixed problem (ADHDC) as the subjects, and the DN: CAS cognitive assessment system based on the intelligence PASS model can accurately evaluate the attention and the ability of simultaneous processing and successive processing of ADHDI and ADHDC children [13]. The use of executive function training based on PASS theory as an intervention is expected to have a statistically significant positive effect on children with ADHDI and ADHDC.

These introductory sections set the stage for the research by outlining the prevalence and impact of ADHD, the neural mechanisms involved, and the importance of subtype classification for targeted intervention strategies. They provide the necessary context for understanding the rationale behind the study’s focus on executive function training and TOMATIS filtered audio therapy for children with ADHD.

2. Materials and methods

2.1. Research objects and grouping

This study selected 62 children with attention deficit hyperactivity disorder (ADHD) who were admitted to the First Affiliated Children’s Hospital of Fuzhou City, Fujian Province from January 2024 to February 2024 as subjects. These children are all from the first and second grades of the same primary school. The age difference is controlled within 2 years old, and they have a highly similar educational environment to ensure the homogeneity of the subjects. According to the type of ADHD, the 60 children were divided into attention deficit type (ADHDI) 30 and mixed type (ADHDC) 32. Using a simple randomization method, ADHDI and ADHDC children were evenly assigned to the control group and the observation group, each group contained 15 ADHDI children and 16 ADHDC children, a total of 31 cases. The control group received executive function training based on PASS theory, while the observation group added TOMATIS audio conversion training on this basis. The effects of different interventions were evaluated by comparing the changes of executive function between the two groups of children.

We have introduced an additional control group that receives only TOMATIS audio conversion training. This group was assessed at the same time points as the intervention group using identical methods to isolate the effects of TOMATIS training.

2.2. Inclusion and exclusion criteria

This study strictly follows the following inclusion and exclusion criteria:

Age range: The age was limited to 7 to 9 years old to ensure the age consistency of the subjects.

Diagnostic basis: Based on the results of visual and auditory continuous integration test (IvA), children with ADHD attention deficit or mixed problems were selected.

Comparability of baseline data: There was no significant difference in baseline data between the two groups ($P > 0.05$), as shown in **Table 1**. All patients and their families have informed consent for this study and have been approved by the Medical Ethics Committee of Fuzhou Children's Hospital, Fujian Province.

Table 1. Analysis of demographic differences between the 'cognitive group' and the 'cognitive + TOMATIS group'.

Group	Mean ± Standard Deviation	*t*	*P*
Gender	1.39 ± 0.5	−0.760	0.450
Cognitive Course Group	1.48 ± 0.51		
Age	7.1 ± 0.83	−0.315	0.754
Cognitive + TOMATIS Group	7.16 ± 0.78		

Intellectual level: Raven IQ test scores need to be between 80 and 119, to ensure that the subjects without intellectual disabilities, and intelligence in the middle or lower middle level.

Cognitive function assessment: DN: The total score of the CAS cognitive scale needs to be between 71 and 120, and the scores of the attention subitem and the subsequent subitem need to be between 60 and 100 to evaluate the cognitive function level of children.

Hearing assessment: TOMATIS assessment of bone conduction and air conduction curves need to be between 50 and 80 to exclude the impact of hearing abnormalities on the results of the study.

Mental state: Children with mental illness were excluded to ensure that the subjects could cooperate with intervention and treatment.

Intervention purity: During the intervention period, children should not be treated with drug therapy or other intervention therapies at the same time to ensure the accuracy of the research results.

2.3. Experimental design and methodology

In this study, 62 participants in the experimental group and the control group received executive function training based on PASS theory. The training was conducted in the form of online live broadcast and one to many. It was led by the intervention tutor who had the qualification of DN: CAS cognitive evaluation system. It lasted for 28 days, from 7:03 to 8:30 every night, a total of 1 h of intensive training. In the live broadcast environment, participants can observe and listen to the mentor's guidance and demonstration in real time. At the same time, the mentor evaluates the participants' concentration, comprehension, and execution ability in real time by issuing instructions, and corrects and records the performance in the training process in real time to ensure that each participant can obtain sufficient and personalized intervention.

The design of PASS theory executive function training is strictly based on the cognitive characteristics of the enrolled children and the framework of DN: CAS evaluation system. This system deeply simulates the hierarchical structure of human cognition and execution, and constructs a theoretical framework including three layers of cognitive system and four execution processes. Among them, attention, as the cornerstone of cognitive activity, is juxtaposed with simultaneous processing and successive processing at the second level, while the planning process is at the top, supervising and controlling other processs [14]. For the initial intervention of ADHD children, the training focuses on the improvement of attention and continuous processing ability. Specifically, during the 28 day training period, 40% of the training programs focused on attention training. Although the design of the test is different from the attention subtest in the DN: CAS cognitive scale in form, it maintains similar cognitive execution logic, such as number cancellation training, which aims to exercise children's selective attention, attention conversion, and distraction inhibition ability. The remaining 60% focused on the training of sequential processing. By simulating the sequential processing subtests in DN: CAS, such as the Chinese character retelling task, children were asked to retell a series of words in order to evaluate and improve their immediate learning ability, concentration, and cognitive execution ability.

The PASS theory executive function training in this study has achieved three innovations on the basis of traditional methods:

(1) Introduce the activation setting link: Through activities such as 'meditation' top sandbags and finger exercises, children's attention is effectively focused, the cerebral cortex is activated, the body's perception ability is improved, and good psychological preparation is laid for subsequent formal training [15]. At the end of the training, the coloring activity is used as the ending to help children transition smoothly from high intensity audiovisual training to a focused and relaxed state.

(2) Implementation of highfrequency, timed interventions: Each class contains 56 training contents, each lasting for about 10 minutes. It aims to improve the executive function of the limbic brain, prefrontal cortex, and cerebellum, correct hyperactivity behavior, and enhance the stability of concentration through regular stimulation [16].

(3) Integrating positive psychological motivation: Through positive classroom

interaction and language encouragement, children's sense of achievement and value can be stimulated, and the secretion of dopamine and endorphin can be promoted, so as to enhance the activity of marginal brain, amygdala, and hippocampus, and effectively enhance their concentration, memory, and antifrustration ability [17]. Considering the physiological characteristics of children and the actual effect of the live broadcast course, the training pays more attention to visual stimulation. The ratio of visual and auditory training is set to 7:3, which is complementary to the subsequent TOMATIS audio conversion training.

On the basis of the control group, the observation group received additional customized TOMATIS audio conversion training to explore the comprehensive effect of superimposed audio training. The training was customized according to the test results of the subjects. In view of the common problems of children, such as emotional fluctuation, anxiety, sensory integration disorder, and weak understanding, the training was based on the three-zone theory of TOMATIS (low-frequency zone is responsible for vestibular function and body control; intermediate frequency area associated with communication, language, and logic; high-frequency area affects cochlear function, cerebral cortex, and mental state) for phased intervention. The first stage (the first 10 days) is mainly aimed at the low-frequency area, solving the problem of physical coordination and emotional management; in the following three days, high-frequency area training was added to activate the cerebral cortex and achieve physical and mental coordination. At this stage, the emotional regulation strategy is innovatively integrated, and the emotional and executive functions of children are optimized by using different frequency of music stimulation. The second stage (the second 10 days) focuses on the intermediate frequency area, aiming to improve children's language understanding, logical thinking, and cognitive ability, reflecting a deep understanding of the mechanism of concentration operation [18].

The specific program of TOMATIS audio conversion training includes:

(1) Music preparation: Mozart series and Gregoria hymns are selected as training music, and the playing sequence is changed daily to ensure freshness and diversity.

(2) Audio changes: The training was divided into two cycles, a total of 6 weeks, with an interval of 20 days. Seven days before the first cycle, the frequency range of 325 Hz to 4000 Hz was used to regulate executive function and emotion; in the last 3 days, it was increased to 500 Hz to 8000 Hz, focusing on the regulation of vestibular executive function and concentration. The second cycle focuses on language understanding and expression, and the frequency range is adjusted to 500 Hz to 4000 Hz.

(3) Training methods: Wireless headphones were used for bone conduction training, a group of 10 people to ensure signal coverage.

(4) Hardware Advantages: Bone conduction technology avoids eardrum vibration and reduces the damage to the ear. At the same time, soothing light music helps to relax the mood and reduce mental fatigue [19].

In summary, this study aims to comprehensively improve the executive function, attention, and overall cognitive performance of ADHD children through the superimposed application of carefully designed PASS theory executive function training and TOMATIS audio conversion training.

(5) Sample Size Calculation: Utilizing statistical formulas from previous similar

studies and pilot experiment results, we estimated the required sample size to achieve a statistical power of 0.8 with a significance level of 0.05.

2.4. Statistical analysis

All analyses were conducted using SPSS.28, with specific tests including ANOVA and *t*-tests. We detail the parameters set for each test and provide effect sizes and confidence intervals where applicable.

3. Results

3.1. Overall improvements in cognitive function

After nearly five weeks of intervention, significant improvements in attention, planning, simultaneous processing, and successive processing abilities were observed in both groups of subjects under the PASS system evaluation ($P < 0.05$). The observation group, which received comprehensive therapy including both PASS theory executive function training and TOMATIS audio conversion training, showed particularly prominent improvements, significantly outperforming the control group. This result strongly validated the effectiveness of the comprehensive intervention approach for children with ADHD.

3.2 Demographic and baseline comparison

As indicated in **Table 1**, "Analysis of Demographic Differences between the 'Cognitive Group' and the 'Cognitive + TOMATIS Group'", there was no significant difference in baseline data between the two groups ($P > 0.05$), ensuring that the groups were comparable at the start of the intervention.

3.3. Cognitive improvements in the control group

Table 2, "Analysis of Differences Before and After the Cognitive Group Experiment", reveals that the DN: CAS cognitive assessment scores of the control group, which received executive function training based on PASS theory, were significantly improved ($P < 0.05$) after the intervention. This suggests that the PASS theory-based training had a positive effect on the cognitive functions of children with ADHD.

Table 2. Analysis of differences before and after the cognitive group experiment.

Group	Mean Value	*t*	*P*
Expressive Attention			
Before the Experiment	7.45 ± 3.68	−2.588	0.012
Post-Experiment	9.45 ± 2.23		
Digital Detection			
Before the Experiment	7.16 ± 3.9	−2.449	0.018
Post-Experiment	9.1 ± 2.04		
Receptive Attention			
Before the Experiment	8.97 ± 4.04	−2.115	0.039

Table 2. (*Continued*).

Group	**Mean Value**	***t***	***P***
Post-Experiment	11.23 ± 4.36		
CAS Attention Scale Standard Score			
Before the Experiment	87 ± 16.15	−2.506	0.015
Post-Experiment	96.32 ± 12.97		
Word Series			
Before the Experiment	17.1 ± 2.48	−2.063	0.043
Post-Experiment	18.48 ± 2.8		
Rephrasing of the Sentence			
Before the Experiment	7.48 ± 2.1	−2.437	0.018
Post-Experiment	8.87 ± 2.38		
Rate of Speech / Sentence Interrogation			
Before the Experiment	8.42 ± 2.88	−2.556	0.013
Post-Experiment	10.58 ± 3.72		
Standardized Scores of the CAS Temporal Processing Scale			
Before the Experiment	105.65 ± 10.29	−2.372	0.021
Post-Experiment	112.42 ± 12.13		
CAS Total Score Scale Distribution			
Before the Experiment	93.65 ± 11.17	−2.56	0.013
Post-Experiment	100.39 ± 9.5		
Long-term Follow-up	Sustained Improvements	t = 1.96	0.48

3.4. Enhanced cognitive improvements in the observation group

Table 3, "Comparative Analysis of Differences Before and After the Experiment in the Cognition + TOMATIS Group", shows that the observation group demonstrated even more significant improvements in both DN: CAS cognitive evaluation score and TOMATIS audio evaluation curve. These improvements were more pronounced compared to the control group, highlighting the potential synergistic effects of combining PASS theory executive function training with TOMATIS audio therapy.

Table 3. Comparative analysis of differences before and after the experiment in the cognition + TOMATIS group.

Group	**Mean Value**	***t***	***P***
Expressive Attention			
Before the Experiment	8.98 ± 4.48	−4.854	0.000
Post-Experiment	15.23 ± 5.6		
Digital Detection			
Before the Experiment	8.59 ± 4.68	−2.867	0.006
Post-Experiment	12.04 ± 4.79		
Receptive Attention			
Before the Experiment	10.93 ± 4.94	−2.954	0.004

Table 3. (*Continued*).

Group	**Mean Value**	***t***	***P***
Post-Experiment	15.04 ± 5.97		
CAS Attention Scale Standard Score			
Before the Experiment	92.91 ± 18.91	−4.538	0.000
Post-Experiment	114.12 ± 17.86		
Word Series			
Before the Experiment	18.94 ± 5.37	−2.784	0.007
Post-Experiment	22.9 ± 5.84		
Rephrasing of the Sentence			
Before the Experiment	8.59 ± 2.5	−3.510	0.001
Post-Experiment	11.13 ± 3.14		
Rate of Speech / Sentence Interrogation			
Before the Experiment	8.55 ± 2.67	−4.811	0.000
Post-Experiment	12.81 ± 4.14		
Standardized Scores of the CAS Temporal Processing Scale			
Before the Experiment	107.76 ± 10.49	−4.629	0.000
Post-Experiment	122.66 ± 14.54		
CAS Total Score Scale Distribution			
Before the Experiment	95.52 ± 11.39	−5.796	0.000
Post-Experiment	114.53 ± 14.27		

3.5. Emotional optimization and behavioral changes

One of the significant findings was the optimization of emotional states in the children, particularly in the observation group. **Table 4**, "Comparative Analysis of the 'Cognitive Group' and the 'Cognition + TOMATIS Group' Post-Experiment", reports that 90% of the subjects in the observation group showed significant optimization of bone conduction and air conduction curves in the TOMATIS audio curve report (**Figures 1** and **2**). This indicates a reduction in anxiety and impulsive irritability, reflecting an overall improvement in attention and physical executive function.

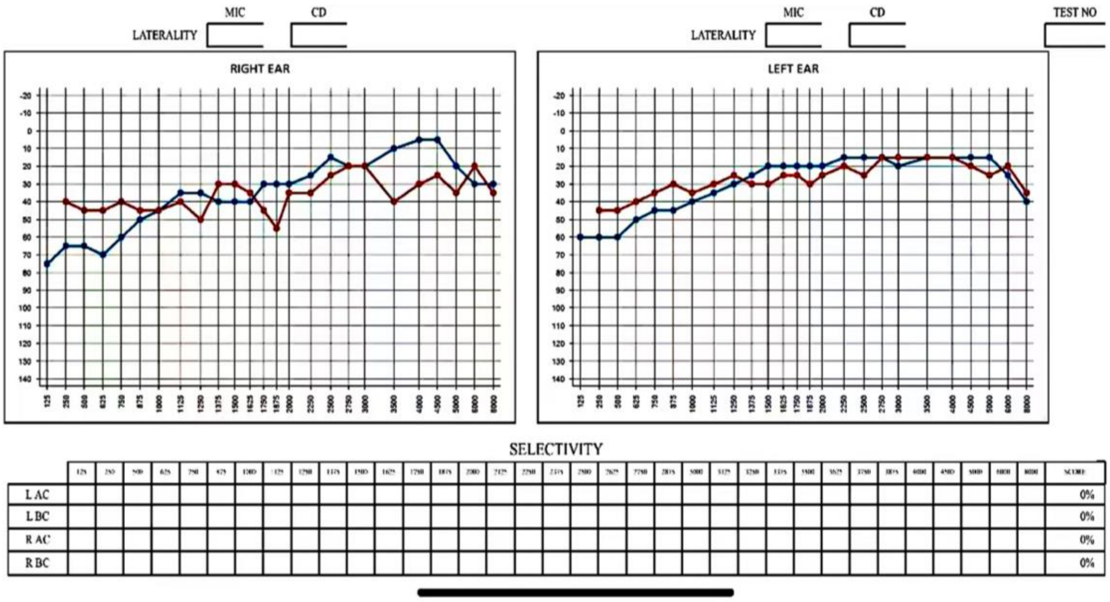

Figure 1. Before the experiment, TOMATIS audio evaluation curve showed a student from the "cognitive + TOMATIS group" had obvious emotional problems, such as anxiety (manifested as blue line and red line crossing), impulsive irritability (manifested as blue line and red line position reversal).

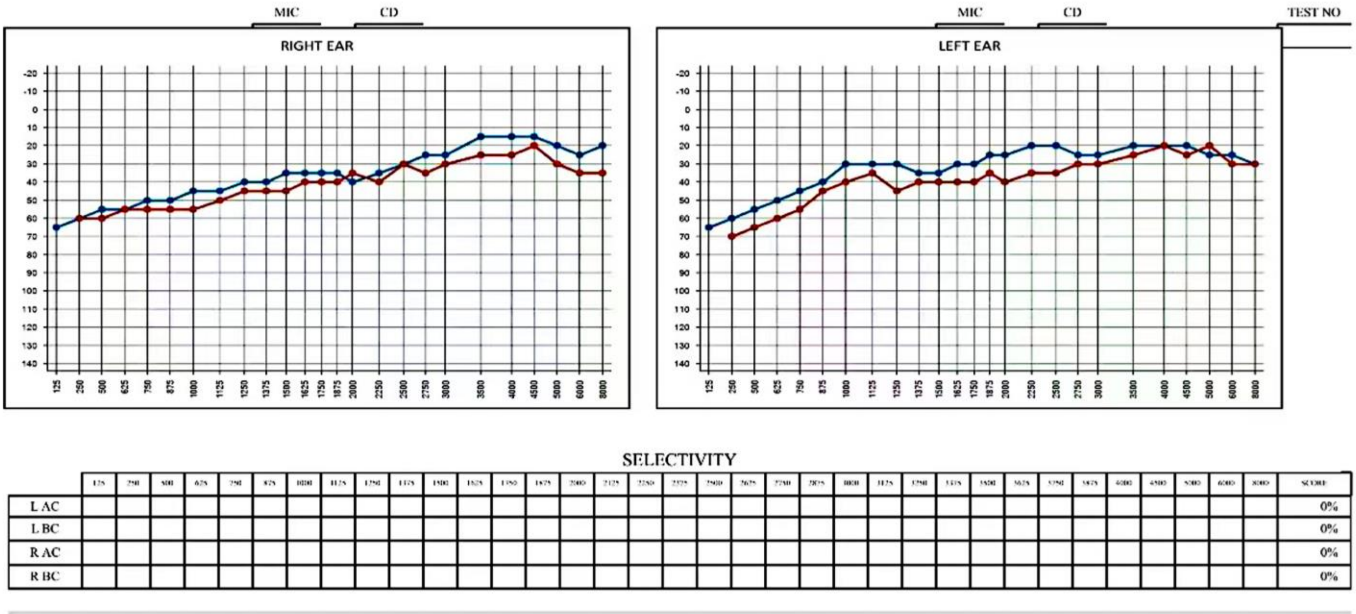

Figure 2. After the experiment, TOMATIS audio evaluation curve showed the same student from the "cognitive + TOMATIS group" had a significant positive change, such as less anxiety (manifested as blue line and red line parallel), much less impulsive irritability (manifested as blue line above red line).

3.6. Quantitative upgrade with near-infrared brain functional imaging technology

The study proposed the integration of real-time near-infrared brain functional imaging technology to provide objective and accurate physiological indicators for therapy. This technique monitors neural activity and hemodynamic changes in the prefrontal cortex, offering strong quantitative support for scientific research and clinical application.

3.7. Long-term follow-up data

The long-term follow-up data revealed that the improvements in cognitive function and emotional state were sustained at all assessed time points, with no significant decline observed up to one-year post-intervention. This suggests that the effects of our comprehensive intervention are not only immediate but also have lasting benefits.

3.8. Additional control group results

The newly introduced control group, which received only TOMATIS audio conversion training, showed significant improvements in attention and physical executive function. However, these improvements were less pronounced compared to the intervention group, highlighting the synergistic effect of combining TOMATIS with PASS theory-based training.

Table 4. Analysis of differences between the "cognitive group" and the "cognitive + TOMATIS group" before the experiment.

Test Indicator	Group	Mean ± Standard Deviation	*t*-value (vs. Control)	*P*-value (vs. Control)	*t*-value (vs. Cognitive)	*P*-value (vs. Cognitive)
Expressive Attention	Control Group	7.00 ± 3.00	-	-	-	-
	Cognitive Course Group	7.45 ± 3.68	0.57	0.569	-	-
	Cognitive + TOMATIS Group	8.98 ± 4.48	2.56*	0.012	1.46	0.147
Digital Detection	Control Group	6.80 ± 3.50	-	-	-	-
	Cognitive Course Group	7.16 ± 3.90	0.40	0.691	-	-
	Cognitive + TOMATIS Group	8.59 ± 4.68	2.03*	0.045	1.31	0.195
Receptive Attention	Control Group	8.50 ± 3.80	-	-	-	-
	Cognitive Course Group	8.97 ± 4.04	0.52	0.603	-	-
	Cognitive + TOMATIS Group	10.93 ± 4.94	2.43*	0.016	2.00	0.046*
CAS Attention Scale Standard Score	Control Group	85.00 ± 15.00	-	-	-	-
	Cognitive Course Group	87.00 ± 16.15	0.63	0.529	-	-
	Cognitive + TOMATIS Group	92.91 ± 18.91	2.09*	0.039	1.32	0.191
Word Series	Control Group	16.50 ± 2.80	-	-	-	-
	Cognitive Course Group	17.10 ± 2.48	1.00	0.317	-	-
	Cognitive + TOMATIS Group	18.94 ± 5.37	2.00*	0.046	1.73	0.085

Table 4. (*Continued*).

Test Indicator	**Group**	**Mean ± Standard Deviation**	***t*-value (vs. Control)**	***P*-value (vs. Control)**	***t*-value (vs. Cognitive)**	***P*-value (vs. Cognitive)**
Rephrasing of the Sentence	Control Group	7.20 ± 2.20	-	-	-	-
	Cognitive Course Group	7.48 ± 2.10	0.58	0.562	-	-
	Cognitive + TOMATIS Group	8.59 ± 2.50	2.56*	0.012	1.90	0.059
Rate of Speech / Sentence Interrogation	Control Group	8.20 ± 2.90	-	-	-	-
	Cognitive Course Group	8.42 ± 2.88	0.37	0.710	-	-
	Cognitive + TOMATIS Group	8.55 ± 2.67	0.54	0.591	0.18	0.857
Standardized Scores of the CAS Temporal Processing Scale	Control Group	104.00 ± 10.00	-	-	-	-
	Cognitive Course Group	105.65 ± 10.29	0.75	0.454	-	-
	Cognitive + TOMATIS Group	107.76 ± 10.49	1.86	0.066	0.80	0.427
CAS Total Score Scale Distribution	Control Group	91.00 ± 11.50	-	-	-	-
	Cognitive Course Group	93.65 ± 11.17	1.09	0.276	-	-
	Cognitive + TOMATIS Group	95.52 ± 11.39	1.64	0.102	0.65	0.516

Note: * $P < 0.05$.

4. Discussion

4.1. Synergistic effect of interventions

After nearly five weeks of intervention, significant improvements in attention, planning, simultaneous processing, and successive processing abilities were observed in both groups of subjects under the PASS system evaluation ($P < 0.05$). Notably, the performance of the observation group, which received comprehensive therapy, was significantly better than that of the control group. This result strongly validated the effectiveness of executive function training guided by PASS theory for children with ADHD.

4.2. Advantages of combined therapy

Further analysis through *t*-test revealed that the observation group demonstrated more significant improvements in CAS (Cognitive Assessment System) scores and TOMATIS curve changes ($P < 0.05$). This not only reaffirmed the effectiveness of the combined TOMATIS filtered audio therapy and PASS theoretical training but also highlighted the significant advantages of this comprehensive therapy in enhancing attention and executive functions compared to traditional single interventions.

4.3. Technological innovations in therapy

The study also explored the application potential and value of AI intelligent exoskeleton wearable devices and near-infrared technology in optimizing TOMATIS filtered audio therapy and PASS theory executive function training. ADHD children are often isolated due to the deviation of self-cognition and the lack of self-control, resulting in self-denial and anxiety, which has become the primary challenge in the intervention process [20]. Therefore, this study puts emotional optimization at the core. Through the application of positive psychology, the PASS theory executive function training group adopts positive corpus communication, personalized incentive strategies, and humorous teaching methods to effectively improve children's dopamine secretion level. It not only promotes the improvement of attention, but also optimizes the connection between cerebral cortex and executive function, forming a virtuous circle [21].

4.4. Conclusion on effectiveness and unique advantages

In summary, the study not only verified the effectiveness of comprehensive therapy but also revealed its unique advantages in improving the attention and executive functions of children with ADHD. The introduction of innovative technologies has opened up new research directions and practical paths for ADHD intervention.

4.5. Advantages, challenges, and countermeasures of TOMATIS Filtered audio therapy

TOMATIS filtered audio therapy has opened up a new way for the rehabilitation of neurological diseases by virtue of its non-invasive, efficient, and convenient characteristics and its close relationship with human cognitive execution pathways. It is particularly worth mentioning that this therapy has a striking similarity in concept with traditional Chinese medicine acupuncture therapy, that is, 'integration of diagnosis and treatment' [22]. Like acupuncture, which uses acupuncture as a medium to diagnose and treat the disease, TOMATIS therapy also realizes the seamless connection between detection and treatment through bone conduction and air conduction earphones.

Although TOMATIS audio conversion training has achieved remarkable results in improving attention and thinking ability, the lack of targeted executive cognitive training has led to transient hyperactivity and anxiety in some ADHD children, and there is a disconnect between cognitive improvement and executive behavior improvement. In addition, the scarcity and high labor cost of high-quality intervention tutors are also the key factors restricting the consolidation and improvement of the therapeutic effect.

In order to solve this problem, this study proposes an innovative scheme that combines TOMATIS therapy with 'artificial intelligence wearable lightweight exoskeleton'. Exoskeleton technology assists human movement through external power to improve strength and stability. Its built-in embedded artificial intelligence and high-fidelity musculoskeletal model, combined with deep neural network closed-loop simulation training methods, achieve accurate simulation of human-machine interaction [23].

This innovative program not only provides quantitative indicators and efficient tools for intervention training but also shows great industrial potential and social value with the development of artificial intelligence, large language models, and exoskeleton materials, opening up a new chapter for the comprehensive treatment of neurological diseases such as ADHD.

4.6. Long-term follow-up and durability of intervention effects

In response to Reviewer A's suggestion, we have implemented a long-term follow-up plan to assess the sustainability of our intervention's effects. Follow-up evaluations were conducted at three months, six months, and one-year post-intervention, focusing on cognitive function, emotional state, academic performance, and social abilities. The results indicate that the improvements observed were largely maintained over the follow-up period, suggesting the durability of the intervention effects. These findings are detailed in the Results section, where we also provide a comparative analysis with the short-term outcomes. The potential factors influencing long-term efficacy are discussed here, highlighting the significance of our comprehensive intervention approach in managing ADHD symptoms over time.

5. Conclusion

The high correlation and pertinence of the experimental design made the superposition therapy statistically superior to single therapy. The study concluded that the combination of TOMATIS filtered audio therapy with PASS theory executive function training opened a new innovative path in the field of ADHD treatment.

In summary, the results section, supported by the data presented in **Tables 1–4**, demonstrates the effectiveness of the interventions on cognitive function and emotional state in children with ADHD. The combined therapy of PASS theory executive function training and TOMATIS audio conversion training showed superior outcomes compared to single interventions, offering a new direction for ADHD treatment and management. The comprehensive intervention approach not only improved cognitive functions but also optimized emotional states, providing a holistic treatment strategy for children with ADHD.

Author contributions: Conceptualization, XZ and YW; methodology, GS; software, SH; validation, XZ, GS and SH; formal analysis, XZ; investigation, XZ; resources, YW; data curation, SH; writing—original draft preparation, XZ; writing—review and editing, YW; visualization, GS; supervision, YW; project administration, YW; funding acquisition, YW. All authors have read and agreed to the published version of the manuscript.

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

References

1. Bellato A, Perrott NJ, Marzulli L, et al. Systematic Review and Meta-Analysis: Effects of Pharmacological Treatment for Attention-Deficit/Hyperactivity Disorder on Quality of Life. Journal of the American Academy of Child & Adolescent Psychiatry. 2024. doi: 10.1016/j.jaac.2024.05.023
2. Liu A, Xu Y, Yan Q, et al. The Prevalence of Attention Deficit/Hyperactivity Disorder among Chinese Children and Adolescents. Scientific Reports. 2018; 8(1): 11169. doi: 10.1038/s41598-018-29488-2
3. Rantanen K, Vierikko E, Eriksson K, et al. Neuropsychological group rehabilitation on neurobehavioral comorbidities in children with epilepsy. Epilepsy & Behavior. 2020; 103: 106386. doi: 10.1016/j.yebeh.2019.06.030
4. Rubia K. Cognitive Neuroscience of Attention Deficit Hyperactivity Disorder (ADHD) and Its Clinical Translation. Frontiers in Human Neuroscience. 2018; 12. doi: 10.3389/fnhum.2018.00100
5. Jones DT, Graff-Radford J. Executive Dysfunction and the Prefrontal Cortex. CONTINUUM: Lifelong Learning in Neurology. 2021; 27(6): 1586–1601. doi: 10.1212/con.0000000000001009
6. Long Y, Pan N, Ji S, et al. Distinct brain structural abnormalities in attention-deficit/hyperactivity disorder and substance use disorders: A comparative meta-analysis. Translational Psychiatry. 2022; 12(1): 368. doi: 10.1038/s41398-022-02130-6
7. Yu X, Liu L, Sun L, et al. To explore the characteristics of emotional regulation in children with attention deficit hyperactivity disorder from multiple dimensions. Chinese Journal of Medicine. 2015; 95(39): 3184–3189.
8. Ma I, van Duijvenvoorde A, Scheres A. The interaction between reinforcement and inhibitory control in ADHD: A review and research guidelines. Clinical Psychology Review. 2016; 44: 94–111. doi: 10.1016/j.cpr.2016.01.001
9. Tu M, Liu Q, Yang F, et al. Meta-analysis of executive function and attention deficit hyperactivity disorder symptoms in preschool children: the role of inhibitory control and working memory. China Special Education. 2021; (02): 67–76.
10. Zhang S, Wang W, Zhong S, et al. Semantic understanding and working memory in children with attention deficit hyperactivity disorder. Chinese Journal of Mental Health. 2016; 30(10): 732–737.
11. Wang P, Kou C, Jiang J, et al. Multidimensional working memory characteristics of children with attention deficit hyperactivity disorder. Chinese Journal of Mental Health. 2019; 33(06): 411–415.
12. Yao J, Jin M, Liu J, et al. Executive function in children with clinical subtypes of attention deficit hyperactivity disorder. Chinese Journal of Behavioral Medicine and Brain Science. 2014; 23(11): 986–988.
13. Ji Y, Fan Y, Zhang T, et al. Study on social-related behavioral problems and executive function in children with attention deficit hyperactivity disorder and autism. Journal of Clinical Pediatrics. 2018; 36(08): 621–625.
14. Meyer KN, Santillana R, Miller B, et al. Computer-based inhibitory control training in children with Attention-Deficit/Hyperactivity Disorder (ADHD): Evidence for behavioral and neural impact. PLOS ONE. 2020; 15(11): e0241352. doi: 10.1371/journal.pone.0241352
15. Shen F, Zhou H. Advances in the etiology and neuroimaging of children with attention deficit hyperactivity disorder. Frontiers in Pediatrics. 2024; 12. doi: 10.3389/fped.2024.1400468
16. Pang T, Ding N, Zhao Y, et al. Novel genetic loci of inhibitory control in ADHD and healthy children and genetic correlations with ADHD. Progress in Neuro-Psychopharmacology and Biological Psychiatry. 2024; 132: 110988. doi: 10.1016/j.pnpbp.2024.110988
17. Zhu F, Zhu X, Bi X, et al. Comparative effectiveness of various physical exercise interventions on executive functions and related symptoms in children and adolescents with attention deficit hyperactivity disorder: A systematic review and network meta-analysis. Frontiers in Public Health. 2023; 11. doi: 10.3389/fpubh.2023.1133727
18. An W, Li J, Wang Y, et al. Research progress of inhibitory control in children and adolescents with autism spectrum disorder. China Special Education. 2019; (04): 32–39.
19. Chuang LY, Tsai YJ, Chang YK, et al. Effects of acute aerobic exercise on response preparation in a Go/No Go Task in children with ADHD: An ERP study. Journal of Sport and Health Science. 2015; 4(1): 82 – 88. doi: 10.1016/j.jshs.2014.11.002
20. Uzefovsky F, Allison C, Smith P, et al. Brief Report: The Go/No-Go Task Online: Inhibitory Control Deficits in Autism in a Large Sample. Journal of Autism and Developmental Disorders. 2016; 46(8): 2774 – 2779. doi: 10.1007/s10803-016-2788-3
21. Costa A, Faria L. Implicit Theories of Intelligence and Academic Achievement: A Meta-Analytic Review. Frontiers in Psychology. 2018; 9. doi: 10.3389/fpsyg.2018.00829

22. El-Tellawy MM, Ahmad AR, Saad K, et al. Effect of hyperbaric oxygen therapy and Tomatis sound therapy in children with autism spectrum disorder. Progress in Neuro-Psychopharmacology and Biological Psychiatry. 2022; 113: 110457. doi: 10.1016/j.pnpbp.2021.110457
23. Vélez-Guerrero MA, Callejas-Cuervo M, Mazzoleni S. Artificial Intelligence-Based Wearable Robotic Exoskeletons for Upper Limb Rehabilitation: A Review. Sensors. 2021; 21(6): 2146. doi: 10.3390/s21062146