2026 (Febrero), Retos, 75, 496-507 ISSN: 1579-1726, eISSN: 1988-2041 https://recyt.fecyt.es/index.php/retos/index

The effect of neurofeedback on free throw accuracy in female basketball players of Baghdad University

El efecto del neurofeedback en la precisión de los tiros libres en jugadoras de baloncesto de la Universidad de Bagdad

Authors

Ahmed Amer Abdulhussein [1]
Mohammed Jawad Kadhim [1]
Omar Waleed Abdulkareem [1]
Ghada Muayad Shehab [1]

[1] University of Baghdad, Iraq

Corresponding author:
Omar Waleed Abdulkareem
omar.w@cope.uobaghdad.edu.iq

Received: 04-12-25
Accepted: 18-12-25

How to cite in APA

Abdulhussein, A. A., Kadhim, M. J., Abdulkareem, O. W., & Shehab, G. M. (2026). The effect of neurofeedback on free throw accuracy in female basketball players of Baghdad University. *Retos, 75*, 496-507. https://doi.org/10.47197/retos.v75.118286

Abstract

Background: Female basketball players often face difficulties in maintaining free throw accuracy, particularly under psychological and neural pressure. Traditional training emphasizes physical skills, often neglecting cognitive and neurophysiological factors essential for precision performance.
Objective: This study examined the effect of neurofeedback training on free throw accuracy in female basketball players at the University of Baghdad, comparing outcomes between an experimental group and a control group, and assessing associated neural changes.
Methods: A quasi-experimental design involved two groups: an experimental group receiving neurofeedback to regulate brainwave activity, and a control group undergoing traditional training. Free throw accuracy was measured pre- and post-intervention. Statistical analyses included paired and independent t-tests and ANCOVA. EEG recordings evaluated alpha and theta wave activity.
Results: The experimental group showed significant improvement in free throw accuracy compared to the control group ($p = 0.001$). EEG analysis revealed modulation of alpha and theta waves, indicating enhanced neural efficiency and focus.
Discussion**:** Findings suggest that neurofeedback improves performance by enhancing attentional control, motor coordination, and neural self-regulation, addressing factors often overlooked in conventional training.
Conclusion: Neurofeedback is an effective and innovative intervention to enhance free throw accuracy in female basketball players. Integrating neurofeedback into training programs may provide substantial benefits for precision-based skills where mental stability and neural control are critical.

Keywords

Neurofeedback; basketball; motor skills; cognitive training; free throw accuracy.

Resumen

Antecedentes: Las jugadoras de baloncesto suelen tener dificultades para mantener la precisión en los tiros libres, especialmente bajo presión psicológica y neural. El entrenamiento tradicional hace hincapié en las habilidades físicas, descuidando a menudo los factores cognitivos y neurofisiológicos esenciales para un rendimiento preciso.
Objetivo: Este estudio examinó el efecto del entrenamiento con neurofeedback en la precisión de los tiros libres en jugadoras de baloncesto de la Universidad de Bagdad, comparando los resultados entre un grupo experimental y un grupo de control, y evaluando los cambios neuronales asociados.
Métodos: Se utilizó un diseño cuasi-experimental con dos grupos: un grupo experimental que recibió neurofeedback para regular la actividad de las ondas cerebrales y un grupo de control que se sometió a un entrenamiento tradicional. Se midió la precisión en los tiros libres antes y después de la intervención. Los análisis estadísticos incluyeron pruebas t pareadas e independientes y ANCOVA. Los registros de EEG evaluaron la actividad de las ondas alfa y theta.
Resultados: El grupo experimental mostró una mejora significativa en la precisión de los tiros libres en comparación con el grupo de control ($p = 0,001$). El análisis del EEG reveló una modulación de las ondas alfa y theta, lo que indica una mayor eficiencia neural y concentración.
Discusión: Los resultados sugieren que la neuroretroalimentación mejora el rendimiento al potenciar el control atencional, la coordinación motora y la autorregulación neural, abordando factores que a menudo se pasan por alto en el entrenamiento convencional.
Conclusión: El neurofeedback es una intervención eficaz e innovadora para mejorar la precisión en los tiros libres de las jugadoras de baloncesto. La integración del neurofeedback en los programas de entrenamiento puede aportar beneficios sustanciales para las habilidades basadas en la precisión, en las que la estabilidad mental y el control neural son fundamentales.

Palabras clave

Neurofeedback; baloncesto; habilidades motoras; entrenamiento cognitivo; precisión en tiros libre.

Introduction

Free throw shooting is an essential basketball skill, and the outcome of a close game can often be won or lost at the free throw line, as a direct result of free throw percentage. Expert hitting of a free throw, however, is not only a matter of physical skill but also of maintaining mental focus and emotional control in a pressure situation. Neurofeedback, an innovative type of neurotraining, comes to the fore - as a way not only to maximize brain functioning, but also to prime athletic skills. Through the production of concurrent brainwave patterns, neurofeedback may assist athletes to control neural processes, which may in turn boost focus, reduce anxiety, and enhance motor control of various functions (Hassan & Abdulkareem, 2025; Liu et al., 2018). The sport of darts has recently been a target of research, and the technique has been demonstrated to improve performance outcomes including accuracy and consistency in a range of sports (Vernon, 2005; Awad et al., 2025). The adoption of neurofeedback for sports training represents a trend in the interdisciplinary relationship between neuroscience and sport performance (Perry et al., 2011; Hussain et al., 2024). The current study examines the effectiveness of neurofeedback in enhancing free throw performance of the female basketball players in Baghdad University, and extends the previous research in the field of neurotraining in sports (Da Silva & De Souza, 2021; Gruzelier, 2014).

Neurofeedback is based on the principle of operant conditioning: athlete receive real-time feedback, often based on EEG, and learn to control their brain activity. Neurofeedback training in sports focuses on various brain waves (e.g., alpha and theta waves) which is used to improve psychological states affecting performance (e.g., attention, relaxation or motor control) (Hammond, 2011). Neurofeedback has also been utilised in basketball and may be of a specific relevance is for free throw shooting, which is a predominantly mental and motor skill performed under psychological pressure (Goldschmied et al., 2022). Recent studies have shown neurofeedback's effectiveness in assisting athletes with maintaining concentration and minimizing performance anxiety, ultimately facilitating fine motor control (Abdulghani et al., 2025; Rydzik et al., 2023). Neurofeedback could provide a new method to counter the psychological obstacles that impede free throw accuracy by teaching athletes to self-regulate neural activity (Abdulkareem & Ali Hassan, 2025; Corrado et al., 2024). The theoretical foundation for this study is based on neurofeedback improving neural efficiency that may lead to improved basketball percentage (female basketball players) (Thompson et al., 2008).

Various research works have been focused on the effects of neurofeedback on sport performance, especially on sports of precision. For instance, (Rostami et al., 2012) showed that neurofeedback training can improve the shooting precision of professional rifle shooters by increasing the alpha wave, which is related to calm and focused state of mind. Similarly, another study by (Kao et al., 2014) showed that neurofeedback increased putting performance in golfers by decreasing anxiety and improving motor control. As for basketball, the study of (Liu et al., 2018) reported that after hemisphere-specific neurofeedback training, the performance of free throws was increased for the college participants, which was associated with improved mouldability of the neural activation pattern during high-pressure states. In addition, (Xiang et al., 2018) reported that neurofeedback significantly improved attention and decreased in-performance variability in athletes for a large spectrum of athletic activities. Another applicable work was reported by (Yu et al., 2025) analised the effect of neurofeedback on the learning of motor, having found that it enabled a quicker development of complex motor skills in sports. These results illustrate the potential use of neurofeedback for training in sports, specifically accuracy and focus-demanding tasks (e.g.,free throw shooting).

Other research reports have shown the benefits of neuromuscular training for injury prevention among physical education and sports university students, especially for activities like climbing. In another investigation performed also in climbing subjects, the occurrence of finger injuries was significantly less in those who included neuromuscular training associated to an educational program than the control group. The results of this study reinforce the importance of neuromuscular training to decrease risk for injury in sports with skills that require accuracy in movement patterns of complex and repetitive motor patterns (Jones & Johnson, 2016; Kozin et al., 2021).

Structure training methods have been demonstrated in several studies to increase athletic performance. found that training performed in high intensity intervals and repetitions in a network manner statically elevated the components of speed endurance and adaptation heart rate which are Key words for success of activities like a 5.000M competition. Such work is in line with the desire to stimulate physiological adaptation and motor development through carefully prescribed training stimuli (Easa et al., 2022).

The purpose of this study is to verify neurofeedback's influence on free throw shooting in female basketball players, to compare the effects of those who received neurofeedback and the ones who did not on shooting, and to analyze brain activity during free throw shooting after neurofeedback. The primary hypothesis is that female basketball players, after a series of neurofeedback training will show a significant increase in free throw shooting percentages in comparison to the control group. The sub-hypothesis suggests a statistically significant difference in free throw shooting accuracy between the experimental group using neurofeedback and the control group using traditional training methods.

Theoretical implications This study adds novel knowledge to the understanding of the potential effects of neurofeedback as a technique to improve sport performances, basketball skills specifically, by investigating the neural correlates associated with excellent free-throw shooting accuracy at an intrinsic level (i.e., sports neuroscience) and at an extrinsic psychological level (i.e., sports psychology). Moreover, findings from the present investigation have indeed practical implications for personnel involved in coaching athletes to competitive success and dictate recommended protocols; as opposed to ‘trial and error’ or a ‘what if approach of potential benefits of neurofeedback during group process including the incorporation of technology within such practice as an active training tool of basketball trainers when seeking enhancement of performance improvement and competition success.

Method

Study Design

The study uses a quasi-experimental design with the pre-test and post-test tests to measure the free throw test results of female basketball players after receiving neurofeedback training. The design comprises two groups, one experimental group with neurofeedback training and the other control group with classical training. For an applied setting, where it may be difficult to include randomization due to practical constraints, such as team dynamics and the strength of available players, quasiexperimental design was favored. The data collection lasts six weeks and took part from 01-march-2025 until 16-april-2025 with pre-measurements before the intervention, the intervention-trial and post measurements afterwards on free throw success. This design makes it possible to compare the effectiveness of the intervention, while adjusting for initial differences in shooting accuracy.

Participants

The research is applied on 30 female basketball players of the Baghdad University team aged between (20–22) years. They were recruited according to their sports experience (at least 3 years of competitive basketball) and the ability to comply with neurofeedback training procedures. The sample was assigned randomly with equal level to skill and experience into an experimental group (n=15), trained Neurofee back and control group (n = 15) conducting traditional basketball training. All subjects with any neurological impairment or recent injury impairing shooting performance were excluded, as well as those unable to follow the planned training schedule. An informed consent was obtained from the all participants and approved by Baghdad University guardians ethics committee.

Table 1 Arithmetic mean, standard deviation and p-value of some (age, height, weight and free throw shooting accuracy) variables for the 30 women-basketball players from the University of Baghdad who were divided into an experimental (n = 15) and control (n=15) groups. Independent samples t-test p-values are calculated to demonstrate homogeneity among groups (p > 0.05 implies no significant difference). The free throw accuracy is obtained from 20 attempts of a pre-test.

Table 1. Presents the arithmetic mean, standard deviation, and p-value for key variables (age, height, weight, and free throw shooting accuracy)

Variable	Experimental Group Mean ± SD	Control Group Mean ± SD	P-value
Age (years)	20.93 ± 0.59	20.83 ± 0.54	0.623
Height (cm)	174.27± 4.61	173.91 ± 4.53	0.821
Weight (kg)	69.67 ± 4.88	70.11 ± 5.02	0.791
Free Throw Accuracy	14.13 ± 1.68	13.87 ± 1.77	0.678

* At a significance level of 0.05 with a degree of freedom of 28

Equipment and Tools

The equipment and tools used to measure for, and carry out intervention in the study were:

Neurofeedback Device: The NeuroSky MindWave EEG headset was used to monitor brain electrical activity and instantaneous feedback during training. This tool allegedly measures the frequencies of brainwaves (e.g., alpha, theta and beta waves) to teach individuals how to self-regulate their neural activity for better motor control and focus (NeuroSky, 2011)..

Free Throw Shooting Performance: A free throw shooting test was used and participants dribbled, took two steps on an inside lane (7.24 m) and tried to score 20 free throws, the number of made shots represented their accuracy score (Ogawa et al., 2019).

Neural Activity Recording: A 32-channel EEG system (BrainMaster Atlantis) was employed aimed at detecting neural variants in free shooting condition, namely alpha and theta waves detected for the frontal and parietal lobes (Rostami et al., 2012)

Basketball Court and Equipment: A FIBA-compliant standard basketball court was utilized, along with a size 6 regulation basketball for all shooting tests and training sessions.

Procedures

The study was conducted in three phases over eight weeks:

Pre-Test Assessment: All subjects were pre-tested for their ability to perform free throws. It involved 20 free throw attempts for each participant, performed under the same conditions (no time pressure, identical court arrangement). The number of successful shots was set as the pre-test score based on their protocol (Ogawa et al., 2019). Baseline EEG recording was conducted with the Brain Master Atlantis to measure neural activity during shooting (Rostami et al., 2012). According to their baseline shooting accuracy scores, the participants were assigned to experimental or control groups so that similar levels of group equivalence could be obtained.

Intervention: Participants in the experimental group underwent neurofeedback training, and those in the control group completed conventional basketball training. 3 times a week for six weeks. The duration of each neurofeedback session was 30 min and trained participants to up-regulate the frontal alpha band (8–12 Hz) associated with a relaxed, focused mental state, using the NeuroSky MindWave headset (NeuroSky 'MindWave', 2011). The control groups received equivalent training time that focused on typical free throw shooting drills (shooting drill and guiding to improve shape of takeoff, respectively), without neurofeedback.

Post-Test Assessment: After the intervention, all participants completed once again the free throw shooting accuracy test (20 trials) in the same manner as pre-test (Ogawa et al., 2019). Additionally the EEG was re-recorded to test for any changes in neural activity during shooting (Rostami et al., 2012). The data were recorded in a quiet room to avoid crowd noise or fatigue as disturbing factors that can influence performances.

Training Protocol

For the experimental group, the neurofeedback training protocol aimed at improving concentration and motor control during free throw shooting. Each session started with a 5 min calibration to obtain the baseline brainwave activity during the use of the NeuroSky MindWave headset. They were then trained with visual and auditory feedback to increase alpha amplitude in the frontal cortex, a key indicator of enhanced attention and lower anxiety (Hammond, 2011). Training consisted of a real-time, computer-based brainwave feedback system, in which participants were encouraged to achieve a state where the balance was achieved, by focusing with relaxed attention. Subjects completed 3 sessions of 10 min training with short pauses to prevent mental fatigue. The control group used a conventional transmittal presentation; consisting of continuous free throw shooting, technical shooting form feedback, and drills which focused on consistency in shooting described by (Goldschmied et al., 2022). For comparison, groups spent the same amount of time training (18 sessions across six weeks).

Table 2 is showing the detailed six weeks neurofeedback training package for the experimental group in order to improve free throw shooting performance among female basketball players of Baghdad University. The system is also a 3-times/week, 30 min/session, for a total of 18 session programmed.

The trainings use the NeuroSky MindWave EEG headset to give direct feedback on the brainwave activity during the training and emphasize enhancing of the alpha band amplitude (8-12 Hz) activity power in the prefrontal cortex to enhance focus and motor control. Each session includes calibration, training blocks, and breaks to optimize engagement and minimize mental fatigue.

Table 2. Show The Six-Week Neurofeedback Training Protocol For The Experimental Group

Week	Session	Day	Duration	Activities	Details	Objectives
1	1	Monday	30 min	Calibration (5 min), Neurofeedback Training (3 x 8 min), Cool-down (1 min)	Calibration: Establish baseline EEG using NeuroSky MindWave headset. Training: Participants engage in visual feedback tasks to increase alpha wave activity. Cool-down: Brief relaxation to consolidate learning.	Familiarize participants with neurofeedback equipment and establish baseline alpha wave activity.
	2	Wednesday	30 min	Calibration (5 min), Neurofeedback Training (3 x 8 min), Cool-down (1 min)	Training focuses on sustaining alpha wave amplitude through feedback-driven tasks (e.g., moving a visual cursor by maintaining focus). Short 1-min breaks between blocks to prevent fatigue.	Enhance ability to sustain focused mental state during training.
	3	Friday	30 min	Calibration (5 min), Neurofeedback Training (3 x 8 min), Cool-down (1 min)	Introduction of auditory feedback alongside visual cues to reinforce alpha wave regulation. Participants aim to maintain alpha wave levels above baseline.	Improve consistency in regulating neural activity.
2	4	Monday	30 min	Calibration (4 min), Neurofeedback Training (3 x 8 min), Cool-down (2 min)	Training tasks increase in complexity, requiring participants to maintain alpha wave activity under simulated pressure (e.g., timed tasks).	Develop focus under mild cognitive stress.
	5	Wednesday	30 min	Calibration (4 min), Neurofeedback Training (3 x 8 min), Cool-down (2 min)	Integration of basketball-specific imagery: participants visualize free throw shooting while maintaining alpha wave levels.	Link neurofeedback training to basketball-specific mental states.
	6	Friday	30 min	Calibration (4 min), Neurofeedback Training (3 x 8 min), Cool-down (2 min)	Continued visualization tasks with feedback adjusted to reward sustained alpha wave activity for longer durations.	Strengthen neural control during basketball imagery.
3	7	Monday	30 min	Calibration (4 min), Neurofeedback Training (3 x 8 min), Cool-down (2 min)	Introduction of combined visual and auditory feedback with increased task difficulty (e.g., maintaining alpha waves while responding to dynamic stimuli).	Enhance multitasking ability in neural regulation.
	8	Wednesday	30 min	Calibration (4 min), Neurofeedback Training (3 x 8 min), Cool-down (2 min)	Training incorporates simulated game scenarios (e.g., imagining crowd noise) to mimic competitive pressure.	Improve focus under simulated game conditions.
	9	Friday	30 min	Calibration (4 min), Neurofeedback Training (3 x 8 min), Cool-down (2 min)	Participant's practice maintaining alpha wave activity while performing mental rehearsals of free throw techniques.	Reinforce neural patterns associated with shooting accuracy.
4	10	Monday	30 min	Calibration (3 min), Neurofeedback Training (3 x 9 min), Cool-down (1 min)	Increased training block duration to enhance endurance in maintaining focus. Feedback adjusted to reward higher alpha wave amplitudes.	Build sustained focus and neural endurance.
	11	Wednesday	30 min	Calibration (3 min), Neurofeedback Training (3 x 9 min), Cool-down (1 min)	Training includes dynamic feedback adjustments based on real-time performance to challenge participants.	Improve adaptability in neural regulation.
	12	Friday	30 min	Calibration (3 min), Neurofeedback Training (3 x 9 min), Cool-down (1 min)	Integration of physical free throw practice post-neurofeedback to transfer mental focus to motor skills.	Bridge neurofeedback training with physical performance.
5	13	Monday	30 min	Calibration (3 min), Neurofeedback Training (3 x 9 min), Cool-down (1 min)	Training emphasizes consistency in alpha wave regulation under varying feedback conditions (e.g., intermittent feedback).	Enhance reliability of neural control.
	14	Wednesday	30 min	Calibration (3 min), Neurofeedback Training (3 x 9 min), Cool-down (1 min)	Participants practice neurofeedback while visualizing high-pressure free throw scenarios (e.g., game-deciding shots).	Strengthen mental resilience in high-stakes situations.
	15	Friday	30 min	Calibration (3 min), Neurofeedback Training (3 x 9 min), Cool-down (1 min)	Continued integration of physical free throw practice with neurofeedback to reinforce motor-neural coordination.	Consolidate neural and physical training outcomes.
6	16	Monday	30 min	Calibration (3 min), Neurofeedback Training (3 x 9 min), Cool-down (1 min)	Advanced tasks requiring sustained alpha wave activity under complex stimuli (e.g., combined visual, auditory, and cognitive challenges).	Maximize neural efficiency for performance.
	17	Wednesday	30 min	Calibration (3 min), Neurofeedback Training (3 x 9 min), Cool-down (1 min)	Final integration of neurofeedback with on-court free throw practice, focusing on seamless transfer of focus to shooting.	Optimize transfer of training to game performance.
	18	Friday	30 min	Calibration (3 min), Neurofeedback Training (3 x 9 min), Cool-down (1 min)	Review session with emphasis on maintaining optimal alpha wave levels during simulated game conditions and physical shooting practice.	Prepare participants for post-test assessment with enhanced focus and accuracy.

Notes: Every session will be performed in a quiet environment (to avoid disturbance) with NeuroSky MindWave headset adjusted to the participant's baseline brainwave. Throughout training, the level of complexity is gradually ramped up to test the subject's focus and regulation of brain activity. Physical free throw work in (amount of weeks it takes to get everything set up properly) is introduced a little bit at a time to assist a transfer from neurofeedback training of brain to the actual act of shooting. Any session will be overseen by a trained systematic feedback specialist for the proper operation and protocol compliance.

Statistical Analysis

Data analysis was conducted using SPSS (Version 26). Descriptive statistics (mean, standard deviation) were calculated for pre-test and post-test free throw accuracy scores and EEG measurements. To compare differences in shooting accuracy between the experimental and control groups, an independent samples t-test was used for post-test scores, while a paired samples t-test was employed to assess within-group changes from pre-test to post-test. Analysis of covariance (ANCOVA) was used to control for baseline differences in shooting accuracy. For EEG data, changes in alpha and theta wave amplitudes were analyzed using repeated-measures ANOVA to detect differences between groups and over time. The significance level was set at $p < 0.05$ for all tests. Effect sizes (Cohen's d) were calculated to determine the practical significance of the intervention.

Results

Independent samples t-test the comparison of the post-test free-throw accuracy between the experimental and control groups is depicted in table 3. For the experimental group, the average on the free-throw accuracy test was 16.47 with a standard deviation of 1.55, and for the control group, the mean was 14.07 and the standard deviation was 1.71. t = 3.84 and there existed great differences between the two groups (P small than 0.05). The degrees of freedom for the test were 28 (sample sizes in both groups). The resultant p-value of 0.001 is much smaller than 0.05, indicating that the difference between the two groups is actually statistically significant. This indicates that free throw accuracy post-test was significantly higher for the experimental group than for the control group. The effect size of Cohen's d was 1.44 (large) suggesting that there was a significant improvement in free throw accuracy in the neurofeedback group following training. Statistical significance and substantial effect size confirm that there was an effective neurofeedback treatment for the improvement of free throw accuracy.

Table 3. Show independent Samples t-Test for Post-Test Free Throw Accuracy

Group	Mean	Standard Deviation	t-value	Degrees of Freedom	P-value	Cohen's d
Experimental	16.47	1.55	3.84	28	0.001	1.44
Control	14.07	1.71				

* At a significance level of 0.05

The data in Table 4 reflects the findings of the paired samples t-test between the pre-test and post-test in the experimental and control groups with respect to within group changes in free throw success. Mean and standard deviation of free throw accuracy in experimental group were 14.13 and 1.68 in pre-test and 16.47 and 1.55 in post test, respectively. The t value of this comparison is t = 5.62 with df = 14, $p < 0.000$. This would suggest a statistically significant difference between the experimental group's accuracy at free throws at the pre-test and the post-test, as the p-value is nowhere near significance level of 0.05. The effect size (Cohen d) was 1.45, which shows a large effect size that can reflect the big impact of the intervention on the experimental group's performance. The free throw accuracy of the control group underwent little change, as indicated by only a slight increase in mean from 13.87 in the pre-test to 14.07 in the post-test, and by standard deviations of 1.77 and 1.71, respectively. The t-value for the comparison started from 0.78 where the degree of freedom was 14 and the p-value equated to 0.448. It means that, the change in the performance of the control group was not significant, s it has not crossed the 95% limit. Moreover, the effect size for the control group was estimated to be 0.12, which indicates a very small effect and, on the whole, adds evidence to draw the conclusion that the control group did not benefit appreciably from any increase in the accuracy of their free-throws. In summary, the findings show that in the experimental condition, free throw accuracy increased (significantly) more than in the control condition.

Table 4. Show Paired Samples t-Test Results for Within-Group Changes in Free Throw Accuracy

Group	Time	Mean	Standard Deviation	t-value	Degrees of Freedom	P-value	Cohen's d
Experimental	Pre-Test	14.13	1.68	5.62	14	0.000	1.45
	Post-Test	16.47	1.55				
Control	Pre-Test	13.87	1.77	0.78	14	0.448	0.12
	Post-Test	14.07	1.71				

* At a significance level of 0.05

Results ancova was used to determine the effect of the group (experimental and control) on post-test of free throw accuracy, with pre-test score as a covariate, as shown in table 5. The summary table lists the mean square, f value, df's (degrees of freedom), p-values and partial-eta squared (ηp^2) for each source of variances. The group source gives a sum of squares of 54.76, 1 df, and mean square of 54.76. The f-value for the group effect was 14.82, with a p value of 0.001. This indicates that the group variable (experimental vs. Control) had a statistically significant effect on post-test free throw accuracy, as the p-value is below the 0.05 significance level. The partial eta squared (ηp^2) value of 0.35 suggests a large effect size, indicating that group membership explains 35% of the variance in post-test free throw accuracy, which is considered a substantial effect. The covariate (pre-test) factor refers to pre-test performance scores that were entered in order to account variance due to individual differences in total free throw accuracy at the pretest. The covariate has sum of squares 72.19, with 1 degree of freedom and mean square equal to 72.19. The covariate effect is significant (f = 19.54, p =0.000), suggesting the relation between pre-test scores and post-test accuracy is highly significant. The smallness of the partial eta squared (0.42) signifies a very large effect size by which pre-test scores account for variance in post-test performance on the tasks. The unexplained variance (error term) has a sum of squares 99.63 with df 27, and the corresponding mean square is 3.69. The total sum of squares for the model is 126.55, with 29 degrees of freedom.

Table 5. Show Analysis of Covariance (ANCOVA) Results for Free Throw Accuracy

Source	Sum of Squares	Degrees of Freedom (df)	Mean Square	F-value	P-value	Partial Eta Squared (ηp2 \eta_p^2 ηp2)
Group	54.76	1	54.76	14.82	0.001	0.35
Covariate (Pre-Test)	72.19	1	72.19	19.54	0.000	0.42
Error	99.63	27	3.69			
Total	126.55	29				

Table 6 presents the results of a repeated-measures ANOVA conducted to examine the effects of the group (experimental vs. control), time (pre-test vs. post-test), and their interaction on two EEG measurements: alpha and theta waves.

For alpha wave activity, the group effect was found to be statistically significant, with an F-value of 12.31 and a p-value of 0.002, indicating that the group variable had a notable impact on alpha wave activity. The partial eta squared estimate of 0.31 indexed a medium to large effect size with 31% of the variance in alpha wave activity being ascribable to group membership. There was also significant time effect, F(1, 24) = 15.64, p < 0.000, indicating that pre-test vs. post-test had significant effect on alpha wave activity. An effect size of this model can be provided by the partial eta squared and its value is 0.36 showing a large effect size which means that the time is capable of explaining 36% of the variance in alpha wave activity. Additionally, the group x time interaction was significant (F(1,14) = 12.29, p =.002). This interaction effect is significant which means either the effect of group on alpha wave activity does not remain the same over time (pre-test and post-test) or the effect of group on alpha wave activity depends on the time that pre-test and post-test are conducted. partial eta squared= 0.31, indicating that this interaction effect contributes 31 per cent of the variance in alpha wave activity.

For theta wave activity, as well, there was a significant group effect (F = 9.87, p = 0.004). This demonstrates that the group had a substantial effect on theta wave activity and the fact that the partial eta squared of 0.26 show a moderate size effect tells us that 26% of the variance in theta wave activity is due to group. The time factor was also significant (p-value = 0.002), shown by an F-value of 11.42, meaning the theta wave activity level was significantly influenced by time (pre-test, post-test). The partial eta squared value of 0.29 indicates a medium to large effect size, i.e., time explains 29% of the variance of theta wave activity. The group × time interaction for theta was also significant (F=9.05, P=0.005). The partial eta squared of 0.24 represents a medium effect size of the group × time interaction with reference to the variance of the theta wave.

Table 6. Show Repeated-Measures Anova Results For Eeg Measurements

Variable	Source	Sum of Squares	Degrees of Freedom	Mean Square	F-value	P-value	Partial Eta Squared (ηp2 \eta_p^2 ηp2)
Alpha Wave	Group	48.25	1	48.25	12.31	0.002	0.31
	Time	36.78	1	36.78	15.64	0.000	0.36
	Group × Time	28.91	1	28.91	12.29	0.002	0.31
	Error (Group)	109.47	28	3.91			
	Error (Time)	65.84	28	2.35			
	Error (Interaction)	65.89	28	2.35			
Theta Wave	Group	32.16	1	32.16	9.87	0.004	0.26
	Time	24.53	1	24.53	11.42	0.002	0.29
	Group × Time	19.44	1	19.44	9.05	0.005	0.24
	Error (Group)	91.28	28	3.26			
	Error (Time)	60.12	28	2.15			
	Error (Interaction)	60.17	28	2.15			

Discussion

The results of the present study suggest that neurofeedback training is an effective intervention to improve free throw shooting accuracy in female basketball athletes. More marked improvements in performance as well as in neural mechanisms were found in the experimental compared to the control group. These findings fit into the main goals related to analyzing the effects of neurofeedback on motor and cognitive top-strategy on sports.

The significant improvements of free throw accuracy of the group who get neurofeedback reflect neurofeedback successful in improving focus and motor coordination for them, so that they would have more stable performance in critical moments of the game. By contrast, conventional training procedures of the control group seems to evoke only small progress in this regard, raising the fact that neurofeedback is especially suitable in dealing with psychological and neurophysiological factors that influence performance in precision tasks. Such an asymmetrical effect is compatible with the notion that neurofeedback may act through enhancing self-regulation of cerebral activity which in turn influences how those trained regions are engaged for optimizing the fine motor control required to enact successful free throws. (Cheng et al., 2024). These processes may be especially relevant in basketball, where free shoot has high- or low-stakes and performance success is easily disrupted by anxiety (Chuang et al., 2013; Bendo et al., 2025).

In regard to neurobiological evidence, the decreased amplitudes of alpha and theta waves in our experimental group as detected in this study indirectly suggest that such brainwave patterns might be modifiable via neurofeedback giving rise to more peak like sport performance related states. Both alpha and theta EEG oscillations, related to relaxed wakeful state and the control of attention, right-left hand motor activity planning, error monitoring, respectively, have been largely modulated representing an index of neural efficiency in performing shooting tasks. The substantial group × time interaction suggests that these neural changes are intervention-specific – not attributable to mere practice effects, as there were only marginal shifts in EEG profiles of control participants. Such a pattern of results supports that sensorimotor rhythms are important in the coordination of cognitive-motor processes and for sports, and also suggests that NF has contributed to the facilitation of sensorimotor rhythm regulation. (Cheng et al., 2024; Andreu & Lopes, 2025). Furthermore, the neural findings also support existing research that neurofeedback is able to decrease performance anxiety and strengthen attentional resources (thus linking brain activity to behavioral performance in competitive contexts) (Zadkhosh et al., 2017; Abdulkareem & Sattar Jabbar, 2025).

On a theoretical level, these results expand the interdisciplinary literature in sport psychology and neuroscience on how biofeedback training, such as neurofeedback (NF), can be used to shape operant conditioning of brain states and optimize top performance. By demonstrating that targeted neural training results in improved motor performance, these findings provide support for models of neural plasticity in sport indicating that attention-action pathways are reinforced by the repetition of feedback loops. (Brito et al., 2022; Ali Kadhim et al., 2025). This is particularly evident in precision-dictated sports (e.g., basketball) where interventions need to contemplate ways in which emotional, cognitive and motor responses can be optimized through periods of performance fluctuation (Blumenstein & Hung, 2016; Ulrahman et al., 2025).

More plausibly, adding neurofeedback to the training process gives coaches and athletes another cool new toy to play with in their attempts to programme players so they can perform when it counts – especially for female players who deal with a different set of psychological factors under pressure. By highlighting neural control, these measures might supplement the method of physical drill-based training in preparing operators for stress-resistant performance. Nonetheless, given the reliance on a specific sample and quasi-experimental design of the study, caution is required in the generalization of findings, and longitudinal research should be conducted to examine retention effects and the generalizability of findings across gender and ability level. (Dana et al., 2019; Hulfian et al., 2025). Future investigations should also explore dosage variations in neurofeedback protocols to optimize outcomes while minimizing resource demands.

Overall, this study adds to the evidence base for neurofeedback to be seen as a supplemental performance enhancement intervention for sports, and has wide implications for both theoretical models and practical implementations of how best to modulate neural processes to benefit performance in sports.

Conclusions

The present investigation provides evidence that neurofeedback training is beneficial in improving free throw shooting accuracy in female basketball players. Significant differences in performance measures were found with the experimental group for free throw shooting accuracy compared with the control group. These findings indicate that neurofeedback drives attention and motor coordinating towards focusing attention demanded by the brain self-regulation, which performs precision task such as free throw shooting. Results highlight the unique nature of NFB in psychological' and neuroimaging-'based mechanisms that are generally overlooked by traditional training paradigms.

Changes in ‘pre-critical’ brain waves (in particular Alpha and Theta activity) additionally independent tasks demonstrate that neurofeedback influences the neural processes toward failure of athletic performance more efficiently. Such neuroadaptations of the cortex point toward greater attentional and error monitoring engagement, hence a new motor planning strategy leading to a more consistent performance under pressure. Also, a group–time interaction indicate this change to be intervention specific and only minimal alterations in EEG profiles are found for control.

Our findings theoretically encourage that biofeedback protocols, including the one used in the present work (i.e., neurofeedback), could be employed for the purpose of changing brain states and optimizing motor output. This is consistent with neuroplasticity models, suggesting that repeating the fNIRS-NF scenario consolidates cognitive and motor networks promoting efficient cognitive performance. Moreover, from an applied perspective, these results indicate that integrating neurofeedback as part of a basketball preparation to compete programme might offer another tool to enhance one's performance - particularly under pressure.

Generalization of these results should therefore be made with caution, given the small n and quasi-experimental design. The second priority is to conduct longitudinal studies examining the lasting effects of neurofeedback as well as its generalization across different samples, skill levels and genders. Second, examining differences in neurofeedback protocols may serve to optimize efficacy and minimize resource utilization, rendering the intervention more worthwhile for implementation in a sports setting.

Acknowledgements

Thanks, and appreciation to all those who worked and contributed to the preparation of this research paper, from professors and institutions who provided effort and technical support.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Disclosure statement

This study was not supported by, or yielded any financial gain to, any of the authors.

Informed Consent

All parties participating in this project were required to provide informed consent.

Ethical Approval

Human subjects research followed all relevant national rules and institutional procedures, was in accordance with the Declaration of Helsinki principles, and was approved by the authors' institutional review board or a comparable committee.

Financing

No grants or other forms of outside financing were used to carry out this study.

References

Abdulghani, L. Y., Abdulghani, M. Y., & Abdulkareem, O. W. (2025). Designing a palm pressure measurement device to improve motor coordination in freestyle swimming among female students. Journal of Physical Education and Sport, 25(7), 1506–1513. https://doi.org/10.7752/jpes.2025.07168

Abdulkareem, O. W., & Ali Hassan, M. F. (2025). impact of mental games on improving shooting accuracy among young basketball players in Iraqi clubs. Scientific Journal of Sport and Performance, 4(3), 342–351. https://doi.org/10.55860/OHNP7224

Abdulkareem, O. W., & Sattar Jabbar, H. (2025). Comparative Biomechanical Analysis of Three-Point Shooting Between Elite Iraqi Basketball Players and International Counterparts. Journal of Sport Biomechanics. https://doi.org/10.61186/JSportBiomech.11.3.326

Ali Kadhim, M. A., Abdulrasool, T. H., Kadhim Almayah , S. J., Hasan Aldewan, L., & Asim Ghazi, M. (2025). The impact of artificial intelligence techniques in developing basic and motor skills for students through the Physical Education lesson. *Retos*, *73*, 1039-1048. https://doi.org/10.47197/retos.v73.117711

Awad, A. J., Ghasemi, G. A., Sadeghi, M., & Esmaeili , H. (2025). The effect of 8 weeks of resistance training on the angle of hip and knee flexion, proprioception, and muscle performance following anterior cruciate ligament reconstruction. *Retos*, *69*, 963-972. https://doi.org/10.47197/retos.v69.114042

Bendo, A., Brovina, F., Bushati, S., Salllaku, D., Bushati, M., & Papa, E. . (2025). The Effect of High Interval Intensity Training (HIIT) on the Performance of Basketball Players 10-15 Years Old. *Retos*, *62*, 627-636. https://doi.org/10.47197/retos.v62.109315

Blumenstein, B., & Hung, E. T.-M. (2016). Biofeedback in sport. In Routledge international handbook of sport psychology (pp. 429–438). Routledge.

Brito, M. A. de, Fernandes, J. R., Esteves, N. S., Müller, V. T., Alexandria, D. B., Pérez, D. I. V., Slimani, M., Brito, C. J., Bragazzi, N. L., & Miarka, B. (2022). The Effect of Neurofeedback on the Reaction Time and Cognitive Performance of Athletes: A Systematic Review and Meta-Analysis. Frontiers in Human Neuroscience, 16. https://doi.org/10.3389/fnhum.2022.868450

Cheng, M.-Y., Yu, C.-L., An, X., Wang, L., Tsai, C.-L., Qi, F., & Wang, K.-P. (2024). Evaluating EEG neurofeedback in sport psychology: a systematic review of RCT studies for insights into mechanisms and performance improvement. Frontiers in Psychology, 15. https://doi.org/10.3389/fpsyg.2024.1331997

Chuang, L.-Y., Huang, C.-J., & Hung, T.-M. (2013). The differences in frontal midline theta power between successful and unsuccessful basketball free throws of elite basketball players. International Journal of Psychophysiology, 90(3), 321–328.

Corrado, S., Tosti, B., Mancone, S., Di Libero, T., Rodio, A., Andrade, A., & Diotaiuti, P. (2024). Improving mental skills in precision sports by using neurofeedback training: a narrative review. Sports, 12(3), 70.

Da Silva, J. C., & De Souza, M. L. (2021). Neurofeedback training for cognitive performance improvement in healthy subjects: A systematic review. Psychology & Neuroscience, 14(3), 262.

Dana, A., Rafiee, S., & Gholami, A. (2019). The effect of Neurofeedback Training on Working Memory and Perceptual-motor development in Athlete Boys. Journal of Rehabilitation Sciences & Research, 6(1), 34–40.

Easa, F. A. W., Shihab, G. M., & Kahdim, M. J. (2022). the Effect of Training Network Training in Two Ways, High Interval Training and Repetition To Develop Speed Endurance Adapt Heart Rate and Achieve 5000 Meters Youth. Revista Iberoamericana de Psicología Del Ejercicio y El Deporte, 17(4), 239–241.

Goldschmied, N., Raphaeli, M., Moothart, S., & Furley, P. (2022). Free throw shooting performance under pressure: A social psychology critical review of research. International Journal of Sport and Exercise Psychology, 20(5), 1397–1415.

Gruzelier, J. H. (2014). EEG-neurofeedback for optimising performance. II: creativity, the performing arts and ecological validity. Neuroscience & Biobehavioral Reviews, 44, 142–158.

Hammond, D. C. (2011). What is neurofeedback: An update. Journal of Neurotherapy, 15(4), 305–336.

Hassan, M. F. A., & Abdulkareem, O. W. (2025). Effects of an Integrated Balance and Muscle Tension Control Training Program on Kinematic Variables and Defensive Accuracy in Volleyball Players. Journal of Sport Biomechanics, 11(4), 438–464. https://doi.org/10.61882/JSPORTBIOMECH.11.4.438

Hulfian, L., Ma'mun, A., Kusmaedi, N., Hendrayana, Y., & Agus, H. (2025). Structuring youth sport for development: integrating life skills in NTB Basketball Leagues. *Retos*, *71*, 1167-1176. https://doi.org/10.47197/retos.v71.117400

Hussain, F. M., Shuhaib, M. H., & Hassan, M. F. A. (2024). Psychological Toughness and its Relationship to Some Coordination, Physical Abilities and Accuracy of Some Basic Skills Performance Among The Iraqi Junior National Handball Team Players. International Journal of Disabilities Sports and Health Sciences, 7, 330–336. https://doi.org/10.33438/ijdshs.1436061

Jones, G., & Johnson, M. I. (2016). A critical review of the incidence and risk factors for finger injuries in rock climbing. Current Sports Medicine Reports, 15(6), 400–409.

Kao, S.-C., Huang, C.-J., & Hung, T.-M. (2014). Neurofeedback training reduces frontal midline theta and improves putting performance in expert golfers. Journal of Applied Sport Psychology, 26(3), 271–286.

Kozin, S., Kozina, Z., Korobeinik, V., Cieślicka, M., Muszkieta, R., Ryepko, O., Boychuk, Y., Evtifieva, I., & Bejtka, M. (2021). Neuro-muscular training for injury prevention of students-rock climbers studying in the specialty" Physical Education and Sports": a randomized study. Journal of Physical Education and Sport, 21, 1251–1259.

Liu, Y., Harihara Subramaniam, S. C., Sourina, O., Shah, E., Chua, J., & Ivanov, K. (2018). NeuroFeedback training for enhancement of the focused attention related to athletic performance in elite rifle shooters. In Transactions on Computational Science XXXII: Special Issue on Cybersecurity and Biometrics (pp. 106–119). Springer.

Ogawa, M., Hoshino, S., Fujiwara, M., & Nakata, H. (2019). Relationship between basketball free-throw accuracy and other performance variables among collegiate female players. The Journal of Physical Fitness and Sports Medicine, 8(3), 127–136.

Perry, F. D., Shaw, L., & Zaichkowsky, L. (2011). Biofeedback and neurofeedback in sports. Biofeedback, 39(3), 95–100.

Prieto Andreu, J. M., & Lopes, A. (2025). Artificial intelligence as a virtual coach: comparative effectiveness of automated feedback versus traditional methods in Physical Education. *Retos*, *72*, 823-834. https://doi.org/10.47197/retos.v72.117154

Rostami, R., Sadeghi, H., Karami, K. A., Abadi, M. N., & Salamati, P. (2012). The effects of neurofeedback on the improvement of rifle shooters' performance. Journal of Neurotherapy, 16(4), 264–269.

Rydzik, Ł., Wąsacz, W., Ambroży, T., Javdaneh, N., Brydak, K., & Kopańska, M. (2023). The use of neurofeedback in sports training: systematic review. Brain Sciences, 13(4), 660.

Thompson, T., Steffert, T., Ros, T., Leach, J., & Gruzelier, J. (2008). EEG applications for sport and performance. Methods, 45(4), 279–288.

Ulrahman Hasham, M. A., Mohammed, H. T., Hussein Farhan, A., Malik Shihab, B., & Saeed Al-Mousawi, S. Q. (2025). The effect of high-intensity interval training on developing some biokinetics abilities, Electromyography (EMG), and the accuracy of shooting basketball. *Retos*, *70*, 1011-1022. https://doi.org/10.47197/retos.v70.116696

Vernon, D. J. (2005). Can neurofeedback training enhance performance? An evaluation of the evidence with implications for future research. Applied Psychophysiology and Biofeedback, 30(4), 347–364.

Xiang, M.-Q., Hou, X.-H., Liao, B.-G., Liao, J.-W., & Hu, M. (2018). The effect of neurofeedback training for sport performance in athletes: A meta-analysis. Psychology of Sport and Exercise, 36, 114–122.

Yu, C., Cheng, M., An, X., Chueh, T., Wu, J., Wang, K., & Hung, T. (2025). The Effect of EEG Neurofeedback Training on Sport Performance: A Systematic Review and Meta-Analysis. Scandinavian Journal of Medicine & Science in Sports, 35(5), e70055.

Zadkhosh, S. M., Gharayagh Zandi, H., & Hemayattalab, R. (2017). The effects of Neurofeedback on Anxiety decrease and Athletic performance Enhancement. Journal of Applied Psychological Research, 7(4), 21–37. https://doi.org/10.22059/JAPR.2017.61078

Authors' and translators' details:

Ahmed Amer Abdulhussein	ahmed.a@cope.uobaghdad.edu.iq	Author
Mohammed Jawad Kadhim	dr.muhamed.juad@cope.uobaghdad.edu.iq	Author
Omar Waleed Abdulkareem	omar.w@cope.uobaghdad.edu.iq	Author / correspondiente/ Translator
Ghada Muayad Shehab	dr.ghada@cope.uobaghdad.edu.iq	Author