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Integrating brain-body-behavior data for performance optimization: Augmented technologies for the next generation of sport psychologists

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ABSTRACT

Optimizing sport performance demands a nuanced understanding of the dynamic interaction between the person, the task, and the environment. Within the framework of the Multi-States theory, the integration of brain-body data informs emotion- and action-centered self-regulatory strategies by uncovering the psychophysiological dynamics that characterize proficient information processing and superior performance effectiveness. This theoretical and practical approach offers the opportunity to track athletes' performance states and implement real-time adjustments, while it could also support the development of interventions and training regiments that are individualized and task-specific. We also argue how brain-body-behavior technologies could be combined within virtual mixed or augmented environments to support the transfer of perceptual-cognitive-motor skills from lab-based interventions into real-world performance outcomes. We argue that such measures offer unique, objective windows into performance states and self-regulation skills, particularly in ecologically valid settings. We further discuss current trends and challenges that surround the use of technology in performance optimization interventions within the field of sport psychology, and we propose that future augmented technologies should strive to develop AI-driven brain-body-behavior data analytics to combine objective pattern recognition with subjective experiential insight, urging the next generation of sport psychologists to shift from reactive to proactive approaches to performance optimization to better align current applied practices with the complex dynamics of sport performance. Finally, we argue that research lines investigating team dynamics and e-sport performance are especially well-positioned to benefit from this integrative approach.

1. Introduction

The understanding of the link and the integration among mind, body, and behavior in sport psychology has advanced through cutting-edge technologies and theoretical approaches. Central to these developments is a growing emphasis on assessing the dynamic interaction among person, task, and environment for performance optimization, highlighting the interplay among different systems (Bertollo et al., 2020, pp. 666–693). One of the main challenges in sport psychology is understanding how distributed brain processes support natural, goal-directed behavior in dynamic, real-world settings. Athletes continuously adapt their actions to fulfil performance goals within complex, rapidly changing environments that involve interaction, cooperation and competition with teammates and opponents. For instance, the framework of embodied cognition has become increasingly influential, highlighting that cognitive functions are deeply rooted in sensorimotor processes evolved to optimize action outcomes in three-dimensional space. This perspective is critical for advancing our understanding of how cognitive and neural mechanisms contribute to skilled performance, decision-making, and adaptability in sport.

Moreover, current technologies offer powerful tools for monitoring and regulating affective and emotional states in sport, enabling real-time feedback and personalized interventions. Specifically, augmented technologies — any technology that enhances human capabilities using devices, software, and systems that combine human and machine intelligence — can help athletes enhance emotional control, optimize arousal levels, and improve performance under pressure. Currently, comprehensive psychophysiological and behavioral assessment and intervention enables athletes to develop self-regulation strategies that support optimal performance states, even under competitive pressure (di Fronso et al., 2020). To this purpose, Bertollo and colleagues (2020, pp. 666–693) suggested extending Makeig and colleagues' (2009)

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perspective on Mobile brain/body imaging (MoBI) to integrate a multimodal and multidimensional approach to performance optimization, which leverages synchronized streams of brain-body-behavior-environmental data.

The convergence of sport psychology and technology fosters a synergistic approach to performance optimization by integrating psychophysiological approaches with advanced technological tools (Siekańska et al., 2021). Specifically, this integration supports.

1. The identification and monitoring of brain-body signals that characterize individual performance profiles (i.e., individual zones of optimal functioning, IZOF, Hanin et al., 2016), providing insights into athletes' psychophysiological functioning (Bertollo et al., 2021);
2. The development of personalized interventions designed to enhance the cognitive architecture of movement (Schack & Frank, 2021) and action- or emotion-center regulation strategies in sport contexts (Ruiz et al., 2020, pp. 3–17);
3. The improvement of the ecological effectiveness of training intervention, ensuring that learned strategies are effective and sustainable in real-world competitive environments (Teques et al., 2017).

This integration underscores the idea that technology and sport psychology are complementary, with conceptual and theoretical frameworks guiding the development of theory- and evidence-based, individualized, and context-sensitive strategies that aim at optimizing athletic performance, and that are both scientifically rigorous and practically effective in sport environments (Siekańska et al., 2021).

The psychological foundation underpinning these integrated approaches is self-regulation, as suggested in the Multi-States (MuSt) theory (Ruiz et al., 2020, pp. 3–17). The MuSt theory builds on previous models, including the Multi Action Plan (MAP; Kellermann et al., 2024a; Robazza et al., 2016) and the IZOF model. The MuSt perspective enhances the effectiveness of the interventions by emphasizing the importance of underlying psychobiosocial states for improving psychophysiological efficiency. Enhanced self-regulation allows athletes to develop skills to modulate key psychophysiological states – such as cardiac deceleration to support attentional focus or fostering neural adaptability to facilitate flow-like states – thereby optimizing performance (di Fronso et al., 2020). Furthermore, personalized training approaches allow for interventions tailored to the athlete's and sport-specific needs, such as neurofeedback protocols to enhance motor cortex activation in precision sports (e.g., shooting), or heart rate variability (HRV) training that promote stress resilience in dynamic team sport environments (Christie et al., 2020). Specifically, the work by Bertollo and colleagues (2020, pp. 666–693) on brain technologies, together with Schack's research on cognitive structures (Schack & Frank, 2021), collectively emphasize how technologies serve as a bridge across mental, physiological, and behavioral domains and highlight their interdependence in performance optimization approaches.

The integration of the aforementioned frameworks forms a holistic ecosystem for athletes' development. Modern brain-body and behavioral technologies translate these theoretical foundations into applied practice, enabling athletes to achieve psychophysiological coherence, enhance mental representations, and adapt dynamically to performance and environmental demands. This synthesis underscores the evolution of sport psychology into a tech-integrated, interdisciplinary science, where brain, body, and behavior are optimized through empirically grounded innovation.

While a wide array of technologies has contributed meaningfully to the study of the interplay between brain, body, and behavior, in the following sections we focus specifically on a selection of technologies that exemplify the integration of technological advancements into sport psychology research and practice, including electrophysiological measures, wearables, virtual reality, bio-neurofeedback, and cognitive-motor training setting the stage for the development of augmented technologies as the new leading-edge concept in sport psychology. In the following sections, we provide an overview on how technology can support the development of individualized, ecologically valid, and effective interventions for performance optimization. Accordingly, we categorize technologies based on their primary impact (conscious that many of them can have multiple secondary impact) on either optimizing performance efficiency (i.e., enhancing cognitive control, neural adaptability, and resource management) or improving performance effectiveness (i.e., achieving peak performance in competitive and training environments).

2. Technology to identify and monitor optimal performance

2.1. Electroencephalography to assess neural proficiency

Recent advances in neuroscience and biotechnology have provided valuable insights into the relationship between brain dynamics and sport performance (Holmes & Wright, 2017). Yet, many neuroimaging techniques (e.g., functional magnetic resonance imaging; fMRI), remain impractical for sport settings due to methodological constraints, while others, such as functional near infrared spectroscopy (fNIRS), have yet to reach a large implementation in practice (Perrey, 2022). Conversely, electroencephalography (EEG) can track neural activity in real time, making it particularly well-suited for the dynamic demands of sport performance research (Filho et al., 2021; Marino & Mantini, 2024).

At the cortical level, neural proficiency refers to an effective minimization of neural effort in response to environmental and task demands (Bertollo et al., 2016). Several EEG-based markers have been associated with proficient athletic performance (Cheron et al., 2016), with power modulations across specific bands reflecting distinct neural processes (Beste et al., 2023). For instance, event-related desynchronization/synchronization (ERD/ERS) in the theta band (4–8 Hz) over medial frontal sites has been associated with adaptive resource allocation during the preparatory stages of skilled movement (Kao et al., 2013; Yu et al., 2024) and sport-specific tactical decision-making (Kanatschnig et al., 2025). Similarly, alpha (8–13 Hz) ERS over left-temporal regions during motor preparation has been interpreted as reflecting the inhibition of task-irrelevant cognitive processing (Chueh et al., 2023; Gallicchio et al., 2017).

EEG methodologies provide a means of assessing the neural processes underlying psychological skills training (PST). Indeed, both action-centered and emotion-center coping strategies may be informed by cortical correlates of mental imagery and emotion regulation to support more controlled performance states (Budnik-Przybylska et al., 2021; Chen et al., 2019).

Functional connectivity, typically quantified as the statistical dependence between EEG signals at different cortical sites (Marino & Mantini, 2024), offers another lens into performance-related neural efficiency. For instance, in self-paced sports (e.g., rifle shooting), elite performance has been associated with lower alpha-band coherence between left-temporal (T7) and mid-frontal (Fz) regions (Parr et al., 2021; Raman & Filho, 2024). This is consistent with reduced conscious control and increased automaticity during skilled motor preparation (Cheng et al., 2023; Wang et al., 2020). Elevated anxiety levels, however, may reverse this pattern (Lo, Sheng, & Liu, 2019), potentially implicating this pathway in mechanisms underlying choking under pressure (Raman & Filho, 2024). Still, several authors have cautioned against overly simplistic interpretations, noting the nuanced and, sometimes, non-linear relationship between alpha activity and sport performance (Parr et al., 2021). Furthermore, di Fronso et al. (2018) found that distinct patterns of inter-hemispheric beta (13–30 Hz) coherence between central sites (i.e., C3 and C4) emerged in response to increasing effort demands, with higher levels of coherence observed during dysfunctional (i.e., Type 3) performance states as compared to functional (i.e., Type 1 and Type 2) states.

Event-related potentials (ERPs) offer a complementary approach to studying efficient neural processing in athletes, particularly through expert-novice comparisons (between-subject effects) or within-subject longitudinal designs. ERPs reflect neural activity that is time- and phase-locked to an event or stimulus of interest (Marino & Mantini, 2024), making them particularly well-suited for investigating sport-related brain activity. ERP studies have examined a range of performance-related cognitive and motor functions, including cognitive and motor preparation and inhibition, and motor execution, as well as stimulus detection, evaluation, and response selection (Li & Smith, 2021; Schmidt-Kassow & Kaiser, 2023).

Despite advances in EEG methodology, translating laboratory findings into competitive sport environments remains a challenge (Perrey & Besson, 2018). It is still unclear to what extent sport-related cognitive enhancements observed in lab-based tasks generalize to real-world performance (Broadbent et al., 2015). In this regard, mobile and wireless EEG systems offer a promising approach for improving ecological validity while preserving data quality (Chang et al., 2022). However, their application in dynamic sport environments remains constrained by their susceptibility to movement-related and environmental noise (Chang et al., 2022). Technical advancements in software and hardware are gradually overcoming these limitations (Wang et al., 2019), and the integration of mobile EEG within virtual environments may allow researchers and sport psychologists to identify and monitor athletes' optimal performance states in more ecological, yet controlled, scenarios.

In this context, EEG represents a powerful tool for examining athletes' neural proficiency, particularly in distinguishing when superior performance is characterized by more effortful cognitive control or more automatic, fluent processing. This is crucial for understanding how athletes transition between conscious regulation and proficiency, supporting the identification and monitoring of optimal performance states (Bertollo et al., 2016; Ruiz et al., 2020, pp. 3–17; Kellerman et al., 2024b).

2.1.1. EEG-ECG interaction: heart-brain relationship in self-regulation

Readying the head and steadying the heart is compulsory for understanding cortical and cardiac contribution in the action preparation in sport (Cooke, 2013). Among the various investigations that study the body-mind relationship (e.g. connectivity) in sport, interoceptive signals may inform the identification and monitoring of functional psychobiosocial states underpinning optimal performance (Ruiz et al., 2020, pp. 3–17). The heartbeat evoked potential (HEP), an ERP time-locked to the R-wave of the ECG, is considered a neural marker of interoception (i.e., how the nervous system senses, interprets, and integrates internal bodily signals) (Khalsa et al., 2018), and it is thought to reflect cortical processing of cardiac signals (Park & Blanke, 2019; Pollatos & Schandry, 2004).

Action-based decision-making relies heavily on evaluating predictive sensory consequences (McMorris, 2020; McMorris et al., 2018). For example, submaximal exercise may lead to cognitive fatigue and a reduced sense of available resources due to increased demands for self-regulation (McMorris, 2020), highlighting the potential contributions of interoceptive processing in athletes' appraisals of performance-related resource-demands (Ruiz et al., 2020, pp. 3–17). Moreover, elite athletes show higher interoceptive sensibility, accuracy, and awareness than recreational athletes and controls (Zeng et al., 2025), while sport-specific differences in interoceptive awareness and self-regulation skills were reported in sprinters and distance runners (Seabury et al., 2023). In light of the evidence, HEPs may serve as a valuable marker for studying top-down control of sensory processing and self-regulation, particularly in fatigue or sustained pacing scenarios (Park & Blanke, 2019), due to its association with interoceptive attention (Hodossy et al., 2021; Petzschner et al., 2019).

However, the standardization of HEP measures remains a challenge, with studies showing mixed findings about its relationship to physical activity and training (Yoris et al., 2024; Zeng et al., 2025). This points to the need for objective indexes, such as HEPs, to complement subjective interoceptive assessments for performance optimization (Tanaka et al., 2025).

2.1.2. EEG-EMG connectivity and coherence

Another powerful approach to understanding the mechanisms underlying self-regulatory processes is cortical-muscular coupling. One measure of brain-muscle communication is cortico-muscular coherence (CMC), which is thought to reflect the activity of sensorimotor networks during dynamic movements and sustained isometric contractions (Peng et al., 2024). Specifically, CMC assesses the functional coupling between the cortex and muscles through the integration of cortical (EEG) and muscular (EMG) signals to provide insights into the cortico-muscular dynamics of motor control (Liu et al., 2019).

Since CMC appears to be influenced by performance-related factors, such as fatigue (Liang et al., 2021) or dynamic shifts in attentional focus (Parr et al., 2023), it may provide insights into athletes' ability to adapt to ongoing performance demands, informing training interventions aimed at improving movement efficiency (Parr et al., 2023).

As CMC provides insight into the efficiency and adaptability of sensorimotor networks during voluntary movement, it offers a promising approach to address emerging challenges in network physiology and neuro-rehabilitation (Peng et al., 2024). In sport contexts, CMC can be used to monitor and tailor training interventions by identifying optimal brain–muscle coordination patterns that support efficient movement under varying performance demands (Liang et al., 2021; Parr et al., 2023), thus informing potential transitions between deliberate control and automaticity (Ruiz et al., 2020, pp. 3–17). Moreover, CMC may inform targeted strategies for rehabilitating disrupted cortico-muscular pathways following injury, and may help track recovery (Peng et al., 2024).

2.2. Wearable devices

Wearable devices allow for ecological, real-time streaming of external and internal loads, elucidating transitions between functional and dysfunctional performance states, translating theory into practice (Düking et al., 2021; Impellizzeri et al., 2019; Sargent et al., 2015).

Li and colleagues (2016) categorized wearables into three groups: (1) movement sensors, such as accelerometers, gyroscopes, and Global Positioning System (GPS); (2) physiological sensors, monitoring variables like heart rate (HR), HRV, and body temperature; (3) integrated or multimodal sensors combining both. Movement sensors provide metrics such as total running distance, sprinting distance, and number of accelerations, helping sport staff evaluate external load – for instance, checking running metrics after a soccer match (Curtis et al., 2020; Ferguson et al., 2023). Conversely, physiological parameters such as HRV provide insight into an athlete's autonomic and metabolic reserves, helping in the assessment of states from tapering (functional) to under-recovery or overtraining (dysfunctional) (Balk & De Jonge, 2020; Michael et al., 2018). Integrated sensors deliver both kinematic and physiological data into a single dashboard, enabling a more holistic load management and providing rapid feedback (Altini & Amft, 2016).

Contemporary wearable technologies can also be differentiated by their temporal reference. Continuous and immediate monitoring relies on high-frequency inertial measurement units, GPS, accelerometers, chest strap HR monitors, and wrist-worn sensors to stream second-by-second data during drills or competition (Li et al., 2016). This real-time stream allows practitioners to adjust training load, tactics, or rest intervals based on real-time data. For instance, substituting a player when sprint number reaches the predefined threshold, helps him recover better the next day (Curtis et al., 2020). Moreover, motion capture suits (clusters of accelerometers) show not just the quantity but also the quality of the movement, translating "how much" into "how well". These wearables capture performance markers with good precision giving coaches reliable kinetic and kinematic fingerprint of an athlete specific skills (Chen et al., 2025; Debertin et al., 2024). Deep learning models can now predict behavioural outcomes and movement kinematics, anticipating athlete's performance and status (Chen et al., 2025; Pinelli et al., 2025). However, constant exposure to self-tracking data may have unintended psychological consequences, potentially shifting athletes toward dysfunctional states by fostering excessive self-monitoring and over-control (Guppy et al., 2023; Ruiz et al., 2020, pp. 3–17).

Wearables are also employed for longitudinal monitoring, recording data over extended periods for individualized comparisons (Russell et al., 2023). New generation wrist-, ring- and chest-worn devices integrate movement and physiological sensors, flagging declines in self-regulation before performance slips (Altini & Amft, 2016). Such monitoring maintains control over acute performance status and mitigates chronic risks such as under-recovery, non-functional overreaching, overtraining, and burnout balancing demands and resources (Addleman et al., 2024; Ruiz et al., 2020, pp. 3–17). In this context HRV data are used to fine-tune training loads (Kaikkonen et al., 2011), as its fluctuations can identify fatigued states in athletes (Schmitt et al., 2015). Düking and colleagues (2021) showed that HRV-guided endurance training outperformed fixed training programs, improving sub-maximal performance (e.g. time-to-exhaustion and time-trial tasks) by 2–5 %. Overnight actigraphy integrated with skin-temperature and HRV represents a valid tool to quantify recovery debt, accounting for cumulative physical and psychological strain (de Zambotti et al., 2023; Sargent et al., 2015). Mobile smart-glass systems allow real-time monitoring of *where, when and in what order* athletes focus their attention. Its longitudinal employment within training increases athletes' ability to exclude non-relevant targets, focusing mostly on core components of performance (Wilson et al., 2018). The afterwards comparison with performance models helps in fine-tuning the quiet-eye routine, preventing mindless automation that could undermine performance within high pressure-scenarios.

Merging multimodal data into coaching platforms and cloud-dashboards increase clarity and interpretation, helping coaches in adjusting training intensity, preventing imbalances between stress and recovery (Russell et al., 2023). New-generation algorithms integrating actigraphy, HRV, skin temperature, and respiration generate ecologically valid stress-recovery indices that outperform traditional models in early dysfunction detection and that can be used by sport psychologists to implement intervention strategies (de Zambotti et al., 2023). Indeed, by combining sleep, GPS, and mood data, machine learning engines can predict athletes' transitions from functional to dysfunctional performance states, allowing training load management to prevent chronic overload – especially during congested periods (Altini & Amft, 2016).

Despite technological advancements, challenges remain regarding measurement accuracy and the generalizability of models. Wrist-based photoplethysmography (PPG) has been shown to be susceptible to posture- and gender-related biases (Dobbs et al., 2019). Moreover, algorithms are predominantly developed and validated on endurance sport, underperforming when applied to other sport profiles (Dobbs et al., 2019). The selection of physiological metrics also matters for accurate interpretation. The low-frequency to high-frequency ratio (LF:HF), may underestimate sympathetic load during hard efforts, as fast breathing and near-total vagal withdrawal blunt LF power. Conversely, rMSSD rebounds quickly once vagal tone returns, potentially masking residual sympathetic activation (Michael et al., 2018). Therefore, pairing a vagal index such as Ln-rMSSD with a sympathetic marker provides a more reliable recovery assessment (Michael et al., 2018).

Measurement itself can introduce unintended drawbacks. Constant alerts may prompt excessive self-monitoring and over-control commonly associated with dysfunctional performance states (i.e., Type 3 in MAP model). Moreover, the physical presence of wearable devices such as suites, chest straps or adhesive patches can add proprioceptive distraction, particularly in precision sports (Guppy et al., 2023). Addressing these issues requires sport-specific validation studies, transparent algorithms, and athlete-centered consent. Robust ethical frameworks must safeguard privacy while enabling timely interventions, ensuring that both acute- and long-data streams can be leveraged to effectively optimize performance effectiveness and processing efficiency (Goodyear, 2017).

3. Technology to develop personalized interventions for optimal performance

3.1. Bio-neurofeedback

Biofeedback (BF) and Neurofeedback (NF) function as closed-loop systems, in which real-time physiological signals are continuously recorded, digitally processed to extract relevant features, and presented to the user via visual, auditory, haptic, or electrical stimulation (Sitaram et al., 2017). When an individual's psychophysiological and/or neural activity approaches or reaches predefined thresholds or configurations, immediate positive feedback is delivered to reinforce the targeted states. In BF, the translation of peripheral physiological signals into sensory feedback enables users to acknowledge and modulate autonomic and somatic functions, such as cardiac (e.g., HRV), electrodermal (EDA), respiratory (belt) and muscle (e.g., via electromyography, EMG) activity (Bolek et al., 2017; Gevirtz et al., 2017). On the other hand, NF focuses on brain-derived signals, most commonly EEG oscillations, but also fMRI blood-oxygenation levels or Near-Infrared Spectroscopy (NIRS) hemodynamic measures, which are fed back to reinforce particular neural configurations (Sitaram et al., 2017). Thus, BF and NF rely on principles such as associative learning, Hebbian plasticity, and reinforcement learning (Ros et al., 2014; Sitaram et al., 2017). Through these conditioning mechanisms, individuals are offered access to volitional control over autonomic (Pagaduan et al., 2020), motor (Onagawa et al., 2023), cognitive and affective functions (Gruzelier, 2014), which highlights the potential of Bio-Neurofeedback (BNF) for enhancing pivotal skills in sports performance.

Over the past three decades, a growing body of research has explored the use of BNF across different sports. For instance, studies implementing NF have reported positive results in rifle shooting performance (Rostami et al., 2012), golf putting (Cheng et al., 2015), dynamic balance (Maszczyk et al., 2018), and cycling endurance (Mottola et al., 2021). Promising effects have also been observed after BF training in serve accuracy of junior elite tennis players (Galloway, 2011), dance performance in collegiate dancers (Raymond et al., 2005), and in reducing anxiety levels in professional athletes of multiple sports (Pusenjak et al., 2015). By bridging laboratory-based neurophysiology and psychophysiology with real-world athletic demands, BNF can offer a practical, athlete-centered means to cultivate psychophysiological self-regulation under competitive pressure, standing out as one of the most ecologically valid and performance-oriented interventions for developing both performance effectiveness and efficiency (Bertollo et al., 2016).

Ongoing technological innovations are advancing the implementation of BNF across diverse performance contexts. The evolution of wearable sensors (see paragraph 2.2) and portable EEG headsets has enabled in-situ recording (Park et al., 2015), paving the way for a deeper understanding of sport-specific physiological profiles and characteristics unique to optimal athletic performance states (Bertollo et al., 2016; 2020, pp. 666–693; Ruiz et al., 2020, pp. 3–17). Crucially, the combination of wireless technologies and cutting-edge online artifact rejection techniques further supports the feasibility of delivering immediate accurate and individualized feedback, even during movement (Butkevičiūtė et al., 2019). Additionally, the use of adaptive algorithms powered by machine learning holds great promise for enhancing training efficacy by tailoring BNF interventions to the unique profile of each athlete and optimizing session parameters such as frequency, duration, and progression (Haotian et al., 2023). A new frontier for increasing the practical relevance and inclusion of such interventions in traditional training protocols lies in the integration of multiple signal sources into the closed loop. This allows for the simultaneous recording and feedback of cortical (EEG), autonomic (HRV) and somatic (EDA, EMG) parameters (Christie et al., 2020; Shokri & Nosratabadi, 2021). On the stimulation side, innovations in feedback modalities are moving beyond traditional screen-based visual and auditory formats, which typically require users to remain still, thereby limiting their engagement. Immersive environments, particularly those employing virtual reality (see section 4), are gaining attention for their potential to enhance engagement, replicate realistic competitive scenarios, and thereby improve learning transfer and facilitate state-dependent learning (for a review, see Kober et al., 2024). While still in an early stage of application, future BNF applications in sports are expected to prioritize portability, individualization, and ecological validity.

Despite growing interest in BNF and promising results from several experimental studies, sports professionals may be hesitant about adopting emerging technologies embedded with such interventions without solid empirical foundations. Evidence for BNF's effectiveness as a valid and reliable tool for enhancing performance remains inconclusive, primarily due to methodological limitations. Research on BF in sports remains constrained by a relatively small number of rigorous experimental trials, and the vast majority of studies have focused exclusively on HRV (Pagaduan et al., 2020), leaving other modalities, such as EMG, EDA, and respiratory feedback, largely underexplored. Recent systematic reviews and meta-analyses on NF have identified a strong need for studies that meet the following criteria: (a) double-blind design, (b) large sample size, (c) randomized sham-controlled methodologies, (d) standardized and pre-registered protocols, and (e) longitudinal follow-ups to isolate the specific effects of NF, establishing its efficacy and dose-response relationships, and to assess both the retention of self-regulation skills and their transfer to real-world sport contexts (Mirifar et al., 2017; Yu et al., 2025). Researchers are encouraged to adopt the CRED-nf checklist to improve study design, reporting clarity, and to mitigate publication bias (Ros et al., 2020). At the same time, the complex and dynamic demands of sports performance are not yet matched by sufficiently tailored and high-precision neuromodulation approaches. The work of Cheron et al. (2016) represents a noteworthy step forward in the identification of EEG biomarkers of superior athletic performance. Their review represents an important contribution towards grounding NF-based interventions in sport-relevant neurophysiological evidence and provides a foundational framework for the development of more individualized and context-specific protocols. When implemented within empirically grounded and methodologically rigorous study designs, emerging technologies can serve as critical assets in optimizing performance-oriented BNF protocols, enhancing both their specificity and effectiveness in applied sports contexts (Bertollo et al., 2020, pp. 666–693).

In summary, BNF research in sports performance offers athletes a promising avenue for the development of psychophysiological and neurophysiological self-regulation techniques. Nevertheless, contemporary research should address methodological heterogeneity and control limitations to yield robust and generalizable results suitable for applied settings. Through advanced wearable technologies, AI-driven personalization, and sport-specific evidence-based research practices, BNF holds the potential to evolve into a scientifically grounded and practically valuable component of integrated performance optimization programs.

3.2. Cognitive-motor training

Cognitive-motor training (CMT) refers to structured training protocols that integrate both cognitive and motor functions under varying task and environmental constraints (Katanić et al., 2020). These training protocols engage both low-order (e.g., inhibition, shifting, updating, and attention) and high-order (e.g., planning, problem solving, and decision-making) executive functions (EFs; Diamond, 2013) within sport-specific motor activities (Badau et al., 2022; Vater & Strasburger, 2021). Applications span several sports, including basketball (Silvestri et al., 2023), soccer (Casella et al., 2022), tennis (Forni et al., 2021), and judo (Campanella et al., 2024). Implemented in emotionally and socially dynamic contexts, CMT engages both "cool" (i.e., socio-emotionally decontextualized) and "hot" (i.e., socio-emotionally contextualized) EFs, offering a more integrated alternative to traditional, decontextualized cognitive trainings (e.g., computer-based training). As an action-centered self-regulation strategy that does not neglect the emotional dimension, CMT emphasizes the real-time interaction between perception, cognition, and action (Tomporowski & Pesce, 2019), aligning with the MuSt theory's holistic framework grounded in the interplay between the individual, task, and environment.

While the foundational principles of CMT do not necessarily require technology (Moreira et al., 2021), its integration with technological tools is increasingly common to enhance the effectiveness and precision of training. In practice, CMT often includes dual-task exercises and reaction-based drills using sensor-based systems in real-world scenarios, where athletes make rapid decisions during complex motor actions (Badau et al., 2022). This tech-supported approach allows for quantitative monitoring of performance metrics (e.g., reaction times, movement accuracy, and decision-making speed; Hassan et al., 2022; Katanić et al., 2020) and may enable real-time tracking of critical variables (e.g., effort and fatigue levels, attentional focus), providing insights into how athletes respond to CMT stimuli and when adjustments are needed to optimize performance (Di Martino et al., 2024). The CMT approach is also increasingly implemented within virtual or augmented reality environments (see section 4). Crucially, CMT protocols can be tailored in difficulty to match the demands of the sport (Heilmann et al., 2022), as well as the athlete's individual role and the unique cognitive-motor challenges it entails (Chiu et al., 2020).

CMT is particularly advantageous as it reflects the inseparable nature of cognition and action in sport (Voigt & Raab, 2024), aligning with current perspectives that reject mind-body dualism (for an integrated analysis in movement science, see Pesce & Tocci, 2024). While often rooted in a cognitivist perspective, where movement is considered as the outcome of internal cognitive representations and planning processes (Schack & Frank, 2021), CMT strengthens these processes through structured, measurable drills. This focus directly supports one of the MuSt theory's key pillars: the mental encoding of core action components. Importantly, CMT does not oppose embodied and ecological-dynamic theories. While emphasizing cognitive engagement, its embodied, embedded, and extended structure also aligns with approaches that consider performance as emerging from the continuous athlete-task-environment interaction (Araújo et al., 2020). This dynamic interplay is another cornerstone of the MuSt theory, where environmental factors, task demands, and personal characteristics jointly shape appraisal and performance. These elements are also essential for skill acquisition and expertise development (Renshaw et al., 2019). Therefore, CMT offers a hybrid approach that integrates internal cognitive functions with externally driven, context-sensitive demands to support holistic athletic development and optimal performance.

Given its properties, CMT serves not only as a tool for performance optimization, but also as a promising strategy to address current challenges in assessment, injury prevention, and rehabilitation in sport. These areas have traditionally prioritized motor components, and only recently have begun to acknowledge the role of cognitive functions (Piskin et al., 2022). This reductionist approach overlooks the complex, real-time interaction between perception, cognition, and action that defines sport performance. CMT addresses this gap by embodying and embedding cognitive demands within ecologically valid motor tasks. This makes it well-suited for ecological assessment (Hooper et al., 2022; Hornikova et al., 2021; Verschueren et al., 2019), for reducing injury risk through enhanced attentional control and dual-task management (Clark et al., 2020), and for rehabilitation processes that aim to re-establish disrupted cognitive-motor pathways (Brinkman et al., 2020). These benefits are particularly relevant during return-to-play phases, where true functional readiness is more critical than just physical recovery (Piskin et al., 2022).

In light of the evidence discussed, CMT emerges as an effective and flexible strategy for enhancing performance effectiveness, particularly within Type 2 states described by the MuSt theory (Ruiz et al., 2020, pp. 3–17). It does so by improving proficiency efficiency – performing complex tasks with fewer cognitive and physical resources (Bertollo et al., 2016). This increased efficiency may also indirectly facilitate the emergence of automatic, flow-like Type 1 states (Bertollo et al., 2016; Ruiz et al., 2020, pp. 3–17). In fact, while flow is defined by the absence of executive control and conscious monitoring (Nakamura & Csíkszentmihályi, 2002), it depends on a high level of expertise developed through extensive deliberate practice (Zentgraf & Raab, 2023) and supported by robust EFs and attention (Brimmel, Edwards, & Vaughan, 2024). By improving EFs and cognitive-motor integration, CMT reduces cognitive load and increases the probability of transitioning from controlled (Type 2) to more automatic and efficient (Type 1) performance states. At the same time, it may help prevent dysfunctional Type 3 and disengaged Type 4 states, associated with stress, distraction, and loss of control, by promoting self-regulation and situational awareness. This makes CMT a powerful and integrative tool for supporting the multidimensional nature of sport performance as conceptualized by the MuSt theory.

4. Improving the ecological effectiveness of lab-based interventions through augmented, mixed and virtual reality

In the context of sport, the results of systematic explorations of the mechanisms underlying optimal performance – as well as the ecological validity of performance optimizing interventions – may be limited by laboratory-based approaches, which confound the real-world applicability of lab-based results (Stone et al., 2018). For example, laboratory settings, as much as they allow for a systematic control of confounding variables, may fail at recreating environments that mimic ecologically valid sensory experiences that directly influence the variables of interest (Trpkovici et al., 2025). In this context, augmented (AR), mixed (MR) and virtual reality (VR) allow for the creation of environments that can be tailored to the specific needs of the user, even when they are intrinsically complex, such as in pilot samples and surgeon training (Michalski et al., 2019). VR is a “visual-based computer simulation of a real or imaginary environment” (Craig, 2013, p. 164). Moreover, AR refers to a technology that overlays computer-generated images onto the real world (Berryman, 2012), while MR extends this by enabling interaction between real and virtual environments (Rauschnabel et al., 2022). Finally, using controllers or a hand-recognizing system, immersive Virtual-Reality (i-VR) allows athletes to interact with the environment, enhancing the level of perceived immersion (Mocco et al., 2024). To make that possible, two different hardware components are available: the more popular – the Head Mounted Display (HMD), a visor display that places two small screens, or a single screen that renders two separate images before the eyes, and the Cave Automatic Virtual Environments (CAVE) which consists of multiple large screens rendered from the point of view of a participant with head tracking (Rebenitsch & Owen, 2016).

The integration of cameras on HMD permits the overlay of computer-generated information onto the real world (i.e., AR) (Berryman, 2012). Recently, interest has been growing toward immersive technologies such as VR and AR in sport contexts, gaining attention from both athletes and coaches (Neumann et al., 2018). One of the main reasons behind this interest is its applicability in tailoring artificial environments according to athletes’ needs and objectives. This flexibility opens many opportunities to use VR as a tool to boost psychological skills and consequently increasing sport performance.

Among the multitude of applications, VR is particularly suitable to work on performance-related subjective experiences, such as stress and anxiety. For instance, Stress Inoculation Training (SIT) involves gradual exposure to stressors, with the goal of increasing an individual’s resilience to stress over time (Trpkovici et al., 2025). In this sense, the concepts of immersion and sense of presence become crucial. The former refers to the technical quality of the environment; while the latter is related to the subjective experience of “being there” (Slater, 2003). Thanks to these features, VR allows for a more ecological reproduction of stressful sport situations characterized by time pressure, unexpected events, close scores with opponents, and even environmental factors like adversarial spectators (Ruiz et al., 2020, pp. 3–17). All these virtual components may trigger stress and anxiety responses similar to those experienced during actual competitive scenarios (Stinson & Bowman, 2014; Trpkovici et al., 2025). This being considered, VR represents a versatile tool to train athletes’ ability to self-regulate emotions by simulating ecologically valid experiences. These simulations allow for controlled manipulations of environmental factors that may negatively influence the appraisal of the balance between task demands and personal resources (Ruiz et al., 2020, pp. 3–17), thereby emphasizing the utility of individualized VR-based interventions, such as SIT.

Besides emotional regulation, immersion and the sense of presence in VR approaches are pivotal to cognitive processes, such as decision-making. Indeed, a previous study suggests that higher levels of immersion – such as those provided by HMDs compared to traditional flat screens – can positively influence decision-making processes and visual search behavior even in non-interactive interventions like video stimulation (Fortes et al., 2021).

VR usage has also proven to be effective for the training of motor skills, especially regarding the open-skills transfer to real-world contexts (Michalski et al., 2019). Accordingly, a VR-based training intervention was shown to improve table tennis performance (Michalski et al., 2019), as well as motor skill acquisition in precision sports (e.g., darts; Tirp et al., 2015) Moreover, these results in motor skill transfer are especially prominent in inexperienced athletes (Tirp et al., 2015), suggesting that VR-based interventions may be particularly valuable to accelerate skill-learning in novices.

Beyond VR, MR places virtual objects in the real world, similarly to AR, but with the possibility to interact with these objects (Le Noury et al., 2022). The potential of this technology is represented by the possibility of putting virtual objects or even virtual non-playable characters (NPC) inside a real-world environment, such as a lab or a gym, to recreate a competitive situation, but in a hybrid reality (Adams et al., 2020). A major advantage of AR/MR is greater freedom of movement, as users can still see the real world while wearing the headset.

VR integrated eye-tracking system enable not only the analysis, but also the training of attentional processes leveraging a bottom-up mechanism, gradually modifying stimuli toward functional states. Indeed through real time analysis and modulation of fixation, saccades and accommodation, athletes can improve their focus ability functional components excluding dysfunctional afferences (Pastel et al., 2023).

Despite the applicability and advantages of VR technology in sports contexts, some challenges remain, especially regarding its effective integration in athletes’ training routines. The efficacy of VR largely depends on the “sense of presence” (Slater, 2003), which is influenced by both individual and hardware-related factors (Weech et al., 2019). Among the individual factors, awareness of the equipment (Weech et al., 2019) and a person’s propensity for immersion (Weibel et al., 2010) are especially important. On the other hand, the quality and resolution of the display, the level of interaction within the virtual environment, and the synchrony between athletes’ actions and the system’s visual responses all shape the user’s experience. As such, hardware and software components play a critical role in determining the overall effectiveness of the intervention (Slater & Usoh, 1993).

Another relevant barrier to the use of VR is cybersickness, a condition characterized by symptoms similar to motion sickness, such as nausea, headache, and dizziness (Stanney et al., 1997). Its onset remains unpredictable, and not all individuals experience it during VR exposure (Weech et al., 2019), highlighting individual differences in susceptibility

(McCauley & Sharkey, 1992). Sensory mismatch (e.g. uncoupling between afferent information from VR environment and proprioception) appears to be one of the main contributing factors (Rebenitsch & Owen, 2016). Additional factors include display characteristics (Moss & Muth, 2011) and gameplay experience (Weech et al., 2019). Finally, cybersickness is also negatively associated with the sense of presence generated by VR (Weech et al., 2019).

While ongoing technological developments will likely enhance both software and hardware, overcoming current barriers may require more than just technical improvements alone. Specifically, implementing screening protocols that account for personal and social characteristics – such as equipment awareness and immersion propensity – could help to mitigate challenges related to sense presence. Similarly, screening for susceptibility to motion sickness may be an effective strategy for preventing or minimizing the impact of cybersickness in VR applications. Finally, an AI-integrated approach within VR environments may help to identify and address these challenges, thereby unlocking the full potential of VR for sport performance optimization.

5. Future directions

5.1. Toward more intelligent, adaptive systems

Psychological, physiological, task-related and environmental constraints all interact to determine performance outcomes. Therefore, the study of performance optimization requires an interdisciplinary integration of multimodal and multidimensional approaches (Bertollo et al., 2020, pp. 666–693; Glazier, 2017). So far, technology has served as a powerful means to acquire objective assessments of athletes' performances profiles, uncovering the underlying mechanisms and idiosyncratic states that characterize and support processing proficiency and performance effectiveness. Moreover, advancements in mobile and wearable systems have assisted in ever more ecological monitoring of psychophysiological and behavioral variables, while the advent of virtual, mixed, and augmented environments suggest a smoother transfer of skills from lab-based interventions to real-world competitive outcomes.

Nonetheless, the future of performance optimization may not be determined solely by our capacity to develop new technologies, but it should achieve a meaningful integration with more traditional theoretical and practical approaches to inform functional performance states and successful interventions to achieve them. Moreover, a multimodal and multidimensional perspective on the interaction of brain-body-behavior with task and environmental constraints (Glazier, 2017) highlights the interdependence among these systems. This perspective frames sport performance as a multidimensional, emergent property, which requires an interdisciplinary, rather than a unidimensional, mono- or multidisciplinary approach (De Fano et al., 2025; Glazier, 2017). Within this framework that encompasses psychological, physiological, task-related, and environmental factors, the integration of multimodal technologies helps to identify, monitor, and potentially predict functional or dysfunctional states, offering insights that can inform real-time or preventive intervention strategies.

5.2. Enhancing Machine–Machine and Human–Machine communication

To enable such integration, future research and practice must enhance machine–machine communication (e.g., synchronization of multiple data streams, optimal sampling frequencies) and human–machine interaction (e.g., the combination of machine learning outputs with expert interpretation). Moreover, different professionals must join their forces and work together via a mixed-method and interdisciplinary culture to predict qualities of athletes' behavior combining human and artificial intelligence (Raab et al., 2023). Artificial Intelligence (AI) holds particular promise in sport performance, synergically working in support of humans' efforts to classify, recognize, and analyze optimal performance (Araújo et al., 2021). The development of novel machine-learning algorithms based on brain-body-behavior data may detect subtle patterns that emerge from the integration of psychophysiological and performance metrics, potentially supporting the prediction of successful performance and preventing injurious ones (Van Eetvelde et al., 2021). Moreover, AI-enhanced technology may proactively support functional states through individualized and task-specific reactive action- and emotion-centered strategies (Chidambaram et al., 2022).

5.3. Group dynamics and E-sports

The integration of brain-body-behavior data may be especially impactful in the study of non-verbal interpersonal interactions and, more specific to sport contexts, team dynamics (De Fano et al., 2025; Filho, 2023). Whether the interaction requires mutual coordination between individuals or is defined by independent actions that share a common goal, the intrinsic link between brain-body-behavior has inspired investigations of the underlying functional brain interconnections occurring between individuals during cooperation or competition (De Fano et al., 2025). In this regard, the implementation of novel hyper-scanning techniques may capture the neural and physiological dynamics underpinning optimal performance states not only in individual athletes, but in teams, too (Filho, 2023).

E-sports could also represent a promising avenue for implementing comprehensive performance optimization approaches (Beres et al., 2023). Indeed, the digital nature of the sport introduces a series of unique sets of emotionally-charged stimuli, which can be related to technical or interpersonal factors (Kou & Gui, 2020; Pedraza-Raminez et al., 2020). Considering the crucial role that emotional control plays in e-sport performance (Beres et al., 2023), the implementation of brain-body-behavior technologies in e-sport contexts could inform the development of action- and emotion-centered regulation strategies, highlighting new practical pathways for training and performance optimization in highly ecological settings.

5.4. Reducing the research-practice gap

The transfer of lab-based results into real-world outcomes should be the final goal of sport psychology research that strives to optimize performance. Through mobile and wearable technologies we can study optimal performance in ever more ecologically valid settings (Park et al., 2015): on the court, in the ring, or on the field. In this context, the integration of psychophysiological approaches with virtual/mixed/augmented environments can further enhance ecological validity with experimental control.

6. Conclusion

Performance optimization in sport lies in the synergistic integration and augmentation of technologies to support functional performance states (Bertollo et al., 2020, pp. 666–693). Augmented technological approaches may collect multimodal data that can be utilized with AI-driven algorithms recognize psycho-physiological whole-system patterns that characterize functional or dysfunctional states. Practitioners may further integrate the resulting output with subjective experiences to provide comprehensive and adaptive feedback to the athletes. This shift—from static performance metrics to dynamic, individualized state management—has the potential to be the next step to achieve a better understanding of, train, and support optimal performance.

CRediT authorship contribution statement

Luca Bovolon: Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Conceptualization. **Antonio De Fano:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Conceptualization. **Gianluca Di Pinto:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Conceptualization. **Salvatore A. Rosito:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Conceptualization. **Camilla Scaramuzza:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Conceptualization. **Emeline Tanet:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Conceptualization. **Maurizio Bertollo:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Maurizio Bertollo reports a relationship with Psychology of Sport and Exercise, Elsevier that includes: board membership.

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Data availability

No data was used for the research described in the article.

References

Adams, K., Kiefer, A., Panchuk, D., Hunter, A., MacPherson, R., & Spratford, W. (2020). From the field of play to the laboratory: Recreating the demands of competition with augmented reality simulated sport. *Journal of Sports Sciences, 38*(5), 486–493.

Addleman, J. S., Lackey, N. S., DeBlauw, J. A., & Hajduczok, A. G. (2024). Heart rate variability applications in strength and conditioning: A narrative review. *Journal of Functional Morphology and Kinesiology, 9*(2), 93. https://doi.org/10.3390/jfmk9020093

Altini, M., & Amft, O. (2016). HRV4Training: Large-scale longitudinal training load analysis in unconstrained free-living settings using a smartphone application. In *EMBC. IEEE engineering in medicine and biology society. Annual international conference* (pp. 2610–2613). https://doi.org/10.1109/EMBC.2016.7591265, 2016.

Araújo, D., Couceiro, M., Seifert, L., Sarmento, H., & Davids, K. (2021). *Artificial intelligence in sport performance analysis*. Routledge.

Araújo, D., Davids, K., & Renshaw, I. (2020). Cognition, emotion and action in sport: An ecological dynamics perspective. *Handbook of Sport Psychology*, 535–555.

Badau, D., Badau, A., Ene-Voiculescu, C., Larion, A., Ene-Voiculescu, V., Mihaila, I., … Abramiuc, A. (2022). The impact of implementing an exergame program on the level of reaction time optimization in handball, volleyball, and basketball players. *International Journal of Environmental Research and Public Health, 19*(9), 5598.

Balk, Y. A., & De Jonge, J. (2020). The "underrecovery trap": When physical fatigue impairs the physical and mental recovery process. *Sport Exercise and Performance Psychology, 10*(1), 88–101. https://doi.org/10.1037/spy0000249

Beres, N. A., Klarkowski, M., & Mandryk, R. L. (2023). Playing with emotions: A systematic review examining emotions and emotion regulation in esports performance. *Proceedings of the ACM on Human-computer Interaction, 7*, 558–587.

Berryman, D. R. (2012). Augmented reality: A review. *Medical Reference Services Quarterly, 31*(2), 212–218.

Bertollo, M., Berchicci, M., & di Fronso, S. (2021). Mind-body interaction in sport psychophysiology. *Sport, Exercise and Performance Psychology: Research Directions to Advance the Field, 9*, 118–132.

Bertollo, M., di Fronso, S., Conforto, S., Schmid, M., Bortoli, L., Comani, S., & Robazza, C. (2016). Proficient brain for optimal performance: The MAP model perspective. *PeerJ, 4*, Article e2082.

Bertollo, M., Doppelmayr, M., & Robazza, C. (2020). Using brain technologies in practice. *Handbook of sport psychology*.

Beste, C., Münchau, A., & Frings, C. (2023). Towards a systematization of brain oscillatory activity in actions. *Communications Biology, 6*(1), 137.

Bolek, J. E., Rosenthal, R. L., & Sherman, R. A. (2017). Advanced topics in surface electromyography: Instrumentation and applications. In M. S. Schwartz, & F. Andrasik (Eds.), *Biofeedback: A practitioner's guide* (4th ed., pp. 68–84). Guilford Publications, 2017.

Brimmell, J., Edwards, E. J., & Vaughan, R. S. (2024). Executive function and visual attention in sport: A systematic review. *International Review of Sport and Exercise Psychology, 17*(2), 1278–1311.

Brinkman, C., Baez, S. E., Quintana, C., Andrews, M. L., Heebner, N. R., Hoch, M. C., & Hoch, J. M. (2020). The reliability of an upper-and lower-extremity visuomotor reaction time task. *Journal of Sport Rehabilitation, 30*(5), 828–831.

Broadbent, D. P., Causer, J., Williams, A. M., & Ford, P. R. (2015). Perceptual-cognitive skill training and its transfer to expert performance in the field: Future research directions. *European Journal of Sport Science, 15*(4), 322–331.

Budnik-Przybylska, D., Kastrau, A., Jasik, P., Kaźmierczak, M., Doliński, Ł., Syty, P., … Bertollo, M. (2021). Neural oscillation during mental imagery in sport: An olympic sailor case study. *Frontiers in Human Neuroscience, 15*, Article 669422.

Butkevičiūtė, E., Bikulčienė, L., Sidekerskienė, T., Blažauskas, T., Maskeliūnas, R., Damaševičius, R., & Wei, W. (2019). Removal of movement artefact for Mobile EEG analysis in sports exercises. *IEEE Access, 7*, 7206–7217.

Campanella, M., Cardinali, L., Ferrari, D., Migliaccio, S., Silvestri, F., Falcioni, L., … Bonavolontà, V. (2024). Effects of fitlight training on cognitive-motor performance in élite judo athletes. *Heliyon, 10*(7), Article e28712.

Casella, A., Ventura, E., & Di Russo, F. (2022). The influence of a specific cognitive-motor training protocol on planning abilities and visual search in young soccer players. *Brain Sciences, 12*(12), 1624.

Chang, M., Büchel, D., Reinecke, K., Lehmann, T., & Baumeister, J. (2022). Ecological validity in exercise neuroscience research: A systematic investigation. *European Journal of Neuroscience, 55*(2), 487–509.

Chen, T. T., Wang, K. P., Cheng, M. Y., Chang, Y. T., Huang, C. J., & Hung, T. M. (2019). Impact of emotional and motivational regulation on putting performance: A frontal alpha asymmetry study. *PeerJ, 7*, Article e6777.

Chen, T., Xu, D., Zhou, Z., Zhou, H., Shao, S., & Gu, Y. (2025). Prediction of vertical ground reaction forces under different running speeds: Integration of wearable IMU with CNN-xLSTM. *Sensors, 25*(4), 1249. https://doi.org/10.3390/s25041249

Cheng, M. Y., Huang, C. J., Chang, Y. K., Koester, D., Schack, T., & Hung, T. M. (2015). Sensorimotor rhythm neurofeedback enhances golf putting performance. *Journal of Sport & Exercise Psychology, 37*(6), 626–636.

Cheng, M. Y., Wang, K. P., Doppelmayr, M., Steinberg, F., Hung, T. M., Lu, C., Tan, Y. Y., & Hatfield, B. (2023). QEEG markers of superior shooting performance in skilled marksmen: An investigation of cortical activity on psychomotor efficiency hypothesis. *Psychology of Sport and Exercise, 65*, Article 102320. https://doi.org/10.1016/j.psychsport.2022.102320

Cheron, G., Petit, G., Cheron, J., Leroy, A., Cebolla, A., Cevallos, C., … Dan, B. (2016). Brain oscillations in sport: Toward EEG biomarkers of performance. *Frontiers in Psychology, 7*, 246.

Chidambaram, S., Maheswaran, Y., Patel, K., Sounderajah, V., Hashimoto, D. A., Seastedt, K. P., … Darzi, A. (2022). Using artificial intelligence-enhanced sensing and wearable technology in sports medicine and performance optimisation. *Sensors, 22*(18), 6920.

Chiu, Y. K., Pan, C. Y., Chen, F. C., Tseng, Y. T., & Tsai, C. L. (2020). Behavioral and cognitive electrophysiological differences in the executive functions of Taiwanese basketball players as a function of playing position. *Brain Sciences, 10*(6), 387.

Christie, S., Bertollo, M., & Werthner, P. (2020). The effect of an integrated neurofeedback and biofeedback training intervention on ice hockey shooting performance. *Journal of Sport & Exercise Psychology, 42*(1), 34–47.

Chueh, T. Y., Lu, C. M., Huang, C. J., Hatfield, B. D., & Hung, T. M. (2023). Collaborative neural processes predict successful cognitive-motor performance. *Scandinavian Journal of Medicine & Science in Sports, 33*(3), 331–340.

Clark, J., Betz, B., Borders, L., Kuehn-Himmler, A., Hasselfeld, K., & Divine, J. (2020). Vision training and reaction training for improving performance and reducing injury risk in athletes: Sports vision training. *Journal of Sports and Performance Vision, 2*(1), e8–e16.

Cooke, A. (2013). Readying the head and steadying the heart: A review of cortical and cardiac studies of preparation for action in sport. *International Review of Sport and Exercise Psychology, 6*(1), 122–138.

Craig, C. (2013). Understanding perception and action in sport: How can virtual reality technology help? *Sports Technology, 6*(4), 161–169.

Curtis, R. M., Huggins, R. A., Benjamin, C. L., Sekiguchi, Y., Adams, W. M., Arent, S. M., Jain, R., Miller, S. J., Walker, A. J., & Casa, D. J. (2020). Contextual factors influencing external and internal training loads in collegiate men's soccer. *The Journal of Strength & Conditioning Research, 34*(2), 374–381. https://doi.org/10.1519/JSC.0000000000003361

De Fano, A., Fiedler, P.-, Zappasodi, F., Bertollo, M., & Comani, S. (2025). Non-verbal joint action in healthy adults: A systematic scoping review of EEG-hyperscanning research. *Social Cognitive and Affective Neuroscience*. https://doi.org/10.1093/scan/nsaf050

de Zambotti, M., Goldstein, C., Cook, J., Menghini, L., Altini, M., Cheng, P., & Robillard, R. (2023). State of the science and recommendations for using wearable technology in sleep and circadian research. *Sleep, 47*(4). https://doi.org/10.1093/sleep/zsad325

Debertin, D., Wargel, A., & Mohr, M. (2024). Reliability of Xsens IMU-based lower extremity joint angles during In-Field running. *Sensors, 24*(3), 871. https://doi.org/10.3390/s24030871

di Fronso, S., Tamburro, G., Robazza, C., Bortoli, L., Comani, S., & Bertollo, M. (2018). Focusing attention on muscle exertion increases EEG coherence in an endurance cycling task. *Frontiers in Psychology, 9*, 1249.

di Fronso, S., Werthner, P., Christie, S., & Bertollo, M. (2020). Using technology for self-regulation in sport. In *Feelings in sport* (pp. 178–186). Routledge.

Di Martino, G., Giommoni, S., Esposito, F., Alessandro, D., Della Valle, C., Iuliano, E., … di Cagno, A. (2024). Enhancing focus and short reaction time in épée fencing: The power of the science vision training academy system. *Journal of Functional Morphology and Kinesiology, 9*(4), 213.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*(1), 135–168.

Dobbs, W. C., Fedewa, M. V., MacDonald, H. V., Holmes, C. J., Cicone, Z. S., Plews, D. J., & Esco, M. R. (2019). The accuracy of acquiring heart rate variability from portable devices: A systematic review and meta-analysis. *Sports Medicine, 49*(3), 417–435. https://doi.org/10.1007/s40279-019-01061-5

Düking, P., Zinner, C., Trabelsi, K., Reed, J. L., Holmberg, H., Kunz, P., & Sperlich, B. (2021). Monitoring and adapting endurance training on the basis of heart rate

variability monitored by wearable technologies: A systematic review with meta-analysis. *Journal of Science and Medicine in Sport, 24*(11), 1180–1192. https://doi.org/10.1016/j.jsams.2021.04.012
Ferguson, H., Harnish, C., Klich, S., Michalik, K., Dunst, A. K., Zhou, T., & Chase, J. G. (2023). Track cycling sprint sex differences using power data. *PeerJ, 11*, Article e15671. https://doi.org/10.7717/peerj.15671
Filho, E. (2023). Shared and complementary zones of optimal functioning (SZOF and CZOF): Theoretical summary and guidelines for practice. *Journal of Sport Psychology in Action, 14*(3), 131–144.
Filho, E., Dobersek, U., & Husselman, T. A. (2021). The role of neural efficiency, transient hypofrontality and neural proficiency in optimal performance in self-paced sports: A meta-analytic review. *Experimental Brain Research, 239*(5), 1381–1393.
Forni, F., Farinini, E., Leardi, R., & Rinaldo, A. (2021). Effects of visual training on motor performance in young tennis players using FitLight trainer. *The Journal of Sports Medicine and Physical Fitness, 62*(4), 585–592.
Fortes, L. S., Almeida, S. S., Praça, G. M., Nascimento-Júnior, J. R., Lima-Junior, D., Barbosa, B. T., & Ferreira, M. E. (2021). Virtual reality promotes greater improvements than video-stimulation screen on perceptual-cognitive skills in young soccer athletes. *Human Movement Science, 79*, Article 102856.
Gallicchio, G., Cooke, A., & Ring, C. (2017). Practice makes efficient: Cortical alpha oscillations are associated with improved golf putting performance. *Sport, Exercise, and Performance Psychology, 6*(1), 89.
Galloway, S. M. (2011). The effect of biofeedback on tennis service accuracy. *International Journal of Sport and Exercise Psychology, 9*(3), 251–266.
Gevirtz, R. N., Schwartz, M. S., & Lehrer, P. M. (2017). Cardiorespiratory measurement and assessment in applied psychophysiology. In M. S. Schwartz, & F. Andrasik (Eds.), *Biofeedback: A practitioner's guide* (4th ed., pp. 85–97). Guilford Publications, 2017.
Glazier, P. S. (2017). Towards a grand unified theory of sports performance. *Human Movement Science, 56*, 139–156.
Goodyear, V. A. (2017). Social media, apps and wearable technologies: Navigating ethical dilemmas and procedures. *Qualitative Research in Sport Exercise and Health, 9* (3), 285–302. https://doi.org/10.1080/2159676x.2017.1303790
Gruzelier, J. H. (2014). EEG-neurofeedback for optimising performance. I: A review of cognitive and affective outcome in healthy participants. *Neuroscience & Biobehavioral Reviews, 44*, 124–141.
Guppy, F., Muniz-Pardos, B., Angeloudis, K., Grivas, G. V., Pitsiladis, A., Bundy, R., Zelenkova, I., Tanisawa, K., Akiyama, H., Keramitsoglou, I., Miller, M., Knopp, M., Schweizer, F., Luckfiel, T., Ruiz, D., Racinais, S., & Pitsiladis, Y. (2023). Technology innovation and guardrails in elite sport: The future is now. *Sports Medicine, 53*(S1), 97–113. https://doi.org/10.1007/s40279-023-01913-1
Hanin, Y., Hanina, M., Šašek, H., & Kobilšek, A. (2016). Emotion-centered and action-centered coping in elite sport: Task execution design approach. *International Journal of Sports Science & Coaching, 11*(4), 566–588. https://doi.org/10.1177/1747954116654782
Haotian, X., Anmin, G., Jiangong, L., Fan, W., Peng, D., & Yunfa, F. (2023). Online adaptive classification system for brain–computer interface based on error-related potentials and neurofeedback. *Biomedical Signal Processing and Control, 82*, Article 104554.
Hassan, A. K., Alhumaid, M. M., & Hamad, B. E. (2022). The effect of using reactive agility exercises with the FITLIGHT training system on the speed of visual reaction time and dribbling skill of basketball players. *Sports, 10*(11), 176. https://doi.org/10.3390/sports10110176
Heilmann, F., Weinberg, H., & Wollny, R. (2022). The impact of practicing open-vs. Closed-skill sports on executive functions—A meta-analytic and systematic review with a focus on characteristics of sports. *Brain Sciences, 12*(8), 1071.
Hodossy, L., Ainley, V., & Tsakiris, M. (2021). How do we relate to our heart? Neurobehavioral differences across three types of engagement with cardiac interoception. *Biological Psychology, 165*, Article 108198. https://doi.org/10.1016/j.biopsycho.2021.108198
Holmes, P. S., & Wright, D. J. (2017). Motor cognition and neuroscience in sport psychology. *Current Opinion in Psychology, 16*, 43–47.
Hooper, B., Faria, L. O., Fortes, L. D. S., Wanner, S. P., & Albuquerque, M. R. (2022). Development and reliability of a test for assessing executive functions during exercise. *Applied Neuropsychology: Adult, 29*(4), 750–760.
Hornikova, H., Jeleň, M., & Zemkova, E. (2021). Determinants of reactive agility in tests with different demands on sensory and motor components in handball players. *Applied Sciences, 11*(14), 6531.
Impellizzeri, F. M., Marcora, S. M., & Coutts, A. J. (2019). Internal and external training load: 15 years on. *International Journal of Sports Physiology and Performance, 14*(2), 270–273. https://doi.org/10.1123/ijspp.2018-0935
Kaikkonen, P., Hynynen, E., Mann, T., Rusko, H., & Nummela, A. (2011). Heart rate variability is related to training load variables in interval running exercises. *European Journal of Applied Physiology, 112*(3), 829–838. https://doi.org/10.1007/s00421-011-2031-z
Kanatschnig, T., Schrapf, N., Leitner, L., Wood, G., Körner, C., Tilp, M., & Kober, S. E. (2025). EEG theta and alpha oscillations during tactical decision-making: An examination of the neural efficiency hypothesis in volleyball. *PLoS One, 20*(2), Article e0318234.
Kao, S. C., Huang, C. J., & Hung, T. M. (2013). Frontal midline theta is a specific indicator of optimal attentional engagement during skilled putting performance. *Journal of Sport & Exercise Psychology, 35*(5), 470–478.
Katanić, B., Ilić, P., Stojmenović, A., & Vitasović, M. (2020). The application of fitlight trainer system in sports. *Physical Culture, 74*(2).
Kellermann, B., Collins, D., MacPherson, A., & Bertollo, M. (2024a). Investigating in-performance transitions between mental states in high-level judoka using video-based stimulated recall. *Psychology of Sport and Exercise, 74*, Article 102701. https://doi.org/10.1016/j.psychsport.2024.102701
Kellermann, B., Collins, D., MacPherson, A., & Bertollo, M. (2024b). Exploring characteristics of and transitions between mental states within the multi-action plan model in high-level judo. *European Journal of Sport Science, 24*(7), 907–917.
Khalsa, S. S., Adolphs, R., Cameron, O. G., Critchley, H. D., Davenport, P. W., Feinstein, J. S., Feusner, J. D., Garfinkel, S. N., Lane, R. D., Mehling, W. E., Meuret, A. E., Nemeroff, C. B., Oppenheimer, S., Petzschner, F. H., Pollatos, O., Rhudy, J. L., Schramm, L. P., Simmons, W. K., Stein, M. B., … Zucker, N. (2018). Interoception and mental health: A roadmap. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 3*(6), 501–513. https://doi.org/10.1016/j.bpsc.2017.12.004
Kober, S. E., Wood, G., & Berger, L. M. (2024). Controlling virtual reality with brain signals: State of the art of using VR-Based feedback in neurofeedback applications. *Applied Psychophysiology and Biofeedback*, 1–20.
Kou, Y., & Gui, X. (2020). Emotion regulation in esports gaming: A qualitative study of league of legends. *Proceedings of the ACM on Human-Computer Interaction, 4*(CSCW2), 1–25.
Le Noury, P., Polman, R., Maloney, M., & Gorman, A. (2022). A narrative review of the current state of extended reality technology and how it can be utilised in sport. *Sports Medicine, 52*(7), 1473–1489.
Li, R. T., Kling, S. R., Salata, M. J., Cupp, S. A., Sheehan, J., & Voos, J. E. (2016). Wearable performance devices in sports medicine. *Sports Health, 8*(1), 74–78. https://doi.org/10.1177/1941738115616917
Li, L., & Smith, D. M. (2021). Neural efficiency in athletes: A systematic review. *Frontiers in Behavioral Neuroscience, 15*, Article 698555.
Liang, T., Zhang, Q., Hong, L., Liu, X., Dong, B., Wang, H., & Liu, X. (2021). Directed information flow analysis reveals muscle fatigue-related changes in muscle networks and corticomuscular coupling. *Frontiers in Neuroscience, 15*, Article 750936.
Liu, J., Sheng, Y., & Liu, H. (2019). Corticomuscular coherence and its applications: A review. *Frontiers in Human Neuroscience, 13*, 100.
Lo, L. C., Hatfield, B. D., Wu, C. T., Chang, C. C., & Hung, T. M. (2019). Elevated state anxiety alters cerebral cortical dynamics and degrades precision cognitive-motor performance. *Sport, Exercise, and Performance Psychology, 8*(1), 21.
Makeig, S., Gramann, K., Jung, T. P., Sejnowski, T. J., & Poizner, H. (2009). Linking brain, mind and behavior. *International Journal of Psychophysiology, 73*(2), 95–100.
Marino, M., & Mantini, D. (2024). Human brain imaging with high-density electroencephalography: Techniques and applications. *The Journal of Physiology*. https://doi.org/10.1113/JP286639
Maszczyk, A., Gołaś, A., Pietraszewski, P., Kowalczyk, M., Cięszczyk, P., Kochanowicz, A., & Zając, A. (2018). Neurofeedback for the enhancement of dynamic balance of judokas. *Biology of Sport, 35*(1), 99–102.
McCauley, M. E., & Sharkey, T. J. (1992). Cybersickness: Perception of self-motion in virtual environments. *Presence: Teleoperators and Virtual Environments, 1*(3), 311–318.
McMorris, T. (2020). Cognitive fatigue effects on physical performance: The role of interoception. *Sports Medicine, 50*(10), 1703–1708. https://doi.org/10.1007/s40279-020-01320-w
McMorris, T., Barwood, M., & Corbett, J. (2018). Central fatigue theory and endurance exercise: Toward an interoceptive model. *Neuroscience & Biobehavioral Reviews, 93*, 93–107. https://doi.org/10.1016/j.neubiorev.2018.03.024
Michael, S., Jay, O., Graham, K. S., & Davis, G. M. (2018). Influence of exercise modality on cardiac parasympathetic and sympathetic indices during post-exercise recovery. *Journal of Science and Medicine in Sport, 21*(10), 1079–1084. https://doi.org/10.1016/j.jsams.2018.01.015
Michalski, S. C., Szpak, A., Saredakis, D., Ross, T. J., Billinghurst, M., & Loetscher, T. (2019). Getting your game on: Using virtual reality to improve real table tennis skills. *PLoS One, 14*(9), Article e0222351.
Mirifar, A., Beckmann, J., & Ehrlenspiel, F. (2017). Neurofeedback as supplementary training for optimizing athletes' performance: A systematic review with implications for future research. *Neuroscience & Biobehavioral Reviews, 75*, 419–432.
Mocco, A., Valmaggia, L., Bernardi, L., Alfieri, M., & Tarricone, I. (2024). Enhancing physical activity with immersive virtual reality: A systematic review. *Cyberpsychology, Behavior, and Social Networking, 27*(5), 303–317.
Moreira, P. E. D., Dieguez, G. T. D. O., Bredt, S. D. G. T., & Praça, G. M. (2021). The acute and chronic effects of dual-task on the motor and cognitive performances in athletes: A systematic review. *International Journal of Environmental Research and Public Health, 18*(4), 1732.
Moss, J. D., & Muth, E. R. (2011). Characteristics of head-mounted displays and their effects on simulator sickness. *Human Factors, 53*(3), 308–319.
Mottola, F., Blanchfield, A., Hardy, J., & Cooke, A. (2021). EEG neurofeedback improves cycling time to exhaustion. *Psychology of Sport and Exercise, 55*, Article 101944.
Nakamura, J., & Csíkszentmihályi, M. (2002). The concept of flow. *Handbook of Positive Psychology, 89*, 105.
Neumann, D. L., Moffitt, R. L., Thomas, P. R., Loveday, K., Watling, D. P., Lombard, C. L., & Tremeer, M. A. (2018). A systematic review of the application of interactive virtual reality to sport. *Virtual Reality, 22*, 183–198.
Onagawa, R., Muraoka, Y., Hagura, N., & Takemi, M. (2023). An investigation of the effectiveness of neurofeedback training on motor performance in healthy adults: A systematic review and meta-analysis. *NeuroImage, 270*, Article 120000.
Pagaduan, J. C., Chen, Y.-S., Fell, J. W., & Wu, S. S. X. (2020). Can heart rate variability biofeedback improve athletic performance? A systematic review. *Journal of Human Kinetics, 73*, 103–114.
Park, H.-D., & Blanke, O. (2019). Heartbeat-evoked cortical responses: Underlying mechanisms, functional roles, and methodological considerations. *NeuroImage, 197*, 502–511. https://doi.org/10.1016/j.neuroimage.2019.04.081

Park, J. L., Fairweather, M. M., & Donaldson, D. I. (2015). Making the case for mobile cognition: EEG and sports performance. *Neuroscience & Biobehavioral Reviews, 52*, 117–130.
Parr, J. V., Gallicchio, G., Canales-Johnson, A., Uiga, L., & Wood, G. (2023). Cortical, muscular, and kinetic activity underpinning attentional focus strategies during visuomotor control. *Psychophysiology, 60*(6), Article e14249.
Parr, J. V., Gallicchio, G., & Wood, G. (2021). EEG correlates of verbal and conscious processing of motor control in sport and human movement: A systematic review. *International Review of Sport and Exercise Psychology, 16*(1), 396–427. https://doi.org/10.1080/1750984X.2021.1878548
Pastel, S., Marlok, J., Bandow, N., & Witte, K. (2023). Application of eye-tracking systems integrated into immersive virtual reality and possible transfer to the sports sector-A systematic review. *Multimedia Tools and Applications, 82*(3), 4181–4208.
Pedraza-Ramirez, I., Musculus, L., Raab, M., & Laborde, S. (2020). Setting the scientific stage for esports psychology: A systematic review. *International Review of Sport and Exercise Psychology, 13*(1), 319–352.
Peng, J., Zikereya, T., Shao, Z., & Shi, K. (2024). The neuromechanical of beta-band corticomuscular coupling within the human motor system. *Frontiers in Neuroscience, 18*, Article 1441002.
Perrey, S. (2022). Evaluating brain functioning with NIRS in sports: Cerebral oxygenation and cortical activation are two sides of the same coin. *Frontiers in Neuroergonomics, 3*, Article 1022924.
Perrey, S., & Besson, P. (2018). Studying brain activity in sports performance: Contributions and issues. *Progress in Brain Research, 240*, 247–267.
Pesce, C., & Tocci, N. (2024). Creativity and consciousness in motion: The roundtrip of "mindful" and" mindless" processes in embodied creativity. *Progress in Brain Research, 287*, 123–151.
Petzschner, F. H., Weber, L. A., Wellstein, K. V., Paolini, G., Do, C. T., & Stephan, K. E. (2019). Focus of attention modulates the heartbeat evoked potential. *NeuroImage, 186*, 595–606. https://doi.org/10.1016/j.neuroimage.2018.11.037
Pinelli, S., Zinno, R., Jòdar-Portas, A., Prats-Puig, A., Font-Lladó, R., & Bragonzoni, L. (2025). Automated detection of change of direction in basketball players using XSENS Motion tracking. *Sensors, 25*(3), 942. https://doi.org/10.3390/s25030942
Piskin, D., Benjaminse, A., Dimitrakis, P., & Gokeler, A. (2022). Neurocognitive and neurophysiological functions related to ACL injury: A framework for neurocognitive approaches in rehabilitation and return-to-sports tests. *Sports Health, 14*(4), 549–555.
Pollatos, O., & Schandry, R. (2004). Accuracy of heartbeat perception is reflected in the amplitude of the heartbeat-evoked brain potential. *Psychophysiology, 41*(3), 476–482. https://doi.org/10.1111/1469-8986.2004.00170.x
Pusenjak, N., Grad, A., Tusak, M., Leskovsek, M., & Schwarzlin, R. (2015). Can biofeedback training of psychophysiological responses enhance athletes' sport performance? A practitioner's perspective. *The Physician and Sportsmedicine, 43*(3), 287–299.
Raab, M., Schinke, R., & Maher, C. A. (2023). Technology meets sport psychology: How technology and artificial intelligence can shape the future of elite sport performance. *Journal of Sport Psychology in Action, 15*(2), 63–69. https://doi.org/10.1080/21520704.2023.2287324
Raman, D., & Filho, E. (2024). The relationship between T7-Fz alpha coherence and peak performance in self-paced sports: A meta-analytical review. *Experimental Brain Research, 242*(6), 1253–1265.
Rauschnabel, P. A., Felix, R., Hinsch, C., Shahab, H., & Alt, F. (2022). What is XR? Towards a framework for augmented and virtual reality. *Computers in Human Behavior, 133*, Article 107289.
Raymond, J., Sajid, I., Parkinson, L. A., & Gruzelier, J. H. (2005). Biofeedback and dance performance: A preliminary investigation. *Applied Psychophysiology and Biofeedback, 30*, 65–73.
Rebenitsch, L., & Owen, C. (2016). Review on cybersickness in applications and visual displays. *Virtual Reality, 20*, 101–125.
Renshaw, I., Davids, K., Newcombe, D., & Roberts, W. (2019). *The constraints-led approach: Principles for sports coaching and practice design*. New York: Routledge.
Robazza, C., Bertollo, M., Filho, E., Hanin, Y., & Bortoli, L. (2016). Perceived control and hedonic tone dynamics during performance in elite shooters. *Research Quarterly for Exercise & Sport, 87*(3), 284–294.
Ros, T., Baars, J., B, Lanius, R. A., & Vuilleumier, P. (2014). Tuning pathological brain oscillations with neurofeedback: A systems neuroscience framework. *Frontiers in Human Neuroscience, 8*, 1008.
Ros, T., Enriquez-Geppert, S., Zotev, V., Young, K. D., Wood, G., Whitfield-Gabrieli, S., Wan, F., Vuilleumier, P., Vialatte, F., Van De Ville, D., Todder, D., Surmeli, T., Sulzer, J. S., Strehl, U., Sterman, M. B., Steiner, N. J., Sorger, B., Soekadar, S. R., Sitaram, R., … Thibault, R. T. (2020). Consensus on the reporting and experimental design of clinical and cognitive-behavioural neurofeedback studies (CRED-nf checklist). *Brain, 143*(6), 1674–1685.
Rostami, R., Sadeghi, H., Karami, K. A., Abadi, M. N., & Salamati, P. (2012). The effects of neurofeedback on the improvement of rifle shooters' performance. *Journal of Neurotherapy, 16*(4), 264–269.
Ruiz, M. C., Bortoli, L., & Robazza, C. (2020). *The multi-states (MuSt) theory for emotion- and action-regulation in sports*. Routledge eBooks. https://doi.org/10.4324/9781003052012-2
Russell, S., Johnston, R. D., Stanimirovic, R., & Halson, S. L. (2023). Global practitioner assessment and management of mental fatigue and mental recovery in high-performance sport: A need for evidence-based best-practice guidelines. *Scandinavian Journal of Medicine & Science in Sports, 34*(1). https://doi.org/10.1111/sms.14491
Sargent, C., Lastella, M., Halson, S. L., & Roach, G. D. (2015). The validity of activity monitors for measuring sleep in elite athletes. *Journal of Science and Medicine in Sport, 19*(10), 848–853. https://doi.org/10.1016/j.jsams.2015.12.007
Schack, T., & Frank, C. (2021). Mental representation and the cognitive architecture of skilled action. *Review of Philosophy and Psychology, 12*, 527–546.
Schmidt-Kassow, M., & Kaiser, J. (2023). The brain in motion-cognitive effects of simultaneous motor activity. *Frontiers in Integrative Neuroscience, 17*, Article 1127310. https://doi.org/10.3389/fnint.2023.1127310
Schmitt, L., Regnard, J., Parmentier, A., Mauny, F., Mourot, L., Coulmy, N., & Millet, G. (2015). Typology of "fatigue" by heart rate variability analysis in elite Nordic-skiers. *International Journal of Sports Medicine, 36*(12), 999–1007. https://doi.org/10.1055/s-0035-1548885
Seabury, T., Benton, D., & Young, H. A. (2023). Interoceptive differences in elite sprint and long-distance runners: A multidimensional investigation. *PLoS One, 18*(1), Article e0278067. https://doi.org/10.1371/journal.pone.0278067
Shokri, A., & Nosratabadi, M. (2021). Comparison of biofeedback and combined interventions on athlete's performance. *Applied Psychophysiology and Biofeedback, 46*(3), 227–234.
Siekańska, M., Bondár, R. Z., di Fronso, S., Blecharz, J., & Bertollo, M. (2021). Integrating technology in psychological skills training for performance optimization in elite athletes: A systematic review. *Psychology of Sport and Exercise, 57*, Article 102008.
Silvestri, F., Campanella, M., Bertollo, M., Albuquerque, M. R., Bonavolontà, V., Perroni, F., & Curzi, D. (2023). Acute effects of fitlight training on cognitive-motor processes in young basketball players. *International Journal of Environmental Research and Public Health, 20*(1), 817.
Sitaram, R., Ros, T., Stoeckel, L., Haller, S., Scharnowski, F., Lewis-Peacock, J., Weiskopf, N., Blefari, M. L., Rana, M., Oblak, E., Birbaumer, N., & Sulzer, J. (2017). Closed-loop brain training: The science of neurofeedback. *Nature Reviews Neuroscience, 18*(2), 86–100.
Slater, M. (2003). A note on presence terminology. *Presence Connect, 3*(3), 1–5.
Slater, M., & Usoh, M. (1993). Representations systems, perceptual position, and presence in immersive virtual environments. *Presence: Teleoperators and Virtual Environments, 2*(3), 221–233.
Stanney, K. M., Kennedy, R. S., & Drexler, J. M. (1997). Cybersickness is not simulator sickness. *Proceedings of the Human Factors and Ergonomics Society - Annual Meeting, 41*(2), 1138–1142. Sage CA: Los Angeles, CA: SAGE Publications.
Stinson, C., & Bowman, D. A. (2014). Feasibility of training athletes for high-pressure situations using virtual reality. *IEEE Transactions on Visualization and Computer Graphics, 20*(4), 606–615.
Stone, J. A., Strafford, B. W., Toner, C., & Davids, K. (2018). Effectiveness and efficiency of virtual reality designs to enhance athlete development: An ecological dynamics perspective. *Movement & Sport Sciences-Science & Motricité, 102*(4), 51–60.
Tanaka, Y., Ito, Y., Shibata, M., Terasawa, Y., & Umeda, S. (2025). Heartbeat evoked potentials reflect interoceptive awareness during an emotional situation. *Scientific Reports, 15*(1), 8072. https://doi.org/10.1038/s41598-025-92854-4
Teques, P., Araújo, D., Seifert, L., Del Campo, V. L., & Davids, K. (2017). The resonant system: Linking brain–body–environment in sport performance. *Progress in Brain Research, 234*, 33–52.
Tirp, J., Steingröver, C., Wattie, N., Baker, J., & Schorer, J. (2015). Virtual realities as optimal learning environments in sport-A transfer study of virtual and real dart throwing. *Psychological Test and Assessment Modeling, 57*(1), 57.
Tomporowski, P. D., & Pesce, C. (2019). Exercise, sports, and performance arts benefit cognition via a common process. *Psychological Bulletin, 145*(9), 929.
Trpkovici, M., Makai, A., Prémusz, V., & Ács, P. (2025). The possible application of virtual reality for managing anxiety in athletes. *Frontiers in Sports and Active Living, 7*, Article 1493544.
Van Eetvelde, H., Mendonça, L. D., Ley, C., Seil, R., & Tischer, T. (2021). Machine learning methods in sport injury prediction and prevention: A systematic review. *Journal of Experimental Orthopaedics, 8*, 1–15.
Vater, C., & Strasburger, H. (2021). The top five peripheral vision tools in sport. *Optometry and Vision Science, 98*(7), 704–722.
Verschueren, J., Tassignon, B., Pluym, B., Van Cutsem, J., Verhagen, E., & Meeusen, R. (2019). Bringing context to balance: Development of a reactive balance test within the injury prevention and return to sport domain. *Archives of Physiotherapy, 9*, 1–8.
Voigt, L., & Raab, M. (2024). Mind in action: The interplay of cognition and action in skilled performance. *International Journal of Sport and Exercise Psychology, 22*(2), 307–313.
Wang, K. P., Cheng, M. Y., Chen, T. T., Huang, C. J., Schack, T., & Hung, T. M. (2020). Elite golfers are characterized by psychomotor refinement in cognitive-motor processes. *Psychology of Sport and Exercise, 50*, Article 101739.
Wang, C. H., Moreau, D., & Kao, S. C. (2019). From the lab to the field: Potential applications of dry EEG systems to understand the brain-behavior relationship in sports. *Frontiers in Neuroscience, 13*, 893.
Weech, S., Kenny, S., & Barnett-Cowan, M. (2019). Presence and cybersickness in virtual reality are negatively related: A review. *Frontiers in Psychology, 10*, 158.
Weibel, D., Wissmath, B., & Mast, F. W. (2010). Immersion in mediated environments: The role of personality traits. *Cyberpsychology, Behavior, and Social Networking, 13*(3), 251–256.
Wilson, M. R., Webb, A., Wylie, L. J., & Vine, S. J. (2018). The quiet eye is sensitive to exercise-induced physiological stress. *Progress in Brain Research, 35–52*. https://doi.org/10.1016/bs.pbr.2018.08.008
Yoris, A. E., Cira, L. F., Luque-Casado, A., Salvotti, C., Tajadura-Jiménez, A., Avancini, C., Zarza-Rebollo, J. A., Sanabria, D., & Perakakis, P. (2024). Delving into the relationship between regular physical exercise and cardiac interoception in two cross-sectional studies. *Neuropsychologia, 198*, Article 108867. https://doi.org/10.1016/j.neuropsychologia.2024.108867
Yu, C. L., Cheng, M. Y., An, X., Chueh, T. Y., Wu, J. H., Wang, K. P., & Hung, T. M. (2025). The effect of EEG neurofeedback training on sport performance: A systematic

review and meta-analysis. *Scandinavian Journal of Medicine & Science in Sports, 35*(5), Article e70055.

Yu, C. L., Kao, C. W., Wu, J. H., Hung, E., Chang, W. C., Yang, R. T., … Hung, T. M. (2024). Effects of self-efficacy on frontal midline theta power and golf putting performance. *Frontiers in Psychology, 15*, Article 1349918.

Zeng, R., Shen, H., He, Y., Ge, L.-K., Zhao, D., Zhu, S., Cai, L., Wang, Y., Mehling, W. E., & Wei, G.-X. (2025). Exploring individual differences in interoception among athletes based on a three-dimensional construct of interoception. *Psychophysiology, 62*(1), Article e14766. https://doi.org/10.1111/psyp.14766

Zentgraf, K., & Raab, M. (2023). Excellence and expert performance in sports: What do we know and where are we going? *International Journal of Sport and Exercise Psychology, 21*(5), 766–786. https://doi.org/10.1080/1612197X.2023.2229362