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Comparative Effectiveness of Brain Hemisphere Training and Neurofeedback Therapy on Creativity in Students with Academic Underachievement

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A B S T R A C T

Purpose: The aim of the present study was to compare the effectiveness of brain hemisphere training and neurofeedback therapy on creativity among second-grade elementary students with academic underachievement in Isfahan.

Methods and Materials: This study was applied in terms of purpose and employed a quasi-experimental design with a pretest–posttest and follow-up with a control group. The statistical population consisted of second-grade elementary students in Isfahan. In the first stage, purposive sampling was used. Initially, six elementary schools were randomly selected from among the schools in Isfahan, and then all students with academic underachievement in these schools were identified as the sample. Subsequently, 45 students who scored above the cutoff point (0.25) on the creativity test were selected and randomly assigned to three groups of 15 participants each. For the first and second experimental groups, neurofeedback therapy and brain hemisphere training were administered, respectively, while the control group received no intervention. After the training sessions, all three groups were reassessed using the creativity test. The collected data were analyzed using analysis of variance method via SPSS-26 software.

Findings: The statistical results indicated that there was a significant difference between the mean scores of the image completion subscale in the brain hemisphere training group and the neurofeedback group. Additionally, there was a significant difference between the brain hemisphere training group and the control group, whereas no significant difference was found between the neurofeedback group and the control group.

Conclusion: Based on the findings, it can be concluded that brain hemisphere training improves students' creativity.

Keywords: *Creativity; Brain Hemisphere Training; Neurofeedback.*

1. Introduction

Creativity has long been recognized as a fundamental cognitive capacity that underlies problem-solving, innovation, and adaptive functioning across educational and developmental contexts. In contemporary educational psychology, creativity is not merely regarded as a desirable trait but as a core competency essential for academic success and lifelong learning. The increasing complexity of modern societies, coupled with rapid technological advancement, has intensified the need to cultivate creative thinking skills among students from early educational stages. Accordingly, researchers have emphasized the role of educational systems in fostering creativity through targeted interventions and evidence-based instructional approaches (Henriksen et al., 2017; Larraz, 2021; Souri et al., 2024). Creativity encompasses multiple cognitive processes, including divergent thinking, flexibility, originality, and elaboration, which are associated with both structural and functional characteristics of the brain (Manavi Far & Ashrafi Far, 2021; Razumnikova, 2000). These components are particularly crucial during childhood, a developmental period characterized by heightened neural plasticity and cognitive malleability.

Despite the acknowledged importance of creativity, a substantial number of students experience academic underachievement, often accompanied by deficits in executive functions, cognitive flexibility, and motivational engagement. Academic underachievement is a multifaceted phenomenon influenced by cognitive, emotional, and environmental factors, and it has been associated with reduced creative performance and limited problem-solving capacity (Mohseni Zadeh & Andishmand, 2020; Rafigh Irani et al., 2024). Students with learning difficulties frequently demonstrate impairments in attention, working memory, and inhibitory control, all of which are closely linked to creativity and higher-order thinking processes (Arshadi et al., 2022; Pirkhaefi & Akbarvand, 2016). Therefore, interventions that simultaneously target cognitive functioning and creativity may provide a more comprehensive approach to improving academic outcomes in this population.

In recent years, neuroscience-informed educational interventions have gained increasing attention as promising approaches for enhancing cognitive and creative abilities. Among these, neurofeedback has emerged as a non-invasive technique that enables individuals to regulate their brain activity through real-time feedback mechanisms. Neurofeedback is grounded in operant conditioning principles, allowing individuals to modify neural oscillations associated with attention, memory, and cognitive control (Tseng et al., 2021; Zendkarimi et al., 2022). Empirical evidence suggests that neurofeedback can lead to improvements in various cognitive domains, including working memory, executive functioning, and emotional regulation (Alidadi Taeimeh et al., 2019; Ghiasi Gishi et al., 2018). Moreover, neurofeedback has been shown to reduce symptoms of attention-deficit/hyperactivity disorder and enhance academic performance, highlighting its potential applicability in educational settings (Mousavi et al., 2023; Shojaei, 2024). In relation to creativity, neurofeedback has demonstrated positive effects by modulating brain networks associated with idea generation and cognitive flexibility, such as the default mode network (Svanishvili, 2025; Wang et al., 2025). Earlier studies have also reported improvements in creativity following neurofeedback training, suggesting its potential as an effective intervention for enhancing creative thinking (Foroughi et al., 2023a; Rahmati et al., 2014).

Parallel to neurofeedback, brain-based learning approaches—particularly those focusing on hemispheric integration—have been proposed as effective strategies for enhancing creativity and cognitive performance. The concept of left and right brain hemispheric specialization has historically influenced educational practices, although contemporary research emphasizes the importance of interhemispheric connectivity rather than strict lateralization (Allen & van der Zwan, 2019; Moore et al., 2009). Studies have demonstrated that creativity involves the coordinated activity of multiple brain regions across both hemispheres, highlighting the need for interventions that promote integrative neural processing (De Smedt et al., 2016; Miura et al., 2024). Whole-brain education programs aim to stimulate both hemispheres through multisensory, motor, and cognitive exercises, thereby enhancing neural integration and cognitive flexibility (Habib Nejad Allameh et al., 2023; Nabi Zadeh Nodehi et al., 2019). Such interventions often include cross-lateral movements, sensory stimulation, and creative tasks designed to activate diverse neural pathways and improve overall cognitive functioning.

Empirical studies have provided support for the effectiveness of hemispheric training in improving various educational outcomes. For instance, whole-brain education has been associated with improvements in reading comprehension, attention, and cognitive processing in students with learning difficulties (Nabi Zadeh Nodehi et al., 2019). Similarly, research on brain-based learning approaches indicates that engaging multiple sensory modalities and promoting active learning can enhance both cognitive and affective outcomes (Habib Nejad Allameh et al., 2023). Furthermore, studies examining the relationship between hemispheric activity and academic performance suggest that balanced activation of both hemispheres is associated with higher levels of creativity and problem-solving ability (Beyki et al., 2022; Yarmohammadi et al., 2021). These findings underscore the potential of hemispheric training as a viable intervention for enhancing creativity in students with academic challenges.

In addition to neurofeedback and hemispheric training, various cognitive and educational interventions have been explored to enhance creativity. Programs focusing on metacognitive skills, design thinking, and creative problem-solving have demonstrated positive effects on students' creative abilities (Henriksen et al., 2017; Salari Far et al., 2021). Training programs such as the "Learn to Think" initiative have also shown promising results in fostering creativity among young learners (Bai et al., 2020). Moreover, interventions that integrate cognitive rehabilitation techniques with creative activities have been found to improve both executive functions and creative thinking (Pournesaei et al., 2019). These findings highlight the multifaceted nature of creativity and the need for comprehensive interventions that address both cognitive and neural mechanisms.

From a neuropsychological perspective, creativity is closely linked to dynamic interactions among brain networks, including the default mode network, executive control network, and salience network. Research using neuroimaging techniques has revealed that creative thinking involves both spontaneous idea generation and controlled cognitive processes, reflecting the interplay between different neural systems (Miura et al., 2024; Razumnikova, 2000). Neurofeedback and hemispheric training interventions may influence these networks by enhancing neural efficiency and connectivity, thereby facilitating creative performance. Furthermore, the role of arts and aesthetic experiences in stimulating neural activity and promoting creativity has been highlighted in recent research, suggesting that engaging in creative tasks can have therapeutic and cognitive benefits (Barnett & Vasiu, 2024; Christensen et al., 2025).

Despite the growing body of research on neurofeedback and hemispheric training, there remains a need for comparative studies examining the relative effectiveness of these interventions in enhancing creativity, particularly among students with academic underachievement. While both approaches have demonstrated positive outcomes, their mechanisms of action differ, with neurofeedback focusing on direct modulation of brain activity and hemispheric training emphasizing experiential and integrative learning processes. Additionally, existing studies have often examined these interventions in isolation, limiting our understanding of their comparative efficacy and potential interaction effects. Addressing this gap is essential for informing evidence-based educational practices and optimizing intervention strategies for students with diverse learning needs (Foroughi et al., 2023b; Mecias & Palaoag, 2022).

Given the importance of creativity in academic and personal development, and considering the potential of neuroscience-based interventions to enhance cognitive functioning, the present study seeks to contribute to the existing literature by systematically comparing the effectiveness of brain hemisphere training and neurofeedback therapy in improving creativity among elementary school students with academic underachievement. Therefore, the aim of this study was to compare the effectiveness of brain hemisphere training and neurofeedback therapy on creativity in second-grade elementary students with academic underachievement in Isfahan.

2. Methods and Materials

2.1. Study Design and Participants

The present study was applied in terms of its objective and, in terms of data collection, employed a quasi-experimental design with a pretest–posttest and follow-up with a control group. The statistical population included all elementary school students in Isfahan during the 2022–2023 academic year who exhibited academic underachievement. The sampling method in the first stage was purposive. The researcher initially selected six elementary schools from among those in Isfahan and then, by visiting these schools, identified all students with academic underachievement as the sample. Subsequently, 45 students who scored above the cutoff point (0.25) on the creativity test were selected as the sample and randomly assigned to three groups: first experimental group (15 participants), second experimental group (15 participants), and control group (15 participants). Neurofeedback therapy and brain hemisphere training were administered to the first and second experimental groups,

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respectively, while the control group received no intervention. After the completion of the training sessions, all three groups were reassessed using the creativity test.

2.2. Measures

Torrance Creativity Test, Form B (Children): The Torrance Test, which is the result of nine years of work by Ellis Paul Torrance and his colleagues on creative behavior, has been widely used in numerous studies as a criterion for measuring creativity. Torrance and Goff (1989), as cited in Sharifi and Davari (2009), stated that among the existing tests for measuring creativity, the Torrance Test has had the highest level of application and has been used more than any other test in research and educational measurement. To date, it has been utilized in more than two thousand studies, the results of which have been published in scientific literature. The Torrance Creativity Test, Form B (figural), consists of three activities, each with a time limit of 10 minutes. These activities include: (1) Picture Construction Activity, in which responses are evaluated based on originality and elaboration; (2) Picture Completion Activity, which includes 10 incomplete figures that the child must complete into meaningful images within 10 minutes, with responses evaluated based on flexibility, originality, elaboration, and fluency for each completed image; and (3) Circles Activity, which includes 36 circles that the child must transform into meaningful drawings, with responses also evaluated based on the four components of creativity. Torrance (2011) reported correlations between trained and untrained individuals ranging from 0.86 to 0.99, and reliability coefficients of 0.78 for fluency, 0.74 for originality, 0.81 for flexibility, and 0.81 for elaboration (Pirkhaefi et al., 2009; Sharifi & Davari, 2009). Additionally, Form B of the Torrance Creativity Test has been used in numerous studies in Iran, including Ghasemi et al. (2017), indicating its good validity. The reliability of the creativity test used in this study was calculated by the researcher using Cronbach's alpha, yielding a coefficient of 0.78.

2.3. Interventions

Structure of Sessions: Neurofeedback Therapy: One of the therapeutic interventions used in this study was neurofeedback therapy combined with computerized cognitive exercises. Neurofeedback therapy has acceptable validity, and the effectiveness of this training program has been examined and confirmed by researchers (Alidadi Taeimeh et al., 2019). Neurofeedback is based on the theory of operant conditioning, whereby the brain gradually learns through practice and repetition how to achieve desired goals, leading to the self-regulation of brain waves (Zendkarimi et al., 2022). In this study, a two-channel ProComp2 device was used for neurofeedback intervention. The initial assessment was conducted based on a four-task baseline using the international 10–20 system, focusing on the Cz point for each child. Each treatment session was conducted in a monopolar manner for 30 minutes, including unilateral and bilateral exercises, as well as DVD-based tasks at the Fcz point, following the protocol of Ilie-Moghaddam, Jajarmi, and Ghashuni (2020), across 31 sessions (three sessions per week). In this method, three protocols (A, B, and C) were used. Protocol A aimed to improve learning skills at the Cz point by reducing Theta waves (4–8 Hz), increasing SMR (12–15 Hz), and reducing High Beta (21–35 Hz). Protocol B aimed to enhance creativity at the Cz point by reducing Beta waves and increasing Alpha waves (8–12 Hz). Protocol C targeted problem-solving skills at the Pz point by increasing Beta waves and decreasing Theta waves. These protocols aim, through training and conditioning, to bring the individual's brainwave activity closer to an optimal balance. For example, in Protocol A, by placing the active electrode at Cz, the reference electrode on the right ear, and the ground electrode on the left ear, Theta and High Beta waves are reduced while SMR is increased. This process is gradually implemented over approximately 10 sessions, with specific therapeutic goals pursued in each session. During this treatment, brainwave levels are recorded in each session, and efforts are made in subsequent sessions to adjust these levels according to predefined therapeutic directions indicated in the software. For instance, if the Theta wave amplitude is 100 microvolts in the first session, efforts are made to reduce it to approximately 70 microvolts after 15 to 20 sessions. This process occurs through reinforcement (i.e., game progression), representing operant conditioning. Specifically, if the individual successfully adjusts brainwave activity to the desired level during the session, the game progresses; otherwise, no progression occurs. The only task required of the participant during this period is to focus on advancing the game. Subsequently, Protocols B and C were implemented in a similar manner, with 10 sessions allocated to each, resulting in a total of 30 treatment sessions. In addition to neurofeedback sessions, specific exercises were conducted after each session. Throughout the treatment process, progress was monitored through the participant, parents, and school. Furthermore, for more accurate follow-up, diagnostic recordings were repeated during sessions 15 and 31 to ensure full improvement.

The brain hemisphere training intervention was implemented based on the therapeutic protocol developed by Nabizadeh Nodehi, Borjali, Esteki, and Farrokhi (2019), incorporating a structured sequence of sensorimotor, cognitive, and perceptual exercises designed to stimulate and integrate the functional activity of both cerebral hemispheres. The intervention was delivered across sixteen sessions, each building progressively on previously acquired skills while maintaining a consistent emphasis on bilateral coordination, cross-lateral movements, sensory stimulation, and cognitive engagement. The first session included initial orientation and basic motor activities such as forward, backward, and lateral walking, jumping, crawling, cross-pattern walking and running, forward and backward counting, cross-jumping, and thumb-to-finger opposition exercises. The second session involved a review of prior activities, followed by alternate nostril breathing to stimulate hemispheric activation and tracing letters on different body parts. The third session included bilateral drawing of circles in space, reading words in varying sizes and formats, constructing words using modeling clay and tactile exploration with both hands, and repetition of previous exercises. The fourth session incorporated deep breathing, listening to music, blindfolded walking with object localization, and fine motor exercises such as rotating a pencil with the fingers. In the fifth session, participants engaged in writing letters and words using legumes, creating creative drawings, listening to natural environmental sounds, and performing cross-lateral aerobic movements accompanied by music. The sixth session emphasized sensory imagery and spatial awareness through listening to hemisphere-appropriate music with eyes closed, visualizing scenes, navigating pathways blindfolded, and identifying objects through tactile exploration. The seventh session included problem-solving and pattern recognition tasks such as Sudoku, hidden figure identification, puzzles, rhythmic movements, and rope jumping in forward, backward, and cross patterns. The eighth session focused on contrasting cognitive tasks, hand-strengthening exercises such as squeezing a ball, free drawing while listening to hemisphere-specific music, watercolor writing, and balance training. The ninth session involved visual tracking exercises with increased emphasis on the visual field associated with the weaker hemisphere, along with identifying distinct shapes. The tenth session expanded visual tracking through following a flashlight stimulus, multisensory story-based perception, and reading colored words in varying sizes. The eleventh session incorporated olfactory discrimination tasks with greater stimulation of the weaker hemisphere, muscle stretching, group singing, tactile recognition of letters and words in a bag, hopping exercises, and rolling a ball across the body. The twelfth session included brain gym exercises with music, simultaneous drawing of symmetrical shapes, tactile engagement with clay-formed words using both hands, and writing letters and words in different sizes and colors. The thirteenth session focused on reflex integration, cycling leg movements, sentence construction based on images, and walking with a book balanced on the head. The fourteenth session involved jumping in and out of a hula hoop, performing bridge exercises, and matching sentences to emotional expressions and sensory states. The fifteenth session included melody recognition, vestibular system strengthening exercises, prone positioning with limb elevation, and review activities. Finally, the sixteenth session emphasized consolidation through creative problem-solving, estimation tasks, rhythmic tapping, storytelling using disordered images, running in place, and prone extension exercises, thereby integrating cognitive, sensory, and motor functions to enhance hemispheric coordination and ultimately promote creativity.

2.4. Data Analysis

The collected data were first analyzed using descriptive statistics and subsequently using inferential statistics through repeated measures analysis of variance (ANOVA) with SPSS-26 software.

3. Findings and Results

Findings: The descriptive results indicated that the mean creativity score at the pretest stage was 18.53 for the brain hemisphere training group, 16.80 for the neurofeedback group, and 18.52 for the control group. At the posttest stage, the mean creativity score was 22.33 for the brain hemisphere training group, 19.26 for the neurofeedback group, and 19.06 for the control group. Finally, at the follow-up stage, the mean creativity score was 21.46 for the brain hemisphere training group, 17.80 for the neurofeedback group, and 18.26 for the control group. A complete description of the data is presented in Table 1.

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Table 1

Mean and Standard Deviation of Creativity Across Three Measurement Stages by Research Group

Stage	Variable	Subscale	Brain Hemisphere Training (Mean)	SD	Neurofeedback (Mean)	SD	Control (Mean)	SD
Pretest	Creativity	Picture Completion	18.53	2.47	16.80	2.80	18.53	3.60
Posttest		Picture Completion	22.33	2.55	19.26	2.86	19.06	3.45
Follow-up		Picture Completion	21.46	2.47	17.80	2.83	18.26	3.47

As shown in Table 1, the descriptive findings indicate a noticeable increase in creativity scores at the posttest and follow-up stages compared to the pretest in the brain hemisphere training group.

At the inferential level, repeated measures analysis of variance (ANOVA) and the Least Significant Difference (LSD) post hoc test were used to analyze the data and compare the effectiveness of brain hemisphere training and neurofeedback. First, the assumptions required for repeated measures ANOVA were examined. The result of Box's M test for the creativity variable was greater than 0.05, indicating that the null hypothesis was accepted and the covariance matrices across groups were equal (F = 1.720, p = 0.396). To assess the sphericity of the variance–covariance matrix, Mauchly's test of sphericity was applied. The results showed that the significance level for the creativity variable was greater than 0.05, confirming the assumption of sphericity for the picture completion subscale (p = 0.051). Levene's test was used to examine the equality of error variances across the three measurement stages. The results indicated that the assumption of homogeneity of variances was met for the picture completion subscale at all three stages (pretest: p = 0.379; posttest: p = 0.609; follow-up: p = 0.376).

Table 2

Between-Group Effects Test for Creativity

Variable	Source	Sum of Squares	df	Mean Square	F	Sig.	Effect Size
Creativity	Intercept	49344.896	1	49344.896	1906.727	<0.001	0.999
	Group	195.837	2	97.919	3.784	0.031	0.658
	Error	1086.933	42	25.879			

As shown in Table 2, the creativity variable yielded a significance level of less than 0.05, indicating a statistically significant difference in mean creativity scores among the study groups.

To determine which group differences accounted for this significant effect, pairwise comparisons of group means across the three measurement stages (pretest, posttest, and follow-up) were conducted using the LSD post hoc test, given that the number of participants was equal across groups (n = 15 per group). The results of this test are presented in Table 3.

Table 3

LSD Post Hoc Test for Pairwise Comparisons of Creativity Based on Time × Group Interaction

Variable	Time	Group (I)	Group (J)	Mean Difference (J–I)	Std. Error	Sig.
	Pretest	Brain Hemisphere Training	Neurofeedback	1.733	1.095	0.121
			Control	-0.007	1.095	0.999
		Neurofeedback	Brain Hemisphere Training	-1.733	1.095	0.121
			Control	-1.733	1.095	0.121
		Control	Brain Hemisphere Training	0.007	1.095	0.999
			Neurofeedback	1.733	1.095	0.121
	Posttest	Brain Hemisphere Training	Neurofeedback	3.067	1.087	0.007
			Control	3.267	1.087	0.005

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	Neurofeedback	Brain Hemisphere Training	-3.067	1.087	0.007
		Control	0.200	1.087	0.855
	Control	Brain Hemisphere Training	-3.267	1.087	0.005
		Neurofeedback	-0.200	1.087	0.855
Follow-up	Brain Hemisphere Training	Neurofeedback	3.667	1.079	0.002
		Control	3.200	1.079	0.005
	Neurofeedback	Brain Hemisphere Training	-3.667	1.079	0.002
		Control	-0.467	1.079	0.668
	Control	Brain Hemisphere Training	-3.200	1.079	0.005
		Neurofeedback	0.467	1.079	0.668

According to Table 3, at the posttest stage, there was a statistically significant difference in mean creativity scores between the brain hemisphere training group and the neurofeedback group, as well as between the brain hemisphere training group and the control group; however, no significant difference was observed between the neurofeedback group and the control group. Therefore, the brain hemisphere training method alone demonstrated effectiveness at the posttest stage. At the follow-up stage, a similar pattern was observed, with significant differences between the brain hemisphere training group and both the neurofeedback and control groups, while no significant difference was found between the neurofeedback and control groups, indicating that the effect of brain hemisphere training remained effective at follow-up.

4. Discussion and Conclusion

The present study aimed to compare the effectiveness of brain hemisphere training and neurofeedback therapy on creativity among second-grade elementary students with academic underachievement. The findings demonstrated that creativity scores increased significantly in the brain hemisphere training group at both posttest and follow-up stages, whereas the neurofeedback group did not show a statistically significant difference compared to the control group. Furthermore, the post hoc analyses revealed that the brain hemisphere training group outperformed both the neurofeedback and control groups at posttest and follow-up, while no meaningful difference was observed between the neurofeedback and control groups. These results indicate that, within the context of this study, brain hemisphere training was more effective than neurofeedback in enhancing creativity, and its effects were relatively stable over time.

The superiority of brain hemisphere training in improving creativity can be interpreted through the lens of integrative cognitive processing and multisensory stimulation. Brain hemisphere training protocols are designed to engage both hemispheres simultaneously through coordinated motor, sensory, and cognitive activities, thereby enhancing interhemispheric communication and neural integration. Creativity has been conceptualized as a product of distributed neural networks rather than localized brain regions, requiring dynamic interaction between hemispheres and across cortical systems (De Smedt et al., 2016; Moore et al., 2009). Accordingly, interventions that promote bilateral engagement and cross-modal integration are likely to facilitate creative thinking by strengthening neural connectivity and enhancing cognitive flexibility. The findings of this study align with prior research indicating that whole-brain education approaches can significantly improve cognitive and academic outcomes, particularly in students with learning difficulties (Habib Nejad Allameh et al., 2023; Nabi Zadeh Nodehi et al., 2019). These approaches emphasize experiential learning, movement-based activities, and sensory engagement, all of which contribute to the activation of multiple neural pathways involved in creative cognition.

In contrast, the lack of significant improvement in the neurofeedback group relative to the control group may be attributed to several factors related to the nature of neurofeedback interventions and their application in educational settings. Although neurofeedback has been widely recognized as an effective method for enhancing cognitive functions such as attention, working memory, and emotional regulation, its impact on creativity appears to be more complex and context-dependent. Neurofeedback primarily targets the regulation of specific brainwave patterns, which may not directly translate into improvements in higher-order cognitive processes such as divergent thinking and originality unless accompanied by complementary cognitive or behavioral training (Tseng et al., 2021; Zendkarimi et al., 2022). While previous studies have reported positive effects of neurofeedback on creativity (Foroughi et al., 2023a; Rahmati et al., 2014), these outcomes may depend on factors such as training duration, protocol specificity, and individual differences among

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participants. In the present study, it is possible that the neurofeedback intervention, although structured and systematic, was not sufficiently tailored to directly target creative processes or that the duration of training was insufficient to produce measurable changes in creativity.

Another plausible explanation for the differential effectiveness of the two interventions relates to the developmental characteristics of the participants. Elementary school students are in a critical period of cognitive and neural development, during which experiential and interactive learning approaches may be particularly effective. Brain hemisphere training, with its emphasis on movement, sensory input, and active engagement, may be more developmentally appropriate for young learners compared to neurofeedback, which requires sustained attention and abstract understanding of feedback mechanisms. Research has shown that children with academic underachievement often exhibit deficits in executive functions and attentional control, which may limit their ability to benefit fully from neurofeedback interventions (Arshadi et al., 2022; Mohseni Zadeh & Andishmand, 2020). In contrast, interventions that incorporate physical activity and multisensory experiences can bypass some of these limitations by engaging alternative neural pathways and promoting implicit learning processes.

The findings of this study are also consistent with theoretical perspectives that emphasize the role of embodied cognition in creative thinking. According to this perspective, cognitive processes are deeply rooted in bodily interactions with the environment, and movement-based activities can enhance cognitive functioning by providing rich sensory and motor experiences. Brain hemisphere training incorporates various forms of cross-lateral movements, rhythmic activities, and sensory stimulation, which may facilitate the integration of perceptual and cognitive processes underlying creativity. This interpretation is supported by research demonstrating that physical and sensorimotor activities can enhance neural plasticity and cognitive performance (Miura et al., 2024; Movahedi & Pour Mohammadi, 2017). Furthermore, studies on design thinking and creative problem-solving highlight the importance of experiential learning and active engagement in fostering creativity (Henriksen et al., 2017; Larraz, 2021).

The persistence of the effects of brain hemisphere training at the follow-up stage suggests that this intervention may lead to relatively durable changes in cognitive functioning. This durability may be attributed to the repetitive and practice-based nature of the training, which allows for the consolidation of neural changes over time. In contrast, the effects of neurofeedback may require ongoing reinforcement to be maintained, particularly if the training does not involve explicit transfer to real-world tasks. The concept of neural plasticity provides a useful framework for understanding these findings, as repeated activation of neural circuits through structured training can lead to long-term changes in brain function and behavior (Miura et al., 2024; Razumnikova, 2000).

It is also important to consider the broader educational implications of these findings. Creativity is increasingly recognized as a key competency in 21st-century education, and there is a growing emphasis on developing instructional methods that foster creative thinking. The results of this study suggest that brain hemisphere training may be a valuable addition to educational programs aimed at enhancing creativity, particularly for students with academic difficulties. This aligns with research highlighting the effectiveness of educational strategies that integrate cognitive, emotional, and sensory dimensions of learning (Hasani et al., 2021; Souri et al., 2024). Moreover, the integration of arts and creative activities into educational curricula has been shown to have positive effects on both cognitive and emotional development, further supporting the use of holistic and interdisciplinary approaches (Barnett & Vasiu, 2024; Christensen et al., 2025).

Another noteworthy aspect of the findings is the role of individual differences in responsiveness to interventions. Not all students may benefit equally from a given intervention, and factors such as baseline cognitive abilities, motivation, and learning styles may influence outcomes. Future research should consider these variables in order to develop more personalized and adaptive intervention strategies. Additionally, the potential interaction between different types of interventions, such as combining neurofeedback with cognitive or behavioral training, warrants further investigation. Some studies have suggested that multimodal interventions may produce synergistic effects by targeting multiple aspects of cognitive functioning simultaneously (Alidadi Taeimeh et al., 2019; Ghiasi Gishi et al., 2018).

Overall, the findings of this study contribute to the growing body of literature on neuroscience-based educational interventions and provide evidence for the relative effectiveness of brain hemisphere training in enhancing creativity among students with academic underachievement. By highlighting the importance of integrative and experiential approaches to learning, this

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study underscores the need for educational practices that are aligned with the principles of cognitive neuroscience and developmental psychology. At the same time, the limited effectiveness of neurofeedback in this context suggests that further research is needed to optimize its application for enhancing creativity and to better understand the conditions under which it may be most beneficial.

One limitation of the present study is the relatively small sample size, which may limit the generalizability of the findings. Additionally, the study was conducted within a specific cultural and educational context, which may influence the applicability of the results to other populations. Another limitation is the reliance on a single measure of creativity, which may not fully capture the multidimensional nature of this construct. Furthermore, the duration of the interventions may not have been sufficient to observe the full effects of neurofeedback on creativity. The lack of long-term follow-up beyond the immediate post-intervention period also limits the ability to assess the sustainability of the observed effects over time.

Future research should aim to replicate these findings with larger and more diverse samples in order to enhance the generalizability of the results. It would also be beneficial to employ multiple measures of creativity, including both standardized tests and real-world assessments, to provide a more comprehensive evaluation of intervention outcomes. Longitudinal studies are needed to examine the long-term effects of brain hemisphere training and neurofeedback on creativity and related cognitive functions. Additionally, future studies should explore the potential benefits of combining these interventions with other educational and therapeutic approaches to maximize their effectiveness.

From a practical perspective, educators and practitioners should consider incorporating brain hemisphere training techniques into classroom activities to enhance students' creativity and cognitive engagement. Such interventions can be implemented through structured programs that include movement-based exercises, sensory activities, and creative tasks. Schools may also benefit from integrating neuroscience-informed approaches into their curricula to support the development of higher-order thinking skills. Moreover, training programs for teachers could include components related to brain-based learning strategies to facilitate the effective implementation of these interventions in educational settings.

Authors' Contributions

All authors significantly contributed to this study.

Declaration

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

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

In this study, to observe ethical considerations, participants were informed about the goals and importance of the research before the start of the study and participated in the research with informed consent.

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