# REZILISPORT: Prevention of Neurocognitive Exhaustion and Sustained Mental Performance in Elite Athletes During Intensive Competitive Seasons Through Integrated Brain Training

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***Abstract***

*Elite professional athletes competing in high-density seasons are exposed to sustained physical, cognitive, and emotional stressors that may precipitate neurocognitive fatigue before the onset of overt physical decline. The present randomized, controlled, longitudinal multicenter study investigated the efficacy of an integrated brain training protocol in preventing neurocognitive exhaustion and preserving executive, emotional, and autonomic functioning across a nine-month competitive season in elite team-sport athletes. Participants were randomly assigned to an experimental group receiving a structured neurotechnological intervention or to a control group undergoing standard training and monitoring. The intervention combined personalized EEG neurofeedback, transcranial photobiomodulation (alpha–gamma frequencies), heart rate variability (HRV) biofeedback, non-invasive vagal nerve stimulation, and guided binaural stimulation. Neurophysiological and psychometric assessments were conducted at four time points (T0–T3), including quantitative EEG (qEEG), HRV indices (RMSSD, SDNN, LF/HF ratio), GP-8 stress scores, and global EEG coherence measures. At season completion, the experimental group demonstrated significant increases in vagally mediated HRV parameters, improved autonomic balance, reduced psychophysiological stress scores, and enhanced global EEG coherence compared to controls. These findings indicate strengthened functional connectivity within executive and salience networks, as well as improved neurovisceral integration. The results suggest that integrated brain training represents a feasible, non-invasive, and clinically meaningful strategy for sustaining neurocognitive performance and preventing seasonal mental fatigue in elite sport. The study supports the inclusion of structured neurophysiological training within performance and medical infrastructures of professional clubs.*

***Keywords:*** *Neurofeedback; Elite athletes; Neurocognitive fatigue; Heart rate variability; EEG coherence; Autonomic regulation; Performance resilience*.

## 1. Introduction

In contemporary elite professional sport, sustained cognitive and emotional performance has become as decisive as physical conditioning and tactical preparation. Athletes competing in high-density seasons, characterized by national and international fixtures, congested match calendars, transmeridian travel, media exposure, contractual pressure, and continuous public scrutiny, are exposed to an extraordinary cumulative neurophysiological burden. While physical fatigue is routinely monitored through workload metrics, biochemical markers, and musculoskeletal screening, the progressive emergence of neurocognitive fatigue often remains under-recognized and insufficiently quantified in applied settings.

Accumulating evidence indicates that neurocognitive exhaustion frequently precedes overt physical decline and may act as an early determinant of performance deterioration. Mental fatigue has been shown to impair decision-making speed, inhibitory control, sustained attention, and perceptual anticipation, core components of elite sport execution (Smith et al., 2019). Experimental studies further demonstrate that prolonged cognitive effort can negatively influence endurance performance and technical precision, even in the absence of peripheral muscular fatigue (Meeusen et al., 2013). In team sports, where millisecond-level decisions and rapid contextual adaptations are critical, subtle cognitive degradation may translate into tactical errors, delayed reactions, and compromised emotional regulation under pressure.

From a neurobiological perspective, chronic exposure to competitive stress is associated with dysregulation across multiple systems. Persistent sympathetic activation and reduced heart rate variability (HRV) reflect diminished autonomic flexibility and impaired recovery capacity (Thayer & Lane, 2007; Thayer et al., 2012). In parallel, sustained activation of the hypothalamic–pituitary–adrenal (HPA) axis contributes to cumulative allostatic load, affecting emotional processing, executive functioning, and stress resilience (McEwen, 2007). Over time, these mechanisms may foster a state of neurophysiological rigidity characterized by decreased adaptability, impaired cognitive-emotional integration, and vulnerability to burnout.

At the network level, high-performance sport relies on the coordinated functioning of large-scale brain systems. The Executive Control Network (ECN), involving dorsolateral prefrontal regions such as Brodmann areas (BA) 9, 10, and 46, underpins planning, cognitive inhibition, strategic reasoning, and rapid decision-making. The Salience Network (SN), including the anterior cingulate cortex (BA24, BA32) and insula (BA13), facilitates the detection of relevant stimuli and the adaptive allocation of attentional and emotional resources. The Default Mode Network (DMN), particularly medial prefrontal and posterior cingulate structures (e.g., BA10, BA31), supports reflective processing, experiential integration, and mental recovery. Efficient athletic performance depends not only on the isolated activation of these systems but on their dynamic synchronization and flexible switching according to situational demands. Chronic stress exposure, however, has been associated with disrupted connectivity within and between these networks, contributing to reduced cognitive efficiency and emotional dysregulation (Thayer & Lane, 2007).

Given these converging lines of evidence, a critical question emerges: how can elite athletes maintain neural efficiency and autonomic adaptability across an entire competitive season without succumbing to cumulative neurocognitive overload? Traditional recovery strategies, such as physical rest, nutrition optimization, cryotherapy, or psychological counseling, address important dimensions of athlete care, yet they rarely intervene directly at the level of functional brain network regulation. The central nervous system, although fundamental to performance execution, is seldom trained with the same systematic rigor as muscular strength or aerobic capacity.

The theoretical foundation of the present study rests on three interconnected concepts: adaptive seasonal neuroplasticity, neurophysiological resilience, and integrative brain-network–based intervention. First, adaptive neuroplasticity represents the brain's capacity to reorganize functionally in response to environmental demands. Research in both clinical and high-performance contexts demonstrates that repeated EEG-based neurofeedback training can induce durable modifications in cortical oscillatory patterns and network connectivity (Ros et al., 2014; Enriquez-Geppert et al., 2017). Structural and functional changes have also been documented following targeted cognitive and sensorimotor training paradigms, underscoring the malleability of adult neural systems (Draganski et al., 2006; Pascual-Leone et al., 2005). In athletes exposed to cyclic stressors throughout a season, structured neurotechnological stimulation may therefore promote beneficial reconfiguration rather than maladaptive fatigue-related decline.

Second, neurophysiological resilience extends beyond psychological coping and encompasses the integrated regulation of cortical and autonomic systems. Elevated HRV, particularly increased RMSSD and balanced LF/HF ratios, has been associated with enhanced emotional regulation, executive functioning, and adaptive stress responding (Thayer et al., 2012). HRV biofeedback interventions have demonstrated efficacy in improving autonomic balance and performance-related self-regulation (Lehrer et al., 2013; McCraty & Shaffer, 2015). These findings suggest that resilience in elite sport can be objectively supported through targeted modulation of vagal tone and sympathetic–parasympathetic equilibrium.

Third, integrative interventions that simultaneously target cortical oscillations, network coherence, and autonomic balance may exert synergistic effects. Neurofeedback enables self-directed modulation of specific frequency bands and prefrontal activation patterns, facilitating executive efficiency (Gruzelier, 2014). Photobiomodulation at gamma frequencies has been shown to enhance cortical synchronization and exert neuroprotective effects in preclinical and translational models (Iaccarino et al., 2016; Chan et al., 2021). Non-invasive vagal nerve stimulation has demonstrated capacity to attenuate HPA-axis activation and improve emotional regulation (Breit et al., 2018; Yuan & Silberstein, 2016). Finally, binaural auditory stimulation has been associated with modulation of cortical rhythms relevant to attention and motivational states (Orozco Perez et al., 2020). When integrated within a coherent protocol, these modalities may collectively sustain functional brain organization during periods of high competitive load.

Against this background, the REZILISPORT study was designed to investigate whether a structured, longitudinal program of integrated brain training could prevent neurocognitive exhaustion and preserve executive, emotional, and autonomic functioning in elite team-sport athletes across a full nine-month competitive season. Rather than addressing pathology, the intervention adopts a preventive and performance-sustaining orientation, conceptualizing the athlete’s brain as a trainable system requiring systematic conditioning. By combining objective neurophysiological monitoring with targeted modulation of functional networks, the study aims to provide empirical grounding for a new paradigm in high-performance sport, one in which mental longevity and neural coherence are treated as strategic pillars of sustained excellence.

## 2. Study Objectives

### 2.1 General Objective

The primary objective of the REZILISPORT clinical trial is to evaluate, in a controlled and longitudinal framework, the efficacy of an integrated brain training protocol in preventing neurocognitive exhaustion and maintaining executive, emotional, and autonomic functioning across a full competitive season (nine months) in elite team-sport athletes.

Specifically, the study seeks to determine whether systematic neurotechnological intervention can preserve decision-making clarity, emotional self-regulation under pressure, and adaptive neural reorganization in the context of sustained physical, psychological, and environmental stressors characteristic of high-performance sport.

### 2.2 Specific Objectives

The specific objectives of the study are as follows:

1. **Maintenance of Executive Control Network (ECN) activation**
    - To evaluate and stabilize activity in prefrontal regions (BA9, BA10, BA46).
    - To support rapid decision-making, cognitive inhibition, and strategic planning.
    - To enhance fronto-parietal EEG coherence associated with executive efficiency.

2. **Regulation of the Salience Network (SN)**
    - To maintain balanced activation in anterior cingulate (BA24, BA32) and insular (BA13) regions.
    - To improve selective attention to relevant in-game stimuli and emotional regulation under pressure.
    - To prevent stress-related rigidity of salience processing.
3. **Optimization of autonomic balance through HRV modulation**
    - To increase RMSSD and SDNN as indices of vagal tone and autonomic flexibility.
    - To reduce the LF/HF ratio, reflecting improved sympathetic–parasympathetic balance.
    - To enhance physiological recovery capacity following intense effort.
4. **Reduction of physiological stress and competitive burnout indicators**
    - To decrease GP-8 scores reflecting global psychophysiological tension.
    - To reduce Athlete Burnout Questionnaire (ABQ) scores.
    - To prevent the onset of mental fatigue and cognitive disengagement during the season.
5. **Enhancement and maintenance of global EEG coherence**
    - To preserve functional connectivity within and between ECN, SN, and DMN networks.
    - To reduce EEG fragmentation associated with neurocognitive overload.
    - To validate EEG coherence as a marker of sustained mental performance.
6. **Validation of intraseasonal neurocognitive resilience**
    - To demonstrate stability of EEG and HRV parameters across T1–T2–T3 assessments despite competitive stressors.
    - To correlate neurophysiological markers with performance indicators and technical staff observations.
    - To position the protocol as a preventive and performance-supporting mechanism capable of mitigating neurofunctional decline during prolonged competitive exposure.

## 3. Study Design

The present investigation was conceived as a randomized, controlled, longitudinal, multicenter clinical study designed to examine the sustained impact of an integrated brain training protocol on neurocognitive functioning in elite athletes exposed to the demands of a full competitive season. The methodological architecture was developed not merely to test the short-term efficacy of a neurotechnological intervention, but to evaluate its capacity to preserve functional neural organization and autonomic balance under ecologically valid, high-performance conditions.

Unlike laboratory-based studies conducted in artificial environments, the current design intentionally reflects the real structure of elite team-sport seasons. Athletes were monitored while actively competing, traveling, and engaging in regular training schedules. This ecological validity is central to the scientific relevance of the findings, as neurocognitive fatigue and autonomic dysregulation typically emerge progressively in authentic performance contexts rather than in controlled experimental simulations.

The study incorporated repeated multimodal assessments across the season in order to capture dynamic changes, adaptive responses, and potential resilience patterns over time. The longitudinal approach allows differentiation between transient adaptation and sustained neurophysiological stabilization, which is critical when evaluating preventive interventions in high-performance sport. The research design includes two parallel arms:

- **Experimental group**: participants receiving the full integrated brain training intervention.
- **Control group**: participants undergoing the same assessment protocol without active neurotechnological intervention.

Random allocation was performed using computerized procedures while ensuring balance across sport type, playing position, and reported workload. This structure permits clear differentiation between intervention-specific effects and natural seasonal fluctuations. The inclusion of a control group aligns with established methodological standards for clinical trials (Friedman et al., 2015; Schulz et al., 2010) and strengthens internal validity by minimizing confounding influences.

The longitudinal component is essential for detecting cumulative neurocognitive changes that may not be apparent in short-term studies. Because mental fatigue and autonomic dysregulation develop gradually, repeated measurement across the season provides a more accurate depiction of functional stability or decline.

The total duration of the study was **nine months**, corresponding to the average length of a professional competitive season in elite team sports. This time frame was selected to ensure ecological alignment with the real exposure window to competitive stressors. By embedding the intervention within a full competitive cycle, the study directly addresses the phenomenon of progressive neurocognitive wear rather than isolated episodes of performance fluctuation.

Evaluations were conducted at four strategic time points distributed across the season:

- **T0** – Pre-season baseline assessment, prior to intervention and official competition.
- **T1** – After six weeks (end of first intervention cycle).
- **T2** – Mid-season assessment during peak competitive load.
- **T3** – End-of-season evaluation.

This distribution enables the identification of early neuroplastic adaptations (T1), vulnerability patterns under cumulative stress (T2), and long-term maintenance or decline (T3). The repeated-measures structure supports analysis of trajectory patterns rather than simple pre–post contrasts.

### Target Population

Participants were active professional athletes competing in football, handball, and basketball. Inclusion criteria were: age between 18 and 35 years, active roster status in a professional club, continuous participation in official competitions during the study period, and medical clearance for full training and match participation. Exclusion criteria included ongoing neurological or psychiatric disorders, current use of medication affecting central nervous system function, recent concussion within the previous three months, and participation in other structured neurocognitive interventions.

Randomization ensured comparable distribution across sport discipline, tactical role, and cumulative training volume. The study specifically targeted fully active athletes rather than those undergoing rehabilitation, thereby focusing on preventive neurocognitive maintenance rather than recovery from pathology.

The study was designed as multicentric, with intervention delivery across multiple performance centers and club-affiliated facilities. This approach enhances external validity and demonstrates replicability beyond a single institutional setting. Importantly, the intervention was structured to integrate seamlessly within standard athletic routines, typically during recovery sessions or lower-intensity training days, thereby avoiding interference with physical preparation.

All procedures were conducted in accordance with established ethical standards for human research. Participants provided informed consent prior to enrollment, and confidentiality of neurophysiological and psychological data was maintained throughout the study. The non-invasive nature of the intervention components further supported ethical acceptability and participant safety.

Data analysis followed a repeated-measures comparative model, examining within-group longitudinal changes and between-group differences at each assessment point. Emphasis was placed on trajectory stability and interaction effects between time and intervention condition. This framework allows evaluation not only of improvement but also of resilience against expected seasonal decline.

The principal methodological strengths of the study include its randomized controlled structure, longitudinal seasonal scope, multimodal neurophysiological assessment, and ecological validity within elite competitive sport. By combining objective biomarkers (qEEG and HRV) with psychometric measures and performance-related contextual data, the design permits a multidimensional understanding of neurocognitive sustainability across prolonged competitive exposure.

## 4. Structure of the Intervention

The REZILISPORT intervention was conceived as a structured, integrative brain training protocol designed to support neurocognitive stability and autonomic balance throughout a full competitive season. Rather than targeting pathology or post-injury rehabilitation, the program was preventive and performance-oriented, aiming to preserve functional neural efficiency under sustained physical and psychological load. The intervention combined complementary neurotechnological modalities in a sequenced format, with each component addressing specific cortical and autonomic mechanisms implicated in executive performance, stress regulation, and recovery. The protocol was standardized yet individualized, being calibrated according to each athlete's baseline qEEG and HRV profile. This personalization ensured that the stimulation parameters and training targets corresponded to the athlete's neurophysiological characteristics rather than relying on generic optimization templates.

### 4.1 Duration and Cyclical Organization

The intervention extended across the entire nine-month competitive season and was structured into three therapeutic cycles, each lasting six weeks. Every cycle included three sessions per week, resulting in a total of 54 sessions per athlete over the season. Cycles were interspersed with stabilization and evaluation phases aligned with the T1, T2, and T3 assessments. This cyclical architecture was inspired by principles of neuroplastic consolidation, whereby periods of intensive stimulation are alternated with phases allowing integration and stabilization of functional adaptations (Pascual-Leone et al., 2005; Draganski et al., 2006). Such structuring reflects the biological dynamics of synaptic strengthening and network reorganization rather than continuous overstimulation. Each session lasted approximately 60 minutes and followed a consistent neurophysiological progression from cortical activation to autonomic regulation and integrative consolidation.

### 4.2 Session Components

The first component consisted of personalized EEG neurofeedback training (approximately 20 minutes). Protocols targeted prefrontal regions associated with the Executive Control Network, particularly BA9, BA10, and BA46. Training aimed to reduce excessive high-beta activity linked to cortical overactivation and stress while enhancing alpha and sensorimotor rhythm (SMR) activity associated with calm focus and cognitive stability. Neurofeedback has been shown to modulate oscillatory patterns and improve executive performance under demanding conditions (Gruzelier, 2014; Enriquez-Geppert et al., 2017).

The second component involved transcranial photobiomodulation (approximately 10 minutes), delivered bilaterally over prefrontal and parietal areas. Stimulation combined 40 Hz (gamma-frequency entrainment associated with cortical synchronization and neuroprotective mechanisms) and 10 Hz (alpha-range modulation associated with relaxation and regulatory balance). Experimental and translational research suggests that gamma-frequency stimulation may enhance network synchronization and support neurophysiological resilience (Iaccarino et al., 2016; Chan et al., 2021).

The third element consisted of heart rate variability (HRV) biofeedback training (approximately 15 minutes). Athletes were guided through paced breathing at resonance frequency (approximately 5.5–6 breaths per minute), with real-time visual feedback. The objective was to increase RMSSD and SDNN values and to promote balanced LF/HF ratios, reflecting improved vagal tone and autonomic flexibility. HRV biofeedback has consistently demonstrated efficacy in enhancing stress regulation and recovery capacity (Lehrer et al., 2013; McCraty & Shaffer, 2015).

The fourth component included non-invasive vagal nerve stimulation (approximately 10 minutes), applied auricularly or cervically at low frequency and sub-threshold intensity. This phase followed the active training segments and aimed to deepen parasympathetic activation, attenuate HPA-axis reactivity, and consolidate autonomic recalibration. Non-invasive vagal stimulation has been associated with improvements in emotional regulation and stress resilience (Breit et al., 2018; Yuan & Silberstein, 2016).

The final segment of each session consisted of guided binaural auditory stimulation (approximately 5 minutes). Audio sequences were tailored to the athlete's EEG profile and designed to reinforce desired frequency patterns (e.g., gamma enhancement for focused engagement, alpha reinforcement for balanced regulation). Binaural stimulation has been shown to influence cortical oscillatory activity and attentional states (Orozco Perez et al., 2020), serving here as an integrative consolidation phase.

### 4.3 Sequential Neurophysiological Logic

The intervention followed a deliberate neurophysiological sequence. Initial neurofeedback facilitated active cortical reorganization within executive networks. Photobiomodulation supported network synchronization and metabolic efficiency. HRV biofeedback introduced conscious autonomic regulation, followed by vagal stimulation to reinforce parasympathetic stabilization. Binaural stimulation concluded the session by promoting integrative consolidation across cortical and subcortical systems. Through this structured synergy, the protocol simultaneously addressed executive cortical regions, limbic stress-processing circuits, and the autonomic nervous system. The integrated design reflects a systems-based model of performance in which cognitive clarity, emotional regulation, and physiological adaptability are interdependent rather than isolated domains.

### 5. Measurements and Assessment Instruments

This study employed a multimodal evaluation framework combining objective neurophysiological markers with validated psychometric tools. Assessments were conducted at four time points (T0 – pre-season, T1 – post-cycle 1, T2 – mid-season, T3 – end-season) under standardized conditions to ensure reliability and comparability across the competitive season.

#### Quantitative Electroencephalography (qEEG)

Brain function was assessed using a 19-channel EEG system (International 10–20 system) in eyes-closed and eyes-open resting conditions, in order to quantify functional connectivity, executive activation, stress-related overactivation, and seasonal neural stability. Key parameters analyzed:

- Spectral power (Delta, Theta, Alpha, SMR, Beta, High Beta, Gamma)
- Global and regional EEG coherence
- Cortical asymmetry
- Activity within specific Brodmann areas:
    - BA9, BA10, BA46 (Executive Control Network)
    - BA24, BA32, BA13 (Salience Network)
    - BA6, BA8 (motor planning and anticipatory control)

#### Heart Rate Variability (HRV)

Autonomic regulation was evaluated using medical-grade ECG sensors during a 10-minute seated resting protocol, to objectively assess autonomic flexibility, recovery capacity, and stress-related imbalance. Primary parameters:

- RMSSD (vagal tone)
- SDNN (global autonomic variability)
- LF/HF ratio (sympathetic–parasympathetic balance)
- HRV coherence index

#### Psychophysiological Stress and Burnout Measures

Validated self-report instruments were administered in correlation with physiological data, in order to detect early signs of mental fatigue and emotional strain before observable performance decline.:

- **GP-8 Scale:** global neurophysiological tension and somatic stress indicators
- **Athlete Burnout Questionnaire (ABQ):** emotional exhaustion, sport devaluation, and reduced accomplishment

Individual neurophysiological profiles were mapped across T0–T3 to examine neurocognitive resilience across sustained competitive exposure rather than isolated improvement:

- Stability or decline in EEG and HRV parameters
- Interaction between competitive load and neural regulation
- Correlation with staff performance observations

*Table1. Summary of instruments used*

| Assessment Domain | Instrument | Core Indicators |
|---|---|---|
| Neurophysiology | 19-channel qEEG | Spectral power, coherence, Brodmann activation |
| Autonomic Regulation | ECG-based HRV | RMSSD, SDNN, LF/HF, coherence |
| Stress & Burnout | GP-8, ABQ | Psychophysiological strain indices |
| Seasonal Stability | Longitudinal analysis | Neural and autonomic trajectory patterns |

Together, these complementary instruments enabled comprehensive monitoring of cortical organization, autonomic balance, and psychophysiological resilience throughout the competitive season, forming the empirical backbone of the study's outcome evaluation.

## 6. Results

Comparative analyses between the experimental and control groups at the end of the competitive season (T3), relative to baseline (T0), revealed consistent and clinically meaningful differences across autonomic, neurophysiological, and psychophysiological parameters. These differences were not limited to isolated markers but reflected a coordinated pattern of enhanced neural coherence, improved autonomic flexibility, and reduced stress-related burden in the intervention group.

### Autonomic Regulation: HRV Parameters

One of the most robust findings concerned vagally mediated heart rate variability. The experimental group demonstrated a mean increase in RMSSD of +12.6 ms across the season, compared with a modest +2.1 ms change in the control group. RMSSD is widely regarded as a sensitive marker of parasympathetic activation and adaptive recovery capacity (Thayer et al., 2012). In elite sport contexts, seasonal progression is typically associated with stagnation or decline in RMSSD due to cumulative sympathetic load. Therefore, the observed increase represents not only preservation but enhancement of vagal modulation under competitive stress.

Similarly, SDNN increased by +9.4 ms in the experimental group versus +1.3 ms in controls. SDNN reflects overall autonomic variability and systemic adaptability. Chronic stress exposure is often linked to reduced SDNN, indicating diminished physiological flexibility (McEwen, 2007). The increase observed here suggests that the intervention promoted broader autonomic recalibration rather than isolated parasympathetic activation.

The LF/HF ratio decreased by –1.3 in the experimental group compared with –0.2 in controls, indicating a shift toward improved sympathetic–parasympathetic balance. Lower LF/HF ratios are associated with enhanced stress regulation and more efficient autonomic switching (Thayer & Lane, 2007). These results align with prior research demonstrating that HRV biofeedback can improve regulatory capacity and performance-related stress control (Lehrer et al., 2013).

Collectively, the HRV findings suggest that athletes undergoing integrated brain training developed enhanced autonomic flexibility, characterized by improved recovery kinetics and more efficient transitions between activation and restoration phases.

### Psychophysiological Stress and Burnout Indicators

The GP-8 global stress score decreased by –17.8 points in the experimental group, compared with –2.6 points in the control group. This substantial reduction indicates a meaningful decrease in perceived and physiological tension accumulation across the season. In elite environments, where psychological strain remains constant, such reductions are uncommon without targeted intervention.

Although both groups maintained competitive engagement, the experimental group demonstrated stabilization of Athlete Burnout Questionnaire (ABQ) indices, whereas the control group showed a mild upward trend in emotional exhaustion subscales at T3. Burnout has been associated with chronic autonomic imbalance and prolonged HPA-axis activation (Meeusen et al., 2013). The observed stabilization in the intervention group supports the hypothesis that integrated neural regulation may buffer against cumulative emotional fatigue.

These outcomes correspond with literature linking enhanced HRV to improved emotional regulation and resilience under stress (Thayer et al., 2012), suggesting that autonomic recalibration contributed directly to reduced psychophysiological burden.

**EEG Coherence and Functional Connectivity**

Quantitative EEG analyses revealed a +14.9% increase in global coherence in the experimental group compared with +2.9% in controls. This finding reflects enhanced synchronization across cortical regions, particularly within networks implicated in executive control and salience detection. Increased coherence within fronto-parietal circuits is associated with improved executive efficiency and attentional stability (Enriquez-Geppert et al., 2017). Furthermore, gamma-range synchronization, targeted during photobiomodulation and binaural stimulation phases, has been linked to coordinated network activity and enhanced cognitive processing speed (Iaccarino et al., 2016).

The coherence enhancement observed in the intervention group likely reflects functional reorganization rather than simple upregulation of activity. Excessive activation without coordination may impair performance; by contrast, synchronized oscillatory activity supports efficient information integration across networks. The improvement in global coherence therefore suggests optimized communication between the Executive Control Network (ECN), Salience Network (SN), and Default Mode Network (DMN), which are critical for decision-making, stress filtering, and reflective reset processes. In practical performance terms, such synchronization may underlie improved clarity during high-pressure moments and reduced cognitive fragmentation during prolonged competition.

When considered collectively, the autonomic and EEG findings indicate systemic reorganization rather than isolated parameter fluctuation. The intervention appears to have facilitated adaptive neuroplasticity under real competitive load. Prior research has demonstrated that neurofeedback can induce durable changes in oscillatory patterns and connectivity (Ros et al., 2014), and that repeated network-targeted training can strengthen functional integration (Gruzelier, 2014). The current results extend these observations into the ecological context of elite team sport. Importantly, the control group did not exhibit marked deterioration across parameters; however, the experimental group demonstrated positive adaptation trajectories in an environment where stability alone would be considered successful. Thus, the intervention not only prevented decline but promoted measurable enhancement.

Taken together, the findings indicate that the intervention facilitated a shift from stress-driven neurophysiological rigidity toward adaptive flexibility. Rather than finishing the season in a state of accumulated sympathetic overactivation and cognitive fragmentation, athletes in the experimental group demonstrated enhanced vagal tone, improved autonomic balance, reduced psychophysiological tension, and strengthened cortical network coherence. This pattern reflects what may be termed intraseasonal neurocognitive resilience: the capacity to maintain or even enhance neural efficiency despite repeated exposure to competitive stressors. The synergy between cortical reorganization (via neurofeedback and photobiomodulation) and autonomic recalibration (via HRV biofeedback and vagal stimulation) likely underlies these outcomes.

From a systems perspective, the intervention appears to have improved the brain–heart regulatory loop described in neurovisceral integration models (Thayer & Lane, 2007), reinforcing bidirectional communication between prefrontal executive regions and autonomic control centers. Importantly, these results are not merely statistically significant but clinically meaningful. In high-performance sport, even small declines in decision speed or emotional stability can alter competitive outcomes. The maintenance, and in some parameters enhancement, of executive and autonomic markers across a nine-month season suggests tangible performance sustainability.

*Table 2. Seasonal Changes in Neurophysiological and Psychophysiological Parameters (T3 vs. T0)*

| Parameter | Experimental Group (Δ T3–T0) | Control Group (Δ T3–T0) | Interpretation |
|---|---|---|---|
| **RMSSD (ms)** | +12.6 ms | +2.1 ms | Increased vagal tone and recovery capacity |
| **SDNN (ms)** | +9.4 ms | +1.3 ms | Improved global autonomic flexibility |
| **LF/HF Ratio** | –1.3 | –0.2 | Enhanced sympathetic–parasympathetic balance |
| **GP-8 Score** | –17.8 points | –2.6 points | Reduced psychophysiological stress |
| **Global EEG Coherence** | +14.9% | +2.9% | Strengthened functional neural synchronization |

Beyond statistical differentiation, these findings carry clinical and applied relevance. The experimental group concluded the season with improved autonomic regulation, enhanced neural coherence, and reduced stress burden, an atypical trajectory in elite competition contexts. Rather than exhibiting the common late-season pattern of cognitive fatigue and emotional depletion, these athletes demonstrated stabilization and in several domains enhancement of regulatory capacity. These results support the hypothesis that integrated, network-oriented brain training can function as a preventive and performance-sustaining mechanism in elite sport, fostering both neural efficiency and autonomic adaptability across prolonged competitive exposure.

## 7. Conclusions and Practical Implications

The findings of the REZILISPORT clinical trial support a fundamental reconceptualization of performance sustainability in elite team sports. Across a full competitive season, athletes exposed to an integrated brain training protocol demonstrated preserved, and in several parameters enhanced, neurocognitive and autonomic functioning. These results extend beyond statistical significance and indicate a clinically meaningful capacity to prevent neurocognitive exhaustion under prolonged competitive stress.

From a translational perspective, the study provides empirical validation for incorporating structured neurotechnological training into the performance architecture of professional sports organizations. Traditionally, clubs invest extensively in physical conditioning, tactical analysis, nutrition, and injury prevention. However, despite increasing awareness of mental fatigue and burnout, systematic brain-based preventive protocols remain rare. The present data suggest that the central nervous system can, and should, be trained with comparable intentionality and structure as muscular and cardiovascular systems.

Implementation within club infrastructure is both feasible and scalable. The intervention protocol is modular, standardized, and compatible with existing recovery schedules. Sessions can be integrated on low-intensity training days or post-match recovery blocks without disrupting physical preparation. Baseline qEEG and HRV profiling allows individualized calibration, while ongoing monitoring provides objective markers of neurophysiological stability. Importantly, the approach is non-pharmacological, non-invasive, and well tolerated, aligning with ethical and medical safety standards in professional sport.

Clubs adopting such protocols may benefit in several strategic domains. First, sustained executive clarity under pressure can reduce decision-making errors in critical moments, particularly in high-cognitive-load positions such as playmakers, goalkeepers, and defensive coordinators. Second, proactive modulation of autonomic balance may reduce the risk of stress-related performance decline and silent psychological decompensation. Third, maintaining neural coherence and recovery capacity may indirectly lower injury risk by preserving reaction time, motor coordination, and attentional precision. Fourth, the cultivation of neurophysiological resilience may contribute to athletic longevity, preserving both performance consistency and long-term market value.

Beyond individual performance, the implications extend to collective team dynamics. Efficient functioning of the Executive Control and Salience Networks supports adaptive coordination, tactical flexibility, and shared situational awareness. When athletes maintain emotional regulation and cognitive availability, cooperative decision-making and synchronized execution become more stable. Thus, the intervention may influence not only isolated metrics but also emergent team-level performance patterns.

For coaching and medical staff, the integration of objective neurophysiological metrics offers additional diagnostic insight. HRV and EEG coherence provide quantifiable indicators of stress load and cognitive readiness, complementing observational assessments. Such data-driven approaches enable earlier detection of maladaptive trends, facilitating timely preventive adjustments rather than reactive crisis management.

At a broader level, the study proposes a paradigm shift in sports medicine and performance science. Elite competition demands sustained excellence over extended periods rather than isolated peak performances. In this context, the brain is not merely a reactive organ responding to external stressors but a trainable system whose functional organization can be optimized and stabilized. The integrated protocol examined here demonstrates that systematic modulation of cortical oscillations, network coherence, and autonomic balance can mitigate the progressive neurocognitive wear typically associated with dense competitive calendars.

In conclusion, REZILISPORT provides evidence that integrated brain training constitutes a viable, reproducible, and strategically valuable component of elite sports preparation. The intervention effectively prevented seasonal neurocognitive decline, enhanced autonomic adaptability, reduced psychophysiological stress, and strengthened large-scale network coherence. These outcomes support the conceptualization of neurocognitive resilience as a measurable and trainable capacity. By embedding brain-based optimization within standard performance infrastructures, clubs can move toward a more comprehensive model of athlete development, one that protects mental health, sustains executive clarity, and fosters long-term competitive consistency. In a sporting environment where marginal gains determine outcomes, structured neurophysiological training may represent a decisive competitive advantage.

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