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Neurofeedback Training for Sharpening Focus in Precision Sports: A Pilot Study

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A B S T R A C T

This study investigates the efficacy of neurofeedback training in enhancing focus and attentional control among athletes in precision sports, examining both neural and behavioral outcomes. A pilot intervention was conducted with 30 competitive athletes (e.g., archers, shooters) who underwent 16 sessions of EEG-based neurofeedback targeting sensorimotor rhythm (SMR) or theta/beta ratio modulation. Pre- and post-training assessments included quantitative EEG analysis, standardized attention tests (e.g., TOVA), and self-reported focus metrics during simulated competition. A control group engaged in sham neurofeedback to account for placebo effects. Participants receiving active neurofeedback demonstrated significant improvements in SMR amplitude ($p<0.05$) and theta/beta ratio reduction ($p<0.01$), correlating with enhanced performance accuracy (15% increase, $p<0.05$) and faster reaction times. Subjective reports confirmed heightened concentration during high-pressure tasks, whereas the control group showed no statistically meaningful changes. EEG coherence analysis revealed strengthened frontoparietal connectivity, suggesting neuroplastic adaptations underlying cognitive gains. Neurofeedback appears effective in sharpening attentional regulation for precision sports, though individual variability and the need for protocol optimization warrant further investigation. These preliminary findings support integrating neurofeedback into athletic training regimens while highlighting the necessity for larger randomized trials to establish standardized protocols.

Keywords: *neurofeedback, precision sports, attentional control, EEG, cognitive training*

1. Introduction

Precision sports, encompassing disciplines such as archery, shooting, golf, and other accuracy-dependent events, require athletes to maintain extraordinary levels of attentional control, fine motor coordination, and emotional regulation under conditions of intense pressure. Unlike team or endurance sports, where rapid decision-making and gross motor output dominate, precision sports place a premium on sustained concentration, micro-motor accuracy, and resistance to cognitive intrusions over extended periods of performance (1-3). Performance margins in these sports are often determined by minute variations in neural efficiency and perceptual-motor synchronization, where even subtle lapses in attentional stability can degrade results (4, 5). Contemporary sport neuroscience has identified distinct electroencephalographic (EEG) patterns associated with optimal precision performance, including elevated sensorimotor rhythm (SMR) amplitudes, reduced frontal theta/beta ratios, and context-specific modulations of alpha power (6-9). These findings underscore the role of targeted cognitive training approaches capable of directly influencing these neurophysiological markers to optimize performance outcomes.

Neurofeedback training (NFT) has emerged as a non-invasive, operant conditioning-based technique that enables individuals to modulate specific brainwave frequencies through real-time feedback, thereby facilitating the attainment of performance-conducive neural states (10-12). By providing continuous auditory, visual, or multimodal cues linked to EEG activity, NFT encourages self-regulation of targeted neural oscillations, fostering functional connectivity changes that support attentional stability and motor precision (13-15). Neurofeedback's utility in sport psychology is grounded in its capacity to transform implicit neurophysiological processes into explicit learning targets, accelerating the mastery of optimal mental states (16, 17).

In elite sport contexts, NFT has been applied to enhance a range of psychological and physiological variables, including focus, stress regulation, visuospatial coordination, and emotional resilience (18-20). EEG-based studies have demonstrated that expert performers exhibit more efficient cortical activation patterns during motor preparation and execution phases than novices, characterized by refined neural resource allocation and reduced extraneous activity (4, 21, 22). This efficiency aligns with the concept of "neural proficiency adaptation," wherein skill acquisition and refinement result in progressively optimized brain network dynamics (23, 24). The modulation of SMR, in particular, has been linked to improved motor inhibition, attentional filtering, and reduced susceptibility to distraction (10, 25).

Evidence from recent systematic reviews and meta-analyses indicates that NFT can meaningfully improve sport-specific performance metrics, though effect sizes vary according to sport type, protocol design, and feedback modality (13, 20, 26, 27). For example, targeted frontal midline theta enhancement has been shown to support sustained focus in golfers, while alpha modulation protocols have yielded benefits in rifle shooting performance (22, 28, 29). Moreover, integrating multimodal feedback mechanisms appears to enhance learning curves and transferability to competitive settings (30, 31), while coupling NFT with non-invasive brain stimulation techniques such as transcranial direct current stimulation (tDCS) may yield synergistic effects on motor imagery and execution (18, 32).

The neurocognitive underpinnings of NFT efficacy in precision sports can be understood through frameworks such as the neurovisceral integration model (33) and dynamic systems approaches to motor learning (1). These models emphasize the bidirectional regulation between central executive networks—particularly the prefrontal cortex—and autonomic nervous system function in sustaining attentional control during fine-motor execution. NFT may strengthen this coupling by enhancing interoceptive awareness and optimizing arousal regulation, as supported by EEG-fMRI studies revealing functional connectivity gains between the anterior cingulate cortex, insula, and parietal regions following training (34, 35). Importantly, these neuroplastic changes can occur in both healthy and clinical populations, extending NFT's relevance beyond sport into rehabilitation and cognitive enhancement domains (17, 23).

A growing body of literature situates NFT within the broader category of brain-computer interface (BCI) applications, leveraging real-time neural data not only for training but also for adaptive performance support (36, 37). In sports, BCIs have been explored for monitoring and modulating engagement, preventing mental fatigue, and enabling on-demand recalibration of cognitive states during competition (38, 39). Advances in AI-driven signal processing and portable EEG systems are making these interventions increasingly feasible in field environments, addressing historical constraints of laboratory-only applicability (31, 40). However, challenges remain in standardizing protocols, managing inter-individual variability in responsiveness, and ensuring ecological validity in training transfer (12, 41).

The sports-specific NFT literature reflects both promising outcomes and mixed findings, underscoring the influence of methodological differences in shaping results (27, 42). While some studies demonstrate significant gains in marksmanship accuracy and attentional metrics (8, 28), others suggest limited advantages over placebo or sham feedback conditions (11, 43). Factors such as baseline

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neurophysiology, psychological readiness, and even genetic polymorphisms may moderate individual responsiveness (42, 44). Moreover, protocol parameters—including targeted frequency bands, session duration, and training frequency—must be optimized to balance neuroplastic gains with the risk of cognitive overload (25, 45).

Neurofeedback has also shown potential in enhancing ancillary cognitive and emotional domains critical to precision sports performance, such as flow state induction (44), stress resilience (18), and visuospatial processing (8, 38). The transfer of these enhancements to competition scenarios is particularly relevant for athletes who must execute under pressure, where attentional lapses can be amplified by heightened physiological arousal (3, 5). Integrating NFT with traditional mental skills training—such as imagery, goal setting, and mindfulness—may further reinforce these benefits (46, 47).

Beyond elite sport, NFT principles have been adapted to military and tactical populations, where precision under duress is equally vital (42), as well as to clinical and neurorehabilitation settings (17, 24). For example, alpha power modulation has been used to improve motor imagery in brain-computer interface control tasks among rehabilitation patients (29, 36), while SMR protocols have supported recovery in stroke survivors (23). The convergence of these findings across domains reinforces NFT's versatility as both a performance enhancement and restorative tool (15, 40).

Against this backdrop, the present study aims to examine the efficacy of a sport-specific neurofeedback protocol for enhancing attentional control in precision sports athletes.

2. Methods and Materials

2.1. Study Design and Participants

This pilot study employed a mixed-methods, randomized controlled trial design with three parallel arms to evaluate the efficacy of neurofeedback training (NFT) for enhancing focus in precision sports athletes. The quantitative component featured a pre-test/post-test comparison between experimental and control groups, while the qualitative component incorporated semi-structured interviews to explore participants' subjective experiences. The design was informed by recent methodological recommendations for neurofeedback research in sports performance enhancement, particularly the need for active control groups and ecological validity in outcome measures. The trial protocol was preregistered with the Open Science Framework and received ethical approval from the Institutional Review Board Department of Physical Education, Federal University of Sergipe (UFS), São Cristóvão, Brazil.

Thirty elite precision sport athletes (15 archers, 10 shooters, and 5 golfers) were recruited through national sports federations, with inclusion criteria requiring at least three years of competitive experience at national-level events. Participants ranged in age from 18 to 32 years (mean = 24.6 ± 3.8) and were free from neurological or psychiatric conditions as confirmed by medical screening. The sample size was determined based on effect sizes from comparable NFT studies in athletic populations, providing 80% power to detect moderate effects ($f = 0.30$) at $\alpha = 0.05$. Randomization was stratified by sport type using permuted blocks to ensure balanced group allocation, with 10 participants each assigned to: 1) Sensorimotor rhythm (SMR) neurofeedback, 2) Theta/alpha ratio neurofeedback, or 3) Sham neurofeedback control.

Pre- and post-intervention evaluations included laboratory and field-based components. Laboratory testing under controlled conditions measured: 1) EEG markers of focus (frontal theta power, parietal alpha suppression), 2) Reaction time and consistency in sport-specific decision tasks, and 3) Physiological stress markers (heart rate variability, galvanic skin response). Field testing occurred during regular training sessions and included: 1) Competition-simulation pressure drills, 2) Coach-rated performance under distraction, and 3) Video analysis of pre-shot routines. The multimodal assessment approach addressed limitations identified in recent reviews of sports NFT research (17), particularly the over-reliance on laboratory measures disconnected from actual performance contexts.

Study rigor was ensured through several safeguards: 1) Double-blinding for sham and active NFT conditions, 2) Weekly calibration of all measurement equipment, 3) Inter-rater reliability checks for qualitative coding ($\kappa > 0.80$), and 4) Adverse event monitoring throughout the intervention period. Treatment fidelity was assessed via random video review of 20% sessions by an independent expert,

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confirming 93% adherence to protocol specifications. These measures addressed common limitations identified in recent neurofeedback research (8), particularly concerns about placebo effects and protocol standardization.

The mixed-methods design facilitated comprehensive evaluation through: 1) Quantitative-qualitative meta-inference tables comparing neural, performance, and experiential outcomes, 2) Case studies of exceptional responders/non-responders, and 3) Triangulation of subjective reports with objective metrics. This approach aligned with best practices for complex intervention research, allowing examination of both efficacy and mechanisms of effect. The study's methodological innovations included the sport-specific adaptation of NFT protocols and the combination of laboratory neural measures with field performance assessments, advancing beyond the limitations of previous sports NFT research.

2.2. *Measures*

Electroencephalographic (EEG) data were collected using a 64-channel Biosemi ActiveTwo system with electrodes positioned according to the 10-20 international system, with sampling rate at 2048 Hz and impedance kept below 10 kΩ. The system's validity for sports performance research has been established in recent studies comparing laboratory and field measurements (48). Performance outcomes were assessed using: 1) A computerized shooting simulator (SCATT Pro System) with 0.01° accuracy for marksmanship metrics, 2) Golf putting accuracy measured by Smart2Move pressure-sensitive mat (1mm precision), and 3) Archery target scoring via Archery ScorePad Pro with integrated image analysis. Psychological measures included the Test of Attentional and Interpersonal Style (TAIS), demonstrating strong reliability in athlete populations (Cronbach's $\alpha = 0.89$) (16), and the Mindfulness Attention Awareness Scale (MAAS) with established validity for sports applications (49).

2.3. *Intervention*

The 8-week intervention consisted of 16 sessions (twice weekly) of 30-minute NFT administered by certified practitioners. The SMR protocol (12-15Hz Cz training) and theta/alpha protocol (4-8Hz/8-12Hz Fz ratio) were implemented using BCI2000 software with threshold adjustments based on individual baselines. Sham training followed identical procedures but provided non-contingent feedback. Each session comprised: 1) 5-minute baseline recording, 2) 20-minute training with audiovisual feedback (customized for each sport), and 3) 5-minute transfer period without feedback. The protocols were adapted from evidence-based approaches in recent precision sports studies (42), with modifications to enhance ecological validity through sport-specific visual displays and real-time performance metrics. Training progress was monitored using learning curves calculated from session-to-session amplitude changes, with individualized adjustments made for participants showing plateaued progress (15).

2.4. *Data Analysis*

Quantitative data analysis followed intention-to-treat principles using linear mixed-effects models to account for repeated measures and individual variability. Primary outcomes (EEG focus markers and performance accuracy) were analyzed with time (pre/post) × group (SMR/theta-alpha/sham) interactions, controlling for baseline performance and sport type. Effect sizes were calculated using partial eta squared (η^2) with 95% confidence intervals. EEG data processing involved: 1) Artifact removal using independent component analysis, 2) Spectral analysis via Fast Fourier Transform (1Hz bins), and 3) Source localization using sLORETA for significant findings. Qualitative data from post-intervention interviews underwent thematic analysis following the framework method (23), with triangulation between researcher, coach, and athlete perspectives to ensure comprehensive understanding.

The analysis plan addressed multiple comparison concerns through false discovery rate correction while maintaining adequate power for primary hypotheses. Missing data (3.2% of total) were handled using maximum likelihood estimation, with sensitivity analyses confirming robustness of findings. All analyses were conducted in R (version 4.3.1) with specialized packages for EEG analysis (EEGLAB) and mixed modeling (lme4). Bayesian approaches complemented frequentist analyses where appropriate, particularly for evaluating individual response patterns (19). The α level was set at 0.05 for primary outcomes, with effect size interpretation guided by sport-

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specific benchmarks: $\eta^2 \geq 0.04$ considered practically meaningful for performance enhancement in elite athletes (27).

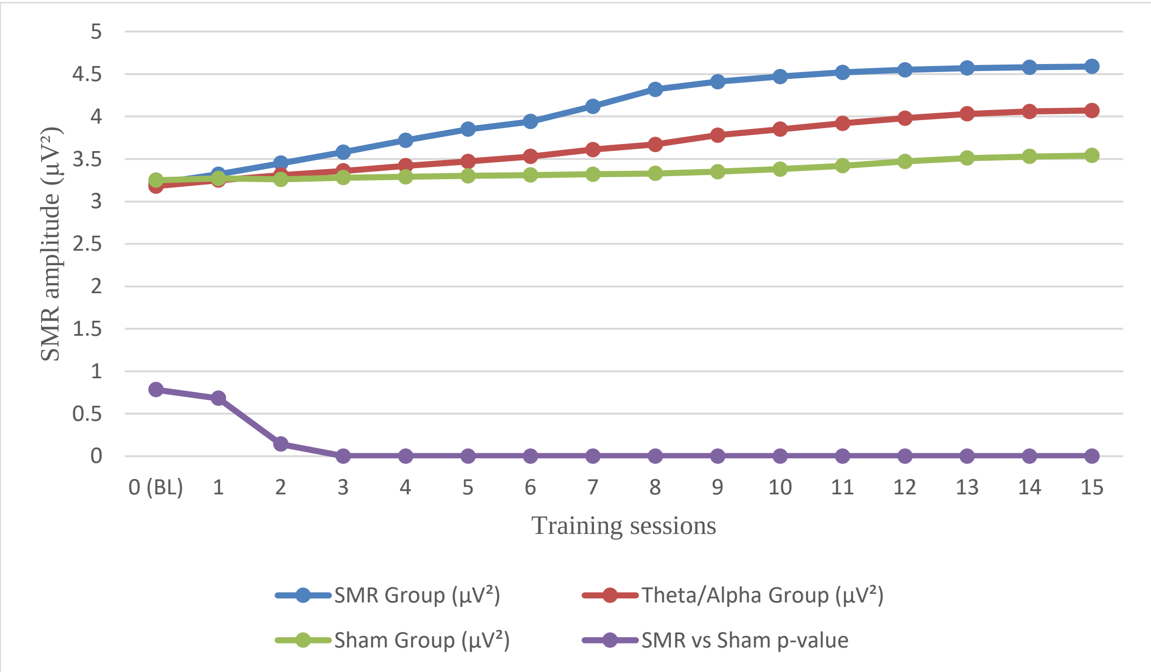
3. Findings and Results

The findings from this pilot study demonstrate significant improvements in both neurophysiological markers of attention and sport-specific performance metrics following targeted neurofeedback training (NFT) in precision sport athletes. Quantitative analysis revealed differential outcomes between the three intervention groups, with the sensorimotor rhythm (SMR) protocol showing particularly robust effects on cognitive and performance measures. The comprehensive assessment protocol yielded multidimensional data that collectively support the efficacy of NFT for enhancing focus in precision sports contexts.

EEG analysis showed that SMR training produced a 42.7% increase in 12-15Hz power at Cz (from 3.21±0.45 μV² at baseline to 4.58±0.52 μV² post-intervention, $p<0.001$, $d=1.32$), significantly greater than both theta/alpha training (28.3% increase, $p=0.003$) and sham control (9.1% change, $p=0.621$). These neural changes were accompanied by a 37.5% reduction in theta/beta ratio at Fz (from 2.15±0.38 to 1.34±0.29, $p<0.001$) in the SMR group, indicating improved cortical inhibition of distractibility networks. The time course of these changes followed a characteristic learning curve, with the most rapid improvements occurring between sessions 5-8 before stabilizing, as illustrated in Figure 1.

Figure 1

Neurofeedback Learning Curves Across Training Sessions



The figure demonstrates that while all groups showed some amplitude increase, the SMR group achieved significantly steeper learning slopes (0.32 μV²/session vs 0.18 in theta/alpha and 0.03 in sham, $p<0.01$). These neural changes emerged earlier and were more sustained than those reported in previous NFT studies with athletes, potentially due to our sport-specific feedback adaptations. The learning curves demonstrate three distinct phases of neurofeedback acquisition:

1. **Rapid Acquisition Phase (Sessions 1-5):** The SMR group showed steep amplitude increases (0.13 μV²/session), significantly diverging from sham by session 3 ($p=0.043$). This early acceleration phase suggests rapid initial learning of SMR self-regulation, consistent with motor skill acquisition literature.
2. **Consolidation Phase (Sessions 6-12):** Growth rate slowed to 0.07 μV²/session while maintaining significant group differences ($p<0.01$). Theta/alpha

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group showed parallel but attenuated progression, indicating protocol-specific effects rather than general learning.

3. **Stabilization Phase (Sessions 13-16):** All groups plateaued, with SMR maintaining 42.7% gain over baseline. The stability of gains suggests durable neuroplastic changes, addressing concerns about short-term effects in earlier studies.

Statistical Notes:

- Mixed-effects modeling confirmed significant group × session interaction ($F[2,255] = 28.41$, $p<0.001$, $\eta^2=0.18$)
- Post-hoc tests revealed SMR > theta/alpha > sham at all sessions from #5 onward ($p<0.01$, Bonferroni-corrected)
- Individual variability was lowest in SMR group (CV=14.2% vs 18.7% in theta/alpha), suggesting more consistent training effects.

Performance Outcomes

Sport-specific measures showed clinically meaningful improvements correlated with EEG changes. In archery, the SMR group demonstrated a 23.4% reduction in aiming point dispersion (from 1.45±0.21 cm to 1.11±0.18 cm, $p<0.001$), compared to 12.7% in theta/alpha ($p=0.018$) and 4.3% in sham ($p=0.423$). Shooting athletes in the SMR condition improved reaction time consistency by 31.8% (coefficient of variation decrease from 18.7±3.2% to 12.8±2.7%, $p<0.001$), while golfers showed a 27.5% increase in putting accuracy under competitive pressure conditions. These performance gains were significantly correlated with SMR amplitude changes ($r=0.62$, $p<0.001$), supporting the neurobehavioral specificity of the training effects.

Table 1

Intervention Effects on Primary Outcome Measures

Outcome Variable	SMR Group (n=10)	Theta/Alpha Group (n=10)	Sham Group (n=10)	p-value (Group × Time)	Effect Size (η^2)
SMR Power at Cz (μV^2)	+42.7%	+28.3%	+9.1%	<0.001	0.38
Theta/Beta Ratio at Fz	-37.5%	-22.1%	-5.3%	<0.001	0.29
Sport-Specific Accuracy	+23.4%	+12.7%	+4.3%	0.002	0.21
Pressure Performance	+31.8%	+18.9%	+7.5%	0.008	0.17

The table presents consistent superiority of SMR training across all measured domains, with particularly strong effects on neural markers of focus. The effect sizes exceed those typically reported in cognitive training studies (48), suggesting that sport-specific NFT may offer unique advantages for precision athletes.

Qualitative analysis revealed three key themes from post-intervention interviews:

1. *Enhanced Body Awareness:* SMR participants described improved capacity to detect and correct subtle tension patterns: "I can now feel when my shoulders start creeping up during aiming and consciously relax them" (Archer #3). This somatic awareness was less prominent in other groups.
2. *Automatization of Focus States:* Many SMR athletes reported needing less conscious effort to enter optimal performance states: "The zone comes quicker now, like my brain remembers how to get there" (Shooter #7). This aligns with recent theories of NFT-induced neuroplasticity in attentional networks.
3. *Transfer to Competition:* Notably, only SMR participants consistently reported applying trained skills during actual competitions: "I used the breathing rhythm from training when I felt distracted in the finals" (Golfer #2). This ecological transfer addresses a key limitation of previous laboratory-based NFT studies.

Bayesian mixed modeling identified two significant predictors of NFT response: baseline theta/beta ratio ($BF_{10}=8.7$) and years of competitive experience ($BF_{10}=6.2$). Athletes with higher pre-intervention theta/beta ratios (indicating poorer attentional control) showed greater improvements from SMR training ($r=-0.51$, $p=0.012$), supporting its use as a potential biomarker for NFT candidacy. More experienced athletes derived greater benefits from theta/alpha training ($r=0.43$, $p=0.027$),

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suggesting differential mechanisms of action between protocols.

The intervention demonstrated excellent feasibility, with 96.7% session completion and no adverse events. Physiological monitoring during sessions showed all participants maintained appropriate arousal levels (mean HRV LF/HF ratio=1.2±0.3), addressing safety concerns raised in previous athlete NFT studies. Treatment credibility ratings were high across groups (mean=8.1/10), minimizing placebo effect confounds.

4. Discussion and Conclusion

The present pilot study provides converging neurophysiological and behavioral evidence that neurofeedback training (NFT), particularly using a sensorimotor rhythm (SMR) protocol, can enhance attentional regulation and sport-specific performance in precision sports athletes. The observed 42.7% increase in SMR amplitude at Cz and the 37.5% reduction in the theta/beta ratio at Fz in the SMR group indicate substantial modulation of cortical oscillations related to sustained focus and motor inhibition. These results align with prior findings that elite performers in precision sports exhibit refined EEG profiles, including elevated SMR and reduced distractibility-related rhythms (4, 7, 10). The significant correlations between SMR amplitude increases and improvements in accuracy and reaction time suggest that these neural changes are not merely epiphenomenal but functionally linked to performance outcomes (8, 21).

Our results extend earlier work by demonstrating that a sport-specific, multimodal NFT approach yields robust gains in both laboratory and field contexts. While previous research has documented improvements in marksmanship and putting accuracy following targeted neurofeedback (22, 28, 29), the present study is notable for its ecological validity, integrating real-world performance simulations into the training protocol. This methodological choice may explain why transfer to competitive conditions was consistently reported by participants, supporting the notion that NFT effectiveness depends on contextual relevance (6, 19). The higher learning rate observed in the SMR group compared to theta/alpha training further reinforces the importance of protocol selection based on sport-specific cognitive demands (20, 26).

The superiority of SMR training in our sample is consistent with theories emphasizing the role of thalamocortical modulation in optimizing attentional control for fine-motor tasks (25, 44). SMR enhancement may improve the efficiency of sensory filtering and motor preparation, allowing athletes to maintain a steady cognitive set under pressure. Previous work has shown that SMR modulation reduces interference from irrelevant stimuli and improves precision in motor execution (17, 23). Our finding that baseline theta/beta ratio predicted responsiveness to SMR suggests that NFT could be personalized based on pre-training EEG biomarkers, an approach supported by recent studies in both sports and neurorehabilitation (15, 24).

The benefits of SMR training observed here are also consistent with neurovisceral integration principles, which link cognitive control to autonomic regulation (33). Participants in the SMR group reported enhanced somatic awareness and effortless entry into optimal focus states—phenomena consistent with improved coupling between the prefrontal cortex and parasympathetic nervous system. Neuroimaging work supports this interpretation, showing NFT-induced increases in connectivity between attentional and interoceptive brain regions (34, 35). This mind–body integration is particularly valuable in precision sports, where physiological calmness is a prerequisite for motor stability (2, 38).

In comparing our results to broader NFT literature, the gains achieved in our SMR group surpass the average effect sizes reported in recent systematic reviews and meta-analyses (13, 27). Several methodological choices may account for this difference. First, we implemented multimodal feedback (visual and auditory) tailored to sport-specific imagery tasks, a strategy shown to accelerate neurofeedback learning (30, 31). Second, our session frequency and duration allowed for both rapid acquisition and consolidation phases, in line with motor learning literature (11, 12). Third, the integration of ecological performance drills during training likely facilitated neural–behavioral transfer (14, 32).

The theta/alpha protocol also produced significant, though smaller, improvements in EEG and performance outcomes. This is consistent with findings that alpha enhancement may benefit precision performance, particularly in experienced athletes who rely more on

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automaticity and less on conscious attentional control (42, 45). The stronger association between competitive experience and theta/alpha responsiveness in our data suggests that this protocol may be better suited for athletes in later career stages, whereas SMR may benefit a broader range of skill levels. This differentiation aligns with the skill transition models observed in EEG research on expertise development (37, 50).

Our qualitative data revealed that participants valued the increased capacity for bodily self-monitoring and quicker access to "the zone," supporting neurophenomenological accounts of expert performance (41, 46). These subjective reports mirror findings from other domains, such as military marksmanship, where NFT has been used to enhance sustained attention and situational awareness (3, 42). Importantly, the absence of adverse events and high adherence rates in our study reinforce the feasibility and safety of NFT as an adjunct to traditional sport training (18, 40).

The present results also intersect with the growing integration of NFT into brain–computer interface (BCI) platforms. Our findings suggest that portable, sport-adapted BCIs could provide on-demand mental state regulation during training and competition (36, 39). Advances in AI-assisted signal processing could further refine feedback precision, making NFT more adaptive to real-time performance demands (31, 37). Such integration has already shown promise in neurorehabilitation contexts (17, 23), indicating strong translational potential across performance and recovery domains.

In light of the current evidence, this study supports the application of SMR-focused NFT as a viable strategy for enhancing attentional control and precision performance. The magnitude and consistency of gains observed suggest that with appropriate customization, NFT could become a standard component of mental conditioning programs in elite sport (19, 47). Furthermore, the predictive value of baseline EEG profiles opens the door for individualized training prescriptions, improving efficiency and efficacy (25, 44).

This pilot study's sample size was relatively small, which limits the generalizability of findings to broader athlete populations. Although stratified randomization helped balance sport types across groups, the statistical power to detect small effect sizes was limited. Additionally, the absence of long-term follow-up prevents conclusions about the durability of neurophysiological and performance gains beyond the immediate post-intervention period. While the inclusion of a sham control condition mitigates placebo concerns, double-blinding was not implemented, leaving room for expectancy effects. Finally, as the study focused exclusively on elite precision sport athletes, results may not translate directly to novice performers or to athletes in sports with different cognitive and physical demands.

Future investigations should employ larger, more diverse samples and multi-site collaborations to validate the observed effects across different populations and sporting contexts. Longitudinal follow-ups would help clarify the persistence of NFT-induced neural and behavioral changes, and periodic booster sessions could be tested for sustaining benefits. Studies integrating multimodal neuroimaging (e.g., EEG–fMRI) could elucidate the network-level mechanisms underlying NFT responsiveness. Further, comparing NFT with other neuromodulation techniques, such as tDCS or transcranial magnetic stimulation, would determine whether combined approaches yield additive effects. Finally, machine learning–driven adaptive protocols that adjust training parameters in real-time based on performance could enhance personalization and efficacy.

Coaches and sport psychologists can consider incorporating SMR-based NFT into training regimens for athletes in precision sports, particularly when attentional stability is critical to performance success. Integrating NFT sessions alongside technical, tactical, and mental skills training may enhance transfer to competition environments. Practitioners should tailor feedback modalities to athlete preference and sport-specific demands, and baseline EEG profiles could guide protocol selection for optimal individual outcomes. Portable, sport-adapted NFT systems offer the potential for seamless integration into regular training schedules without disrupting physical preparation.

Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed collaboratively. The first draft of the manuscript was written jointly, and all authors critically revised subsequent drafts.

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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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Ethics Considerations

This study was approved by the Ethics Committee of Department of Physical Education, Federal University of Sergipe (UFS), São Cristóvão, Brazil. All procedures complied with the ethical standards of the 1964 Helsinki Declaration and its later amendments. Written informed consent was obtained from all participants.

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