FOCUS 946: Training Executive Areas BA9–10–46 to Enhance Decision-Making Speed and Cognitive Inhibition in Elite Sport through Personalized EEG Neurofeedback

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Abstract

Elite sport performance increasingly depends on neurocognitive efficiency, particularly in positions requiring rapid tactical decisions under pressure. The FOCUS 946 study investigated the effects of a personalized EEG neurofeedback protocol targeting prefrontal executive regions (Brodmann areas 9, 10, and 46) on attentional control, cognitive inhibition, and decision-making speed in elite athletes. In a randomized controlled longitudinal design, 40 professional athletes were assigned to either an experimental group receiving 24 sessions of targeted neurofeedback over 8 weeks or a control group undergoing structured relaxation without EEG modulation. Outcomes were assessed at baseline (T0), mid-intervention (T1), and post-intervention (T2) using quantitative EEG (qEEG), computerized Go/No-Go tasks, tactical decision simulations, and subjective clarity scales. Results demonstrated significant improvements in the experimental group compared to controls. Prefrontal EEG coherence (BA9–10–46) increased by 12.42%, Go reaction times decreased by 40.66 ms without loss of accuracy, and No-Go commission errors were reduced by 5.50 on average. Decision consistency improved by 13.37%, accompanied by marked increases in perceived decision clarity. These findings indicate enhanced synchronization within the Executive Control Network and improved inhibitory precision mediated by BA46 engagement. The study provides empirical support for the trainability of executive neural networks in elite athletes and demonstrates that targeted EEG neurofeedback can produce measurable neurophysiological and behavioral benefits. Personalized neurocognitive training may therefore represent a scalable and strategically valuable tool for optimizing performance under competitive pressure.

Keywords: *EEG neurofeedback; executive control network; cognitive inhibition; decision-making speed; elite athletes; prefrontal cortex; performance optimization.*

1. Introduction

In contemporary professional sport, performance is no longer defined exclusively by physical conditioning, technical proficiency, or tactical knowledge. At the elite level, marginal gains determine outcomes, and these gains increasingly depend on neurocognitive efficiency. In team sports and in positions characterized by high tactical density, such as goalkeepers, central defenders, and playmakers, the difference between success and failure often emerges within milliseconds. A brief hesitation, a delayed inhibitory response, or a prematurely executed motor action can decisively alter the trajectory of a match. These critical moments are governed not merely by reflexes, but by the integrity and efficiency of higher-order executive functions.

Two neurocognitive mechanisms are particularly central in this context: directed attentional control and cognitive inhibition. Directed attentional control refers to the capacity to rapidly select and maintain focus on task-relevant stimuli amid a dynamically changing and often noisy environment. Cognitive

inhibition, in contrast, reflects the ability to suppress automatic, prepotent, or contextually inappropriate responses in favor of more adaptive actions. Together, these functions enable athletes to balance speed with precision, ensuring that rapid decisions remain contextually accurate rather than impulsive.

From a neurobiological perspective, these executive processes are primarily supported by the dorsolateral and anterior prefrontal cortices. Converging evidence from cognitive neuroscience demonstrates that the dorsolateral prefrontal cortex (DLPFC; Brodmann areas 9 and 46) plays a fundamental role in working memory maintenance, attentional stability, and flexible rule application (D'Esposito et al., 1995). Brodmann area 10, corresponding to the anterior prefrontal or frontopolar cortex, has been associated with strategic monitoring, integration of multiple decision alternatives, and prospective evaluation of action consequences (Koechlin & Hyafil, 2007). These regions operate as nodes within broader large-scale networks, most notably the Executive Control Network (ECN) and the dorsal fronto-parietal network (dFPN).

The ECN, encompassing prefrontal and parietal regions, is consistently activated during cognitively demanding tasks requiring sustained attention, conflict resolution, and inhibition of habitual responses (Seeley et al., 2007). Efficient ECN functioning is critical in high-pressure environments, where athletes must process ambiguous stimuli and select appropriate responses without succumbing to stress-induced cognitive narrowing. Functional weakening or dysregulation within this network has been linked to delayed decisions, increased variability in performance, and higher susceptibility to errors under pressure.

Similarly, the dorsal fronto-parietal network plays a central role in top-down attentional orientation and in the integration of spatial-temporal information (Corbetta & Shulman, 2002). In goalkeepers, for example, rapid interpretation of an opponent's body posture, ball trajectory, and contextual positioning depends on seamless communication between prefrontal executive regions and parietal spatial-processing areas. The capacity to inhibit a premature dive, to recalibrate positioning within milliseconds, or to delay commitment until sufficient perceptual evidence is available reflects optimal coordination within this network.

Elite sport environments impose sustained demands on these systems. Athletes frequently experience decisional overload, particularly in roles requiring continuous tactical scanning and rapid distribution of play. Additionally, cumulative cognitive fatigue, common during congested competition schedules, may compromise executive control and inhibitory precision. Research on mental fatigue demonstrates that prolonged cognitive effort impairs inhibitory control and increases reaction time variability, even when physical capacity remains intact (Boksem et al., 2005). Importantly, performance decrements under mental fatigue conditions have been documented in soccer and other team sports, affecting both decision quality and technical execution.

Traditional mental preparation methods, such as visualization, motivational coaching, and standardized cognitive drills, offer valuable psychological support. However, these approaches do not directly target the measurable neurophysiological substrates of executive control. They typically operate at the phenomenological level (thoughts, imagery, emotions) rather than at the level of real-time cortical activation and network synchronization. Consequently, while beneficial, they may not sufficiently recalibrate dysfunctional activation patterns within prefrontal circuits responsible for decision speed and inhibition.

Neurofeedback represents a promising alternative, grounded in principles of operant conditioning and neuroplasticity. By providing individuals with real-time feedback about their own brain activity, neurofeedback enables voluntary modulation of specific oscillatory patterns. Research has shown that training in sensorimotor rhythm (SMR) and alpha frequency bands can enhance attentional control and reduce impulsivity (Gruzelier, 2014; Hammond, 2011). Furthermore, targeted neurofeedback interventions

focusing on prefrontal regions have been associated with improved inhibitory control and executive performance (Enriquez-Geppert et al., 2017). In sport-specific contexts, preliminary evidence suggests that EEG-based training can enhance cognitive flexibility, emotional regulation, and performance consistency under stress (Vernon et al., 2009).

The Go/No-Go paradigm provides a robust and widely validated measure of cognitive inhibition and controlled response execution. Originally conceptualized within the framework of response inhibition theory (Logan et al., 1984), this task requires rapid discrimination between action (Go) and inhibition (No-Go) stimuli. Neuroimaging studies have consistently implicated the right inferior and dorsolateral prefrontal cortex, particularly BA46, in successful response suppression (Aron et al., 2004; Huster et al., 2013). Elevated error rates in No-Go trials reflect diminished inhibitory control, while excessively slow reaction times in Go trials may indicate overcautious or inefficient decision processing.

In elite sport, suboptimal inhibitory control manifests as premature actions, mistimed interceptions, or delayed passes. Under high emotional and environmental pressure, athletes with weaker prefrontal inhibitory regulation may exhibit increased impulsivity or hesitation. Importantly, Beilock and Carr (2001) demonstrated that performance pressure can disrupt well-learned motor skills, particularly when cognitive control systems become overloaded. Enhancing the stability and efficiency of executive networks may therefore protect performance in precisely those moments where it is most vulnerable.

The FOCUS 946 study emerges from this theoretical and empirical framework. It is designed to address a critical gap in performance training: the absence of standardized, neurophysiologically grounded interventions targeting executive and inhibitory systems in elite athletes. By combining quantitative EEG (qEEG) mapping, personalized neurofeedback protocols targeting BA9, BA10, and BA46, and behavioral validation through Go/No-Go and tactical decision tasks, the study aims to establish a direct link between cortical regulation, decision-making speed, and motor execution accuracy.

In essence, FOCUS 946 conceptualizes elite performance not solely as a product of muscular power or tactical knowledge, but as the outcome of finely tuned neural networks. In a competitive landscape where matches are decided within fractions of a second, the optimization of executive control and cognitive inhibition may represent the decisive frontier of modern sports science.

2. Objectives of the Study

The clinical study FOCUS 946 is grounded in the premise that the functional efficiency of prefrontal executive and inhibitory networks directly determines the quality, speed, and stability of tactical decision-making in elite sport. While the introduction established the neurobiological rationale for targeting Brodmann areas 9, 10, and 46 within the Executive Control Network (ECN) and the dorsal fronto-parietal network (dFPN), the present section delineates the operational objectives of the intervention. These objectives are formulated in measurable neurophysiological and behavioral terms, allowing for rigorous evaluation of the protocol's efficacy.

2.1 General Objective

The primary objective of the FOCUS 946 study is to evaluate the effectiveness of a personalized EEG neurofeedback protocol targeting prefrontal areas BA9, BA10, and BA46 in improving attentional control, optimizing cognitive inhibition, and reducing timing errors in high-demand tactical situations among elite athletes.

More specifically, the study aims to determine whether the intervention produces measurable changes at three interrelated levels:

1. Neurophysiological (qEEG activation and coherence);
2. Behavioral (performance in Go/No-Go and simulated decision tasks);
3. Sport-specific (decision consistency and observable timing precision under competitive conditions).

2.2 Specific Objectives

1. **Enhancement of Functional Activation in Prefrontal Regions (BA9, BA10, BA46)**
   To increase adaptive oscillatory activity (Alpha and SMR bands) and reduce maladaptive hyperactivation in High Beta within targeted prefrontal regions, thereby improving attentional stability (BA9), strategic integration and anticipation (BA10), and inhibitory control (BA46), consistent with prior findings on executive neuroregulation (D'Esposito et al., 1995; Koechlin & Hyafil, 2007; Aron et al., 2004).
2. **Improvement of Cognitive Inhibition and Controlled Response Speed (Go/No-Go Performance)**
   To reduce commission errors in No-Go trials, reflecting enhanced inhibitory control, and to decrease reaction times in Go trials without compromising accuracy. These changes are expected to correspond with improved functional engagement of BA46 and the broader executive control circuitry (Huster et al., 2013).
3. **Reduction of Timing Errors in Tactical Execution Under Pressure**
   To decrease the latency between stimulus perception and motor response in simulated and real-game scenarios, minimizing premature or delayed actions. This objective targets the recalibration of the decision–execution interface under high cognitive load, as described in performance-pressure literature (Beilock & Carr, 2001).
4. **Increase in Functional EEG Coherence Between Prefrontal and Parietal Regions**
   To enhance synchronization between BA9–10–46 and parietal areas (e.g., BA7/40), thereby supporting more efficient spatial-temporal integration and attentional orientation within the dorsal fronto-parietal network (Corbetta & Shulman, 2002).
5. **Strengthening of Decision Consistency and Cognitive Stability Over Time**
   To reduce intra-individual variability in reaction times and tactical choices, indicating maturation and stabilization of executive processing across repeated high-demand trials.
6. **Exploratory Assessment of Indirect Emotional Inhibition Effects**
   To examine whether improvements in prefrontal inhibitory control are associated with enhanced subjective decision clarity and reduced emotional reactivity under competitive stress, given the documented relationship between prefrontal regulation and affective control (Etkin et al., 2011).

Collectively, these objectives extend beyond generalized executive enhancement. They aim to reconstruct and refine the neural architecture that governs decision-making under pressure, ensuring that increases in speed do not compromise precision, and that inhibitory control functions as a stabilizing mechanism rather than a performance constraint.

3. Study Design

The FOCUS 946 study was designed to allow rigorous scientific evaluation of a targeted neuroregulatory intervention applied to elite athletes, with the aim of improving attentional control, cognitive inhibition, and decision-making speed in high-pressure competitive contexts. The methodological architecture balances three core requirements: strong internal validity through controlled comparison, ecological validity through implementation in real performance environments, and practical reproducibility for integration within professional sports infrastructures.

3.1 Type of Study and Scientific Justification

FOCUS 946 is a randomized, controlled, longitudinal clinical study with two parallel arms:

- **Experimental group**: athletes participating in the personalized EEG neurofeedback protocol;
- **Control group**: athletes following the same competitive schedule and evaluation procedures, without active neurophysiological intervention.

This structure allows for both within-subject (pre–post) and between-group comparisons, enabling isolation of the specific contribution of the EEG intervention. Randomization controls for baseline variability in cognitive performance, playing position, and sport type, while the control arm reduces the likelihood that observed improvements are attributable solely to learning effects, seasonal adaptation, or expectancy influences.

The design is aligned with CONSORT principles for clinical trials (Schulz et al., 2010), adapted to the specific operational realities of elite sport. By embedding the protocol within ongoing training cycles rather than laboratory-only settings, the study preserves ecological validity while maintaining methodological rigor.

3.2 Duration of the Intervention and Neuroplastic Window

The intervention spans **8 weeks**, with:

- 3 EEG training sessions per week
- A total of 24 sessions per participant

This duration was selected based on evidence indicating that stable neuroplastic changes induced by neurofeedback typically emerge within a 6–10 week window (Ros et al., 2014; Enriquez-Geppert et al., 2017). The frequency was calibrated to optimize cortical adaptation while avoiding interference with physical training loads or inducing cognitive fatigue.

Evaluations were conducted at three standardized time points:

- **T0** – Baseline (week 0)
- **T1** – Midpoint evaluation (week 4)
- **T2** – Final evaluation (week 8)

This longitudinal structure permits tracking of progression trajectories rather than relying solely on endpoint comparisons.

3.3 Participant Selection and Eligibility Criteria

A minimum of **40 elite athletes** were enrolled, divided equally between experimental and control groups (n = 20 per arm). Participants were recruited from national-level clubs in football, handball, and basketball. Targeted performance profiles included:

- Goalkeepers and central defenders (anticipatory decision-making demands)
- Playmakers and coordinators (rapid distribution and inhibition under pressure)
- Transition players (offensive–defensive adaptation requiring high-speed recalibration)

Inclusion criteria:

- Age between 18 and 35 years
- Active competitive status

- Minimum of three official matches per month
- No diagnosed neurological or psychiatric disorders

Exclusion criteria:

- Use of psychostimulant substances
- Concurrent participation in other EEG-based or intensive mindfulness interventions
- History of epilepsy or recent traumatic brain injury
- Randomization was computerized and stratified according to:
- Sport type
- Tactical decision profile
- Baseline Go/No-Go performance
- This stratification ensured balanced distribution of cognitive load profiles across groups.

3.4 Structure of the Experimental Intervention

Each EEG session lasted **50 minutes** and followed a standardized structure:

Sequence	Duration	Objective
Rapid EEG mapping	5 min	Confirmation of daily activation profile
Personalized neurofeedback	30 min	Targeted BA9/10/46 training
Go/No-Go correlated feedback	10 min	Real-time reinforcement of inhibitory control
Alpha–SMR binaural cooldown	5 min	Post-training stabilization

All protocols were calibrated based on:

- Baseline EEG parameters (coherence, spectral power, frontal asymmetry)
- Individual Go/No-Go scores
- Tactical cognitive demands specific to playing position

Visual and auditory feedback were adapted dynamically according to threshold performance in each targeted region. This ensured that training remained responsive to daily neurophysiological fluctuations related to sleep, fatigue, or competitive stress.

3.5 Control Group and Placebo Structure

To ensure methodological rigor and to isolate the specific contribution of the personalized EEG neurofeedback intervention, a structurally equivalent control condition was implemented. Athletes allocated to the control group continued their regular competitive and training schedules and underwent the same assessment protocol at T0, T1, and T2 as the experimental group. However, they did not receive active neurofeedback or real-time modulation of cortical activity. Instead, control participants attended structured guided relaxation sessions matched in duration and frequency to the neurofeedback training. These sessions were designed to control for nonspecific factors such as therapist interaction, structured cognitive time, expectation of improvement, and perceived investment in performance enhancement. No EEG feedback was provided, and no thresholds or operant conditioning mechanisms were introduced. Although relaxation may produce short-term reductions in arousal, it does not selectively target oscillatory activity in BA9, BA10, or BA46, nor does it aim to recalibrate executive network coherence. This design element was essential for minimizing expectancy bias and the Hawthorne effect, namely, behavioral changes resulting simply from being observed or participating in an intervention. By ensuring that both groups received equal attention and comparable time allocation within a structured performance-enhancement context, the study strengthened its capacity to attribute observed neurophysiological and behavioral changes specifically to the EEG-based protocol rather than to general psychological engagement.

3.6 Location, Equipment, and Professional Oversight

All interventions were conducted in certified EEG clinical facilities equipped to support high-resolution neurophysiological assessment and real-time neurofeedback implementation. A 19-channel quantitative EEG (qEEG) system, based on the international 10–20 electrode placement standard, was used to ensure reliable cortical mapping of prefrontal and parietal regions. The neurofeedback software allowed for region-specific threshold calibration and dynamic adjustment of oscillatory targets across sessions. In addition, professional-grade binaural auditory stimulation systems were employed during the post-training stabilization phase to consolidate adaptive frequency patterns.

The intervention was supervised by a multidisciplinary team composed of licensed psychologists specialized in neurofeedback and sport-related cognitive training, collaborating physicians providing medical oversight, and certified EEG technicians responsible for data acquisition and signal quality control. This integrated structure ensured both clinical safety and methodological precision throughout the intervention period.

All neurophysiological and behavioral data were pseudonymized at the point of collection and stored on secure digital platforms in compliance with GDPR (EU Regulation 2016/679). Regular internal audits were conducted to verify adherence to procedural standards, electrode placement consistency, signal integrity, and protocol fidelity across sessions.

3.7 Evaluations and Methodological Fidelity

At T0, T1, and T2, participants underwent:

- Full qEEG assessment (spectral power, coherence, frontal asymmetry in BA9–10–46)
- Computerized Go/No-Go testing (reaction time, commission and omission errors)
- Subjective scales of decision clarity and perceived cognitive control
- Tactical simulation performance scoring

All sessions were implemented according to a standardized internal protocol, and procedural fidelity was monitored throughout the intervention period to ensure consistency across participants and evaluators. The FOCUS 946 design enables precise quantification of how targeted EEG neurofeedback influences executive activation, inhibitory regulation, and decision-making speed. By integrating randomized control, longitudinal tracking, neurophysiological monitoring, and ecologically valid performance measures, the study establishes a methodological framework capable of bridging laboratory neuroscience and elite sports performance.

The structure was conceived not only to meet publication standards, but to generate a reproducible and scalable model for neurocognitive optimization within professional athletic training systems.

4. Structure of the Personalized EEG Intervention

The intervention implemented in the FOCUS 946 study was designed as a structured yet highly individualized neuroregulatory protocol. Rather than applying a standardized, one-size-fits-all model, the training was calibrated to each athlete’s neurophysiological profile, cognitive performance metrics, and tactical role within the team. This personalization was grounded in initial quantitative EEG (qEEG) mapping of Brodmann areas 9, 10, and 46, as well as baseline performance in Go/No-Go tasks and position-specific decision demands.

Across the 8-week intervention, each participant completed 24 sessions (three per week), each lasting approximately 50 minutes. The structure of every session followed a consistent sequence to ensure methodological fidelity while allowing for adaptive threshold modulation.

Rapid EEG Re-Mapping (5 minutes)

Each session began with a brief EEG recording conducted in a resting state (eyes open). This short re-mapping phase allowed verification of the athlete's cortical activation profile on that specific day. Because neural activity is sensitive to sleep quality, recent physical exertion, emotional stress, and match exposure, this preliminary step ensured that the subsequent neurofeedback thresholds were precisely adjusted. By recalibrating training parameters session-by-session, the protocol maximized context-sensitive neuroplasticity and minimized the risk of overstimulation or undertraining.

Targeted Neurofeedback Training (30 minutes)

The core of the intervention consisted of real-time neurofeedback focused on BA9, BA10, and BA46. Training parameters were selected to reduce maladaptive high beta hyperactivation, often associated with cognitive rigidity, hypervigilance, or performance pressure, and to enhance adaptive alpha and sensorimotor rhythm (SMR) oscillations that support stable attention and inhibitory control (Hammond, 2011; Gruzelier, 2014).

Specifically:

- BA9 training emphasized increased alpha/SMR activity to promote sustained attentional focus and cognitive flexibility.
- BA10 modulation targeted alpha–theta balance to support anticipatory integration and strategic foresight.
- BA46 regulation focused on SMR/low beta enhancement to strengthen executive inhibition and real-time behavioral adjustment (Enriquez-Geppert et al., 2017).

Feedback was delivered through synchronized visual animations and auditory signals contingent upon the athlete maintaining predefined EEG thresholds. This operant conditioning framework reinforced adaptive cortical states associated with controlled, rapid decision-making.

Integration with Go/No-Go Tasks (10 minutes)

To ensure that neural changes translated into functional decision-making improvements, each session incorporated a brief computerized Go/No-Go task synchronized with live EEG monitoring. This stage operationalized inhibitory control in a dynamic context, enabling direct correlation between BA46 activation patterns and behavioral performance metrics such as reaction time and commission errors. This integration phase distinguished the intervention from passive neurofeedback paradigms by embedding cortical regulation within a decision-relevant framework. The athlete did not merely modulate brain rhythms in abstraction; rather, neural adaptation was immediately linked to response inhibition and controlled execution, reinforcing transferability to competitive scenarios (Huster et al., 2013).

Binaural Alpha–SMR Stabilization (5 minutes)

Each session concluded with a short binaural auditory stimulation protocol within the alpha–SMR range (approximately 10–14 Hz). The objective was to stabilize the trained oscillatory state, consolidate learning effects, and reduce post-training cortical excitability. This phase supported a state of "calm activation", a neurophysiological condition characterized by focused readiness without excessive arousal (Orozco Perez et al., 2020).

Personalization and Monitoring

Throughout the 24-session program, individual progress was tracked using session-by-session metrics, including time spent within target thresholds, fluctuations in inter-regional coherence, and daily Go/No-Go performance. Parameter adjustments were implemented when plateaus or atypical activation patterns were detected. This iterative refinement ensured that the intervention remained responsive to the athlete's evolving neurocognitive state.

Overall, the structure of the FOCUS 946 intervention reflects a deliberate synthesis of localized cortical modulation, network-level synchronization, behavioral integration, and post-training stabilization. It is not merely a technological sequence, but a strategically organized neurocognitive training model aimed at recalibrating the executive systems that govern speed, inhibition, and tactical clarity in elite sport.

5. Results

The results of the FOCUS 946 study indicate statistically and functionally meaningful improvements across neurophysiological, behavioral, and subjective measures in the experimental group compared to controls. These changes reflect a coherent pattern of executive network optimization rather than isolated performance fluctuations.

Table 1. Mean Changes from Baseline (T2 – T0) in Experimental and Control Groups

Evaluated Parameter	Experimental Group (Mean ± SD)	Control Group (Mean ± SD)
Δ EEG Coherence BA9–10–46 (%)	+12.42 (±2.31)	+3.34 (±1.63)
Δ Go Reaction Time (ms)	–40.66 (±8.12)	–6.14 (±6.73)
Δ No-Go Errors (number)	–5.50 (±1.56)	–0.95 (±1.09)
Δ Decision Consistency (%)	+13.37 (±4.25)	+2.51 (±2.89)
Δ Decision Clarity (1–7 scale)	+2.11 (±0.40)	+0.48 (±0.62)

EEG Coherence in Prefrontal Executive Regions

The experimental group demonstrated a mean increase of +12.42% in EEG coherence across BA9, BA10, and BA46, compared to a modest +3.34% increase in the control group. This enhancement in functional connectivity suggests improved synchronization within the prefrontal executive circuitry and between executive and parietal nodes. Coherence reflects the degree of phase consistency between cortical regions and is widely interpreted as an index of functional integration (Thatcher, 2012). Increased coherence within the Executive Control Network (ECN) has been associated with more efficient information transfer and reduced neural noise during cognitively demanding tasks (Seeley et al., 2007). In the context of elite sport, this likely translates into faster and more stable integration of perceptual input with motor planning.

These findings align with prior neurofeedback research demonstrating that targeted modulation of prefrontal oscillations can increase network synchronization and improve executive task performance (Ros et al., 2014; Enriquez-Geppert et al., 2017). The magnitude of change observed in the experimental group suggests not merely short-term state shifts, but structural reinforcement of coordinated executive processing.

Reduction in Go Reaction Time

Reaction times in Go trials decreased by an average of 40.66 ms in the experimental group, compared to only 6.14 ms in controls. Importantly, this acceleration occurred without a concomitant rise in error rates, indicating that speed gains did not come at the expense of accuracy. From a neurocognitive standpoint,

reaction time reductions likely reflect improved efficiency in stimulus discrimination and motor response selection mediated by BA9 and BA10 engagement (D'Esposito et al., 1995; Koechlin & Hyafil, 2007). Faster reaction times in well-trained individuals are often linked to more streamlined cortical processing pathways and reduced unnecessary activation in competing networks.

In applied sport contexts, a 40 ms reduction may appear numerically small but functionally decisive. In fast-paced team sports, perceptual–motor decisions frequently unfold within windows under 300 ms. Even modest latency reductions can determine interception success, shot blocking, or passing accuracy. The observed improvement is therefore operationally meaningful.

Reduction in No-Go Errors (Inhibitory Control)

The experimental group exhibited a mean reduction of 5.50 commission errors in No-Go trials, compared to less than one error reduction in the control group. Commission errors are a direct behavioral marker of inhibitory failure. Neuroimaging literature consistently implicates BA46 and adjacent dorsolateral prefrontal regions in successful response suppression (Aron et al., 2004; Huster et al., 2013). Enhanced performance in No-Go trials suggests strengthened activation and timing precision within these inhibitory circuits.

In elite sport, deficient inhibition manifests as premature movement initiation, mistimed tackles, or impulsive passes. The magnitude of improvement observed here indicates that neurofeedback-driven modulation of BA46 can recalibrate the "stop" mechanism, enabling athletes to suppress automatic impulses and adjust behavior adaptively under pressure. These findings are consistent with controlled neurofeedback trials showing that prefrontal SMR training enhances inhibitory control and reduces impulsive responding (Enriquez-Geppert et al., 2017).

Increased Decision Consistency

Decision consistency increased by 13.37% in the experimental group, compared to 2.51% in controls. This metric captures intra-individual variability in response selection across repeated high-demand trials. Reduced variability is a hallmark of mature executive functioning and stable cortical network organization. High variability in reaction time or choice behavior has been associated with inefficient network connectivity and attentional instability (MacDonald et al., 2006). The observed reduction in variability indicates that improvements were not sporadic but structurally embedded. In performance settings, consistency is often more valuable than isolated peak reactions. A player who performs optimally once but inconsistently thereafter introduces unpredictability into team dynamics. Enhanced executive stability may therefore contribute to collective tactical coherence.

Increased Subjective Decision Clarity

Athletes in the experimental group reported a +2.11 increase (on a 1–7 scale) in perceived decision clarity, compared to +0.48 in controls. Subjective measures of cognitive clarity and control have been shown to correlate with objective neural markers of prefrontal engagement (Kober et al., 2015). Perceived clarity likely reflects improved alignment between intention, evaluation, and execution. When prefrontal networks operate efficiently, athletes experience reduced internal conflict and diminished anticipatory anxiety. Functional coupling between BA10 (strategic integration) and BA46 (inhibitory control) may support this subjective sense of decisional certainty (Etkin et al., 2011). Importantly, the convergence of objective EEG coherence increases, behavioral inhibition gains, and subjective clarity improvements strengthens the internal validity of the findings. Multimodal convergence reduces the likelihood that changes are attributable to placebo effects or motivational bias alone.

Taken together, the results indicate that the personalized EEG neurofeedback protocol induced coordinated changes at three interdependent levels:

1. **Neurophysiological** – enhanced coherence and adaptive oscillatory regulation in executive prefrontal regions.
2. **Behavioral** – faster controlled reactions and significantly improved inhibitory performance.
3. **Subjective/Applied** – increased clarity and stability in decision-making under simulated pressure.

The control group exhibited only minimal improvements, consistent with practice effects or general season-related adaptation. The divergence between groups supports the conclusion that the observed gains are attributable primarily to the targeted neurofeedback intervention.

These findings provide empirical support for the hypothesis that executive networks in elite athletes remain plastic and trainable, and that targeted modulation of BA9, BA10, and BA46 can yield measurable improvements in speed–accuracy balance and inhibitory precision. In high-performance environments where outcomes are determined within fractions of a second, such recalibration of cortical control systems may represent a decisive competitive advantage.

6. Conclusions and Implications for Sports Practice and Club Strategy

The findings of the FOCUS 946 study extend beyond experimental validation and enter the domain of applied performance strategy. By demonstrating that targeted EEG neurofeedback can enhance executive coherence, accelerate controlled reaction time, and significantly improve inhibitory precision, the study provides both a neuroscientific and operational framework for optimizing decision-making in elite sport.

At the scientific level, the results confirm that prefrontal executive regions, specifically BA9, BA10, and BA46, remain functionally plastic even in highly trained athletes. The observed increases in inter-regional coherence and the parallel improvements in Go/No-Go performance indicate that executive networks can be recalibrated through structured neurofeedback. This aligns with broader evidence showing that self-regulation of cortical oscillations can produce durable cognitive and behavioral benefits (Ros et al., 2014; Enriquez-Geppert et al., 2017). Importantly, the present study situates these findings within an ecologically valid athletic context, demonstrating that such neural recalibration translates into measurable gains in tactical consistency and subjective decision clarity.

From a clinical-neuroscientific perspective, the intervention appears safe, well tolerated, and compatible with existing training cycles. No adverse effects were observed, and adherence remained high across the 8-week protocol. The convergence between objective EEG changes, behavioral inhibition gains, and subjective clarity reports strengthens the interpretative robustness of the findings. Rather than reflecting transient motivational fluctuations, the improvements suggest structural reinforcement of executive control mechanisms. Enhanced synchronization within the Executive Control Network likely reduced neural noise and improved the efficiency of information transfer between perceptual and motor systems, thereby optimizing the speed–accuracy trade-off central to elite performance.

From a performance standpoint, the implications are substantial. Many decisive errors in professional sport do not stem from physical incapacity or tactical ignorance, but from momentary breakdowns in inhibition or delayed commitment under pressure. A premature defensive action, a mistimed pass, or a fractionally late goalkeeper response can determine match outcomes. The reduction in No-Go errors and the stabilization of reaction time variability observed in the experimental group suggest that targeted executive training may directly reduce such “critical moment” mistakes.

For sports organizations, the strategic relevance is equally significant. Traditional mental preparation methods, visualization, motivational coaching, generalized cognitive drills, do not directly measure or regulate cortical activation patterns. The FOCUS 946 protocol introduces a data-driven alternative. Through quantitative EEG profiling, clubs can identify individual neurocognitive signatures, detect asymmetries or inhibitory vulnerabilities, and tailor interventions accordingly. This approach transforms mental training from a largely qualitative domain into a measurable, monitorable, and adjustable process.

Integration into club infrastructure is feasible and scalable. The protocol requires three weekly sessions of moderate duration and does not interfere with physical conditioning or tactical rehearsal. Its non-invasive nature and compatibility with competitive schedules allow seamless incorporation into microcycles. Over time, such integration may enable clubs to develop neurocognitive profiles alongside physiological and biomechanical metrics, creating a multidimensional performance assessment model. Particularly relevant are positions characterized by high decisional density, goalkeepers, central defenders, and playmakers. These roles demand continuous anticipation, rapid inhibition of automatic responses, and strategic recalibration under dynamic conditions. The targeted modulation of BA9 and BA10 supports anticipatory integration and attentional stability, while BA46 training strengthens inhibitory gating. For these athletes, executive recalibration may represent not merely an enhancement, but a safeguard against performance collapse in high-stakes contexts.

At a broader strategic level, clubs adopting neurocognitive profiling and targeted EEG interventions may gain a reproducible competitive advantage. By reducing decision variability and enhancing consistency under stress, teams can improve tactical reliability. Furthermore, such innovation may attract athletes seeking evidence-based development pathways and position organizations as leaders in applied performance neuroscience.

The intervention scheme FOCUS 946 establishes that executive brain networks can be trained with specificity comparable to muscular or metabolic systems. Decision speed can be increased without sacrificing accuracy, and inhibition can be strengthened without inducing cognitive rigidity. The study supports a paradigm shift in elite sport preparation: performance is not complete until the neural systems governing decision, inhibition, and execution are calibrated with the same precision as physical and tactical components. In competitive environments where matches are decided within milliseconds, optimizing the neural architecture underlying choice and control may represent the final frontier of sustainable high-level performance.

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