Complex motoric learning through Balinese Legong dance increases resting BDNF in preadolescent girls

El aprendizaje motor complejo a través de la danza Balinesa Legong aumenta el BDNF en reposo en una niña preadolescentes

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Abstract

Introduction and Objective. Brain-derived neurotrophic factor (BDNF) plays a vital role in neuroplasticity, neuronal differentiation, and cognitive function. While aerobic and resistance training are explored to elevate resting serum BDNF, findings remain inconsistent. As BDNF is closely tied to learning processes, motor learning may offer a more targeted approach to stimulating neuroplasticity than repetitive physical activity.
Methodology. The study investigated the effect of motor learning on resting BDNF and physical fitness component improvement in preadolescent girls. Participants with no prior Legong dance experience were the Learning Group (LG; n = 19); those with experience were the Repetitive Group (RG; n = 19). Both groups underwent six weeks of supervised Balinese Legong dance training. LG learned new choreography, while RG repeated familiar routines. Resting serum BDNF, aerobic capacity, and muscle endurance were measured before and after intervention.
Results. Baseline showed the LG had significantly lower BDNF than the RG (p=0.040). Resting BDNF significantly increased in LG (Median 1.995 to 2.546 ug/ml; p=0.001) but not in RG (p=0.469). After intervention, LG successfully closed the initial BDNF gap (p=0.563). LG's aerobic capacity was superior to RG (p=0.014), whereas muscle endurance was lower than RG (p=0.003). No correlation was found between BDNF changes and fitness measures.
Conclusions. These findings suggest motor learning stimulates BDNF more effectively than repetitive movement and highlights the importance of cognitive engagement in physical training, offering potential for education, neurorehabilitation, and skill-based athletic development.

Keywords

Traditional dance; BDNF (brain-derived neurotrophic factor); motor learning; neuroplasticity; adolescent girls.

Resumen

Introducción y objetivo. El BDNF es crucial para la neuroplasticidad, diferenciación neuronal y cognición. Aunque el ejercicio aeróbico y de resistencia busca elevar sus niveles, los resultados son inconsistentes. El aprendizaje motor estimula más la neuroplasticidad que la actividad repetitiva.
Metodología. Este estudio analizó el efecto del aprendizaje motor sobre los niveles de BDNF en reposo en niñas preadolescentes y su relación con la mejora de la condición física. Las niñas sin experiencia en danza Legong fueron asignadas al Grupo de Aprendizaje (GA; n = 19); las con experiencia al Grupo Repetitivo (GR; n = 19). Ambos grupos realizaron seis semanas de entrenamiento. El GA aprendió coreografías nuevas; el GR repitió rutinas. Se evaluaron BDNF en reposo, capacidad aeróbica y resistencia muscular antes y después.
Resultados. El valor inicial mostró que el LG tenía un BDNF significativamente menor que el RG (p=0.040). El BDNF en reposo aumentó significativamente en el LG (Mediana 1.995 a 2.546 ug/ml; p=0.001), pero no en el RG (p=0.469). Después de la intervención, el LG cerró con éxito la brecha inicial de BDNF (p=0.563). La capacidad aeróbica del LG fue superior a la del RG (p=0.014), mientras que el RG mantuvo una resistencia muscular superior (p=0.003). No se encontró correlación entre los cambios en el BDNF y las medidas de aptitud física.
Conclusiones. Estos hallazgos sugieren que el aprendizaje motor estimula el BDNF más eficazmente que el movimiento repetitivo, resaltando la importancia del compromiso cognitivo en el entrenamiento físico, con posible aplicación en educación, neurorrehabilitación y desarrollo deportivo basado en habilidades.

Palabras clave

Aprendizaje motor; BDNF (factor neurotrófico derivado del cerebro); danza tradicional; neuroplasticidad; adolescentes.

Introduction

The brain-derived neurotrophic factor (BDNF) plays a crucial role in both prenatal and postnatal brain development (Karege et al., 2002). It is essential for neuronal differentiation, synaptic plasticity, and survival (Klein et al., 2011). Studies have demonstrated a positive correlation between serum and cortical BDNF levels during maturation and aging (Karege et al., 2002; Klein et al., 2011). Experimental evidence indicates that peripheral BDNF concentrations temporarily increase with acute and chronic aerobic exercise, while strength training does not significantly affect peripheral BDNF levels (Huang et al., 2022; Dinoff et al., 2016). Additionally, the difference between serum and resting plasma concentrations of BDNF is negligible (Dinoff et al., 2016). The impact of exercise on peripheral BDNF levels in humans remains inconsistent; some studies report increases in BDNF following physical activity, whereas others find no significant change or even decreases in BDNF concentrations (Erickson et al., 2011; Schmolesky et al., 2013; Forti et al., 2014; Griffin et al., 2011).

Systematic reviews on the effect of exercise on BDNF have highlighted the impact of variations in study design (Huang et al., 2022; Knaepen et al., 2010; Zoladz & Pilc, 2010; Coelho et al., 2013). Knaepen et al. (2010) found a transient increase in peripheral BDNF after acute aerobic exercise, noting that chronic exercise training was unlikely to elevate resting BDNF levels. Similarly, Zoladz & Pilc (2010) reported transient increases in BDNF following acute exercise but observed mixed results regarding the impact of chronic exercise on resting BDNF levels. Huang et al. (2022) concluded that both acute and chronic aerobic exercise elevate peripheral BDNF, while resistance training has no significant effect on BDNF levels. In addition, these reviews show no effect of resistance training on peripheral BDNF concentrations (Huang et al., 2022; Knaepen et al., 2010; Zoladz & Pilc, 2010). Meta-analysis found consistent increases in peripheral BDNF following acute exercise, though the effects of chronic exercise on resting BDNF concentrations were less clear (Szuhany et al., 2015). While some studies reported significantly higher resting BDNF levels after exercise training, 69% of the research indicated no significant change (Dinoff et al., 2016). The inconsistency in findings regarding peripheral BDNF and physical activity in humans may be due to differences in the type, intensity, and duration of exercise interventions (Pareja-Galeano et al., 2014).

The inconsistent relationship between exercise and resting BDNF prompted us to conduct a more detailed analysis based on the type of exercise. Most systematic reviews on this topic use similar inclusion criteria for exercise types, focusing on aerobic and resistance training (Huang et al., 2022; Dinoff et al., 2016; Knaepen et al., 2010; Zoladz & Pilc, 2010) which typically involve overloading the cardiorespiratory and muscular systems. However, given that BDNF is a biomarker of neurological adaptation, it is important to include exercises that overload or train the neurological system. To study the effect of exercise on BDNF levels, it is crucial to determine whether the exercise involves learning a new complex movement which overload or train the neurological system. Learning new complex movements requires the formation of new neural circuits to control and coordinate these actions. Regular complex movements training stabilizes these circuits, leading to permanent functional and structural changes, a process known as neuroplasticity. Research has shown that complex motor learning can improve resting BDNF levels, memory, and cognitive function. However, there is a lack of research investigating the extent of these improvements in young and healthy individuals, especially after they have mastered complex motor movements. This study aims to investigate whether learning new, complex dance movements increases resting serum BDNF and how it compares to repeating previously learned routines and its correlation to aerobic and muscle endurance.

Method

Participants

This study adopted a two-group experimental design to explore the effects of motor learning on resting serum BDNF levels in young girls. Participants were recruited through open invitations distributed to local schools and dance academies. A total of 38 healthy preadolescent girls, aged between 12 and 14 years, were enrolled in the study. They were divided into two groups based on their prior experience with Legong dance. The first group, referred to as the Learning Group (LG), consisted of 19 participants

who had no previous exposure to Legong dance. These girls underwent a structured training program designed to teach them the dance movements from the ground up, emphasizing motor learning. The second group, the Repetitive Group (RG), also included 19 participants, all of whom had at least two years of experience performing Legong dance. These participants continued to practice the same choreography as part of their established routine, focusing on movement repetition rather than new skill acquisition. To ensure the health and suitability of participants, screening was conducted to exclude individuals with neurological disorders, metabolic conditions, or any prior involvement in structured motor learning programs. Informed consent was obtained in writing from both the participants and their legal guardians before the commencement of the study.

Procedure

The LG participated in supervised Legong dance training sessions led by a certified dance instructor. Training was conducted three times per week over a six-week period, with each session lasting 30 minutes. Each session followed a structured format that began with a 5-minute warm-up consisting of basic flexibility and balance exercises to prepare the body for movement. This was followed by a 20-minute learning phase, during which participants were progressively introduced to new Legong dance movements. The focus during this phase was on enhancing motor coordination, rhythm, and cognitive engagement. Each session introduced 2 to 3 new movements, with approximately 10 to 15 repetitions per movement. Exercises were performed at a moderate intensity, corresponding to a perceived exertion level of 12 to 14 on the Borg scale. To facilitate recovery, rest intervals of 30 to 60 seconds were provided between sets. On average, the total training volume ranged from 60 to 90 movement repetitions per session, with adjustments made according to individual progress. Each session concluded with a 5-minute cool-down period that included stretching and relaxation exercises aimed at reducing muscle tension.

In contrast, the RG engaged in the same 30-minute training sessions but focused solely on rehearsing previously learned Legong dance routines. Although no new movements were introduced, the RG sessions maintained the same structure, intensity, and rest intervals as those of the LG. Each session included 10 to 15 repetitions of familiar movement sequences, resulting in a comparable total training volume of 60 to 90 repetitions per session. This approach ensured that both groups experienced equivalent training duration and intensity, with the key distinction being the presence of motor learning in the LG and its absence in the RG.

Measurements were conducted one day before and one day after the six-week intervention period to evaluate changes in physiological outcomes. Resting serum BDNF levels were assessed using the enzyme-linked immunosorbent assay (ELISA) method. Blood samples were collected in the morning under fasting conditions to control for diurnal and dietary variation. The samples were then centrifuged at 3,000 rpm for 15 minutes, and the resulting serum was stored at –80°C until analysis. Aerobic capacity was evaluated using the multistage fitness test (MFT), a progressive field test commonly used to estimate cardiovascular endurance. The final level reached during the test was converted to an estimated VO_2max using standardized prediction equations validated for a pediatric population. In addition, muscle strength was measured through a sit-up test, which recorded the number of correctly performed repetitions completed within 60 seconds.

Data analysis

Statistical analyses were performed using SPSS version 26.0. Prior to primary analysis, the normality of the data distribution for all variables was assessed using the Kolmogorov-Smirnov test. Although some variables were found to be normally distributed (BDNF in RG), others showed evidence of non-normal distribution ($p<0.05$). To ensure comprehensive comparability and consistency across all physiological and biochemical variables, and given the small sample size (n=19 per group), a non-parametric approach was selected for all subsequent analyses. Consequently, the Wilcoxon Signed-Rank Test was used for intra-group (paired) comparisons, the Mann-Whitney U Test was used for inter-group (independent) comparisons, and Spearman's Rank-Order Correlation was employed to assess the associations between variables. Outliers were identified visually through Box Plots but were retained in the analysis, as the non-parametric statistical methods employed (Wilcoxon Signed-Rank Test and Mann-Whitney U Test) are robust against the influence of extreme values.

Results

There were no significant differences in age, height, weight, and BMI between the LG and RG groups (Table 1). The initial comparison of baseline characteristics, performed using the Mann-Whitney U Test, revealed significant pre-intervention differences between the LG and RG for two key variables (Table 3). Specifically, the LG exhibited significantly lower BDNF levels (Median LG=1.995 ug/ml) compared to the RG (Median RG=2.891 ug/ml; p=0.040). A stark disparity was also noted in muscular endurance (sit up), with the LG scoring significantly lower (Median LG=18.0 repetitions) than the RG (Median RG =30.0 repetitions; p=0.001). Conversely, there was no significant difference in aerobic capacity (VO_2max) between the two groups at baseline (p=0.529).

Table 1. Characteristic of research subject

Groups	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m²)
LG (n=19)	12.95 ± 0.71	153.7 ± 5.7	44.78 ± 6.340	18.92 ± 2.02
RG (n=19)	13.21 ± 0.92	153.0 ± 3.9	47.63 ± 10.40	20.26 ± 3.99

Following the six-week intervention, within-group analysis (Wilcoxon Signed-Rank Test) demonstrated unique adaptive responses (Table 2). The LG experienced significant improvements across all measured outcomes, including BDNF (from Median 1.995 to 2.546 ug/ml; p=0.001), muscular endurance (p=0.016), and aerobic capacity (p=0.001). In contrast, the RG showed no significant change in BDNF (p=0.469), muscular endurance (p=0.589), or aerobic capacity (p=0.549) post-intervention.

Table 2. Non-Parametric Analysis (Wilcoxon Signed-Rank Test) for Paired Comparisons

Measurement	Group		n	Median (IQR)	Z value	p
BDNF (µg/ml)	LG	Pre	19	1.995 (1.127 – 2.145)	-3.622	0.001
		Post	19	2.546 (2.000 – 4.154)		
	RG	Pre	19	2.891 (1.777 – 3.386)	-0.724	0.469
		Post	19	2.980 (1.492 – 4.200)		
VO_2max (ml/kg.min)	LG	Pre	19	22.4 (22.1 – 24.2)	-3.386	0.001
		Post	19	24.2 (23.9 – 24.7)		
	RG	Pre	19	22.8 (22.1 – 23.9)	-0.599	0.549
		Post	19	22.8 (22.3 – 23.5)		
Sit Up (repetition)	LG	Pre	19	18.0 (15.0 – 20.0)	-2.420	0.016
		Post	19	20.0 (15.0 – 29.0)		
	RG	Pre	19	30.0 (27.0 – 35.5)	-0.541	0.589
		Post	19	30.0 (25.0 – 34.5)		

Table 3. Non-Parametric Analysis (Mann-Whitney U Test) for Independent Samples

Measurement	Group		n	Median (IQR)	Mann-Whitney U	Z value	p
BDNF (µg/ml)	Pre	LG	19	1.995 (1.127 – 2.145)	110.5	-2.044	0.040
		RG	19	2.891 (1.777 – 3.386)			
	Post	LG	19	2.546 (2.000 – 4.154)	160.0	-0.599	0.563
		RG	19	2.980 (1.492 – 4.200)			
VO_2max (ml/kg.min)	Pre	LG	19	22.4 (22.1 – 24.2)	176.0	-0.655	0.529
		RG	19	22.8 (22.1 – 23.9)			
	Post	LG	19	24.2 (23.9 – 24.7)	97.0	-2.453	0.014
		RG	19	22.8 (22.3 – 23.5)			
Sit Up (repetition)	Pre	LG	19	18.0 (15.0 – 20.0)	21.5	-4.854	0.001
		RG	19	30.0 (27.0 – 35.5)			
	Post	LG	19	20.0 (15.0 – 29.0)	75.5	-2.925	0.003
		RG	19	30.0 (25.0 – 34.5)			

The post-intervention comparison (Mann-Whitney U Test) confirmed the differential effects of the interventions. The initial significant gap in BDNF levels between the groups was eliminated, with no significant difference observed post-intervention (p=0.563). Furthermore, the LG achieved a greater functional gain in aerobic capacity, resulting in a significantly higher VO_2max compared to the RG at the end of the study (Median LG=24.2 ml/kg.min; Median RG=22.8 ml/kg.min; p=0.014). Despite the LG's internal improvement in muscular endurance, the RG maintained a significantly

superior sit up score post-intervention (p=0.003), reflecting the RG's higher initial mastery. Finally, Spearman's Rank-Order Correlation did not reveal any significant association between the changes in BDNF levels and the changes in VO_2max or muscular endurance before and after intervention (Table 4).

Table 4. Non-Parametric Correlation Analysis (Spearman's rho) Between BDNF and Physical Fitness Parameters Pre and Post Intervention.

	Measurement	Serum BDNF	Aerobic Capacity	Sit Up
Pre Intervention	BDNF (µg/ml)	-	0.092(0.582)	0.164 (0.328)
	VO_2max (ml/kg.min)	0.092 (0.582)	-	-0.064 (0.704)
	Sit Up (repetition)	0.164 (0.328)	-0.064 (0.704)	-
Post Intervention	BDNF (µg/ml)	-	0.108 (0.518)	-0.246 (0.137)
	VO_2max (ml/kg.min)	0.108 (0.518)	-	-0.036 (0.831)
	Sit Up (repetition)	-0.246 (0.137)	-0.036 (0.831)	-

The interquartile range widened slightly in the RG group after the intervention, indicating greater variability in BDNF response among participants. Outliers were observed in the pre-intervention LG group and post-intervention RG group, reflecting individual differences in circulating BDNF levels (Figure 1). The variability of VO_2max remained higher in the RG group post-intervention, as indicated by the wider spread of data and several outliers, suggesting heterogeneous responses to the training protocol (Figure 2). The outliers were detected in both pre- and post-intervention sit-up performance data, suggesting individual differences in response to the training. Overall, these findings indicate that both interventions positively affected core muscle endurance, with a more pronounced relative improvement in the LG group (Figure 3).

Figure 1. Serum BDNF pre- and post-intervention in LG and RG groups.

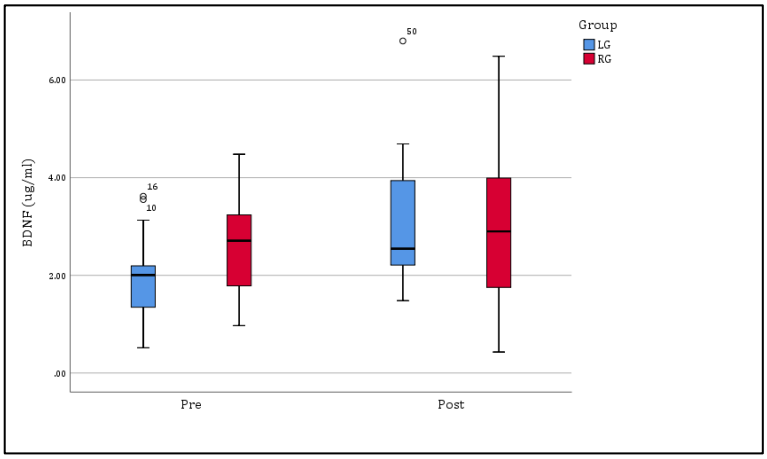


Figure 2. Changes in VO_2max pre- and post-intervention in LG and RG groups.

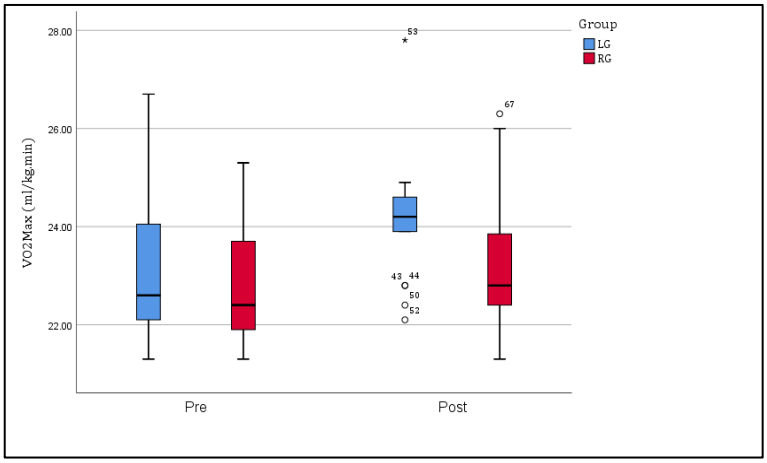
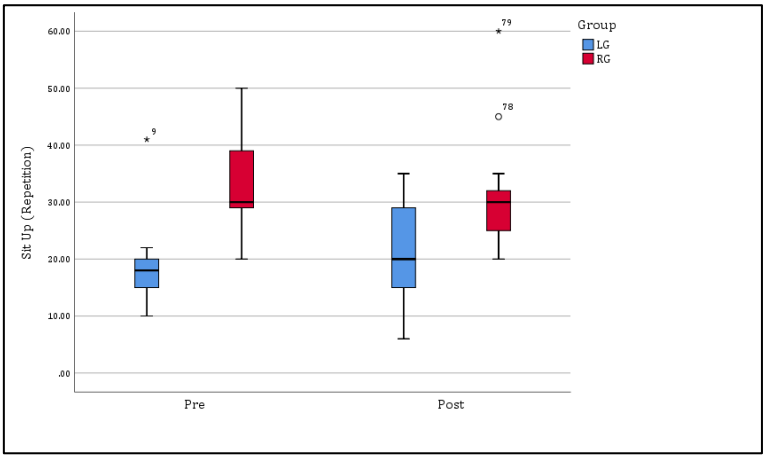


Figure 3. Sit-up performance pre- and post-intervention in LG and RG groups.



Discussion

The results of this study suggest that motor learning exercises can elevate resting serum BDNF levels in the LG to the levels observed in the RG from the beginning of the program. Our findings contribute to a clearer understanding of how different exercise components influence BDNF levels. Previous research has consistently shown that acute exercise, particularly aerobic activity, can lead to a transient, temporary increase in peripheral BDNF due to increased metabolic demand in the brain. However, the effect of chronic exercise on resting BDNF concentrations remains inconsistent, with many studies suggesting it does not necessarily cause a sustained elevation. This highlights a key distinction between a physiological response to acute exertion and a long-term neurobiological adaptation driven by more complex processes.

The results also indicated that the learning process in the LG overloads the aerobic and muscular systems to the same intensity as found in the RG. Previous research has shown that the Legong dance can improve aerobic capacity and muscle strength, as it involves moderate aerobic and muscular training characteristics (Griadhi et al., 2021). Recent systematic reviews have found that peripheral BDNF levels transiently increase after acute aerobic exercise, but chronic exercise training is unlikely to increase resting BDNF concentrations (Knaepen et al., 2010). Other researchers have reported mixed results regarding the effect of chronic exercise training on resting peripheral BDNF concentrations (Zoladz & Pilc, 2010; Szuhany et al., 2015). Most studies included in these reviews focused on aerobic and resistance training modalities. From this perspective, it can be predicted that these types of exercises may not induce the neuroplasticity necessary to increase resting serum BDNF levels.

In contrast, studies on motor learning exercises among elderly individuals with neurological deficits have shown increases in resting serum BDNF. These studies typically use interventions involving motor learning exercises and complex motor movements. Such exercises induce neuroplasticity, leading to the development of new structural and functional capacities in the brain to perform new tasks (Kleim & Jones, 2008; Mang et al., 2016). Our study provides evidence that learning new movements not previously mastered can induce neuroplasticity, as reflected by the elevation of resting serum BDNF. Repeating complex movements that have already been mastered does not involve a learning process and only maintains the existing level of resting serum BDNF. The findings suggest that resting serum BDNF increases only after a motor learning process and not by merely repeating movements that have already been mastered. The result of this study suggests that the motor learning process represents a more specific pathway to long-term BDNF elevation. Unlike repetitive or purely physiological training, motor learning involves a strong cognitive component. This requires the formation of new neural circuits and synaptic remodeling, which directly stimulates neuroplasticity. Thus, the increase in resting BDNF observed in our LG is not merely a physiological response, but a biomarker of this profound neuroplastic adaptation. Richter et al. (2021) provided evidence supporting this view, demonstrating a link between motor learning and the enhancement of executive functions in children and adolescents.

The improvement of serum BDNF due to the learning process is limited to the levels found in individuals who have already mastered the movement, suggesting that the neuronal circuits needed to perform such movements are similar among individuals. A certain level of resting serum BDNF is required to maintain these neuronal circuits. The results indicate that improvements in resting serum BDNF occur only after a period of motor learning, ceasing once the movement is mastered. The improvement is not related to the complexity of the movement; rather, any new motor learning process can enhance resting BDNF levels. This research emphasizes that aerobic exercise alone can result in a transient increase in serum BDNF. For the RG, which repeated a complex movement they had already mastered, only aerobic improvements were observed, without an elevation in resting BDNF. Aerobic exercise increases the metabolic demand of the brain, leading to a temporary rise in serum BDNF (Ferris et al., 2007; Rasmussen et al., 2009).

The number of circuits or neurons required for such motor movements does not differ among individuals. During the learning process, neuroplasticity—marked by the development of new neuronal synapses and circuits—is necessary to perform complex movements. Regular practice of a complex movement by individuals who have already mastered it does not further develop functional and structural neuroplasticity, resulting in no improvement in their serum BDNF levels. A higher serum BDNF level in individuals who have mastered a complex movement helps maintain the functionality of the neuronal circuits. This study suggests that only the motor learning process can stimulate an improvement in resting serum BDNF; repetition without learning does not lead to further improvement. According to Voss (2013), the elevation in BDNF levels does not correlate with advancements in other physical fitness components, thereby highlighting its role as a biomarker of neuroplasticity in the nervous system.

The results of this study indicate that motor learning significantly increases resting serum BDNF levels, supporting the hypothesis that mastering new complex movements enhances neuroplasticity. Our findings align with studies demonstrating that complex motor learning induces neuroplasticity-related BDNF increases, a mechanism distinct from traditional aerobic or resistance training (Kleim & Jones, 2008; Mang et al., 2016). This contrasts with research suggesting that chronic aerobic exercise alone does not necessarily elevate resting BDNF levels (Knaepen et al., 2010; Szuhany et al., 2015). The observed increase in BDNF in the LG but not in the RG suggests that the learning process, rather than repetition, drives neuroplastic adaptations. The increase in resting BDNF observed in the LG can be attributed to neural circuitry formation and synaptic remodeling required for mastering Legong dance. Previous studies indicate that learning new motor tasks activates brain regions associated with memory consolidation, particularly the hippocampus and motor cortex (Voss et al., 2013). This supports the notion that motor learning elicits a more profound neurobiological adaptation compared to repetitive physical activity. Our findings suggest that incorporating motor learning-based activities, such as traditional dance, could serve as a cognitive-exercise intervention for enhancing neuroplasticity. These results align with recent controlled trials showing how the modality and speed of execution in physical training programs can influence executive functions in children, reinforcing the importance of incorporating tasks with a high motor-cognitive component in educational and prevention contexts (Bustos Barahona et al., 2025; Jiménez Roldán & Chavarrías Olmedo, 2025).

This study has several limitations that should be acknowledged. First, the relatively small sample size (n=38) and the exclusive inclusion of female participants restrict the generalizability of the results to a broader population, despite achieving statistical significance in key outcomes. A larger and more diverse cohort in future research would enhance the external validity of the findings. Second, the six-week duration of the intervention may not be sufficient to capture the long-term effects or sustainability of the observed increase in serum BDNF levels, highlighting the need for longitudinal studies. Additionally, the absence of a non-exercise control group limits the ability to fully attribute the observed effects to motor learning alone. It is possible that other uncontrolled factors, such as social interaction or general cognitive stimulation unrelated to movement, may have also influenced the results. The use of neuroimaging techniques such as functional MRI or EEG could offer more direct insights into neural adaptations and structural changes associated with BDNF modulation. Future research should consider addressing these limitations to further validate and expand upon the current findings. Furthermore, potential covariates that could influence BDNF levels, such as the exact age and Body Mass Index (BMI) of the participants, were not controlled for, which may present another limitation to this study.

Future research could build on these findings by exploring several key areas. Longitudinal studies are needed to investigate the long-term effects of motor learning exercises on resting serum BDNF levels, including follow-up assessments after the intervention period to evaluate the sustainability of changes. It would also be valuable to examine whether similar effects occur across different age groups, such as children, adolescents, and older adults, to better understand age-related variability in motor learning-induced neuroplasticity. Future research should assess the effects of other complex motor activities—such as playing a musical instrument or learning a new sport—to determine how various types of motor learning exercises influence BDNF levels. Advanced neuroimaging techniques could be employed to visualize structural and functional brain changes associated with BDNF increases resulting from motor learning. Finally, mechanistic studies are needed to elucidate the biological pathways through which motor learning induces neuroplasticity and elevates BDNF concentrations.

Conclusions

This research underscores the unique role of motor learning exercises in inducing neuroplasticity, as evidenced by elevated resting serum BDNF levels. It highlights the limitations of traditional aerobic and resistance training in achieving similar neuroplastic outcomes. These findings have significant implications for developing targeted interventions to enhance brain health and cognitive function through motor learning exercises.

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