Neurocognitive empowerment, embodied practices, and peak performance in sports: case studies and future challenges

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DOI: https://doi.org/10.7358/neur-2024-035-criv

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ABSTRACT

The integration of neurosciences and sport psychology has revitalized the study of cognitive and emotional mechanisms in achieving peak athletic performance and preventing burnout. Recent advancements in applied neuroscience, including wearable body/brain-sensing devices, are of particular interest to research and professional practice in exercise and sport sciences. These technologies aid in understanding and evaluating sensorimotor and cognitive functions crucial for athletic performance. Sport neuroscience is advancing with the development of neurocognitive empowerment protocols, combining mental training, cognitive-behavioural techniques, and performance testing with neuroscientific devices. This paper introduces the theoretical background and potential of applying neuroscientific models to empowerment in exercise and sport science, presenting examples of protocols aimed at optimizing athletes' performance. These protocols highlight a threefold focus on individual, dyadic, and collective performance.

Keywords: neurocognitive empowerment; peak performance; sport; wearables; embodied practices

1. Introduction

Sports psychology is a relatively young discipline, yet interest in mental aspects of sports practice and performance goes back over a century. In fact, in 1913, in Lausanne, a conference was organized by Pierre de Coubertin, the father of modern Olympic Games, aimed at studying the psycho-physiological aspects in sports. Such insight then grew stronger over the decades and influenced the way athletes training and preparation are planned and implemented in terms of goals, techniques, procedures, and assessment standards.

The integration of neurosciences and sport psychology, more recently, refuelled the study of cognitive and emotional mechanisms for the achievement of peak athletic performance, as well as for prevention of athletic burnout. In high-performance sports, in fact, many cognitive-affective functions are concurrently involved in modulating athletic outcomes, crossing both higher macro-levels and finer-grained micro-levels of mental processes (Table 1).

For each of these two levels (micro and macro), there will be in the next section some examples of applied neuroscience protocols in sports.

Table 1. Synoptic table concerning higher macro-level and finer-grained micro-level functions involved in modulating athletic outcomes and performance

Macro-level functions	*Micro-level functions*
- Ability to self-regulate and optimally manage the stress response	- Information-processing speed and readiness to respond to stimuli
- Emotional control and coping	- Storage capacity in short- and long-term memory
- Attention regulation and focusing	- Fine-grained motor coordination and fine-grained planning of athletic gestures and tactics
- Ability to conceive and implement effective strategies	- Awareness of and sensitivity to interoceptive and proprioceptive signals
- Broad environmental monitoring and inhibition of interfering contextual stimuli	
- Ability to quickly change mindset and action plans on the basis of environmental changes and needs	

Nakata et al. (2010) underlined that, when practicing precise motor acts in in-person competitions or training, athletes need to be able to adapt their athletic gestures in a flexible and efficient way on the basis of the perception of environmental information, detection of relevant stimuli, prompt decision-making, efficient integration of afferent signals, and planning of anticipatory actions. Focusing and attention regulation, behavioural inhibition, and cognitive flexibility are all the same crucial to maintain high-performance levels. It is then nowadays recognized, among sport professionals, that the notable ability of the human brain to learn, adapt, and optimize its functioning becomes an incredibly valuable asset in the path towards optimal performance in both training and competition.

With that in mind, both research and professional practice in exercise and sport sciences is looking with particular interest at recent technological progresses in applied neuroscience and application of non-invasive neurotechnologies such as wearable body- and/or brain-sensing devices (Balconi & Crivelli, 2019a; Cheron et al., 2016; Crivelli & Balconi, 2022; Habay et al., 2021; Park et al., 2015). Indeed, models and tools of applied neuroscience - including wearable electroencephalography (EEG), autonomic measures, and bio/neuro-feedback - may already help professionals to obtain a deeper understanding of the sensory, motor, and cognitive functions needed to prepare, carry out, and imagine complex performance. Also, they may help opening a window on the implicit processes that direct attention resources toward the athletic gesture and competition, and that support self-regulation when put under challenge. Building on that, applied neuroscience techniques can contribute to better outline the complexity of athletic performance and its neural characteristics in both laboratory and real-life ecological contexts, as well as to develop novel ways to support physical and mental training (Balconi & Crivelli, 2019a, 2019b; Balconi et al., 2017; Balconi & Vanutelli, 2017; Crivelli et al., 2022; Crivelli, Fronda, & Balconi, 2019).

One of the latest frontiers in exercise and sport sciences and practice is the design and implementation of neurocognitive empowerment protocols. Sport activity – at both amateur agonistic and professional levels – indeed demands dedication and effort, and may put pressure and obstacles on outcomes (Arnold & Fletcher, 2012; Gustafsson et al., 2011; Sarkar & Fletcher, 2014). In order to efficiently manage such pressure and to favour peak performance, physical activity and athletic gestures education have been, traditionally, paired with mental training, including coaching and "psyching-up" practices - such as goal-setting, self-talk, and relaxation interventions (Balconi, Pala, et al., 2019; Bisio & Bove, 2019; Macnamara et al., 2016; Williams & Straub, 2010). The neurocognitive empowerment approach builds on such tradition and focuses on a blend of mental practices and cognitive-behavioural techniques with

neuroscientific devices able to sense and/or modulate athletes' psychophysiological activity. Namely, it has been defined as:

> "*a voluntary attempt to improve one's own cognitive skills and behavioural performance by means of neuroscience techniques able to influence the activity of neural structures and neural networks subserving such skills and supporting cognitive performance*" (p.12; Balconi & Crivelli, 2019b).

Neurocognitive empowerment strongly grounds on the assumption that enhancement of cognitive skills and neural efficiency can be promoted across all the lifespan by systematic modulation and re-activation of neural networks mediating those cognitive functions – thus fostering specialized brain plasticity – and on positive evidence concerning the contribution of neurotechnologies to such process (Bagdasaryan & Quyen, 2013; Balconi, Crivelli, et al., 2019; Balconi et al., 2021; Balconi, Fronda, et al., 2019; Crivelli, Fronda, Venturella, et al., 2019; Park et al., 2015; Thompson et al., 2008).

Focusing on sports, primary targets of neurocognitive empowerment programs are represented by: (i) the capacity to adopt a quiet and concentrated mindset even during exposure to environmental and endogenous stressors; (ii) the ability to self-regulate automatic affective responses; and (iii) the capability to functionally distribute and refocus attention reserves on the task while actively ignoring task-irrelevant inputs (Balconi, Pala, et al., 2019; Mirifar et al., 2017). In particular, bio-/neuro-feedback – a well-established applied psychophysiology technique promoting embodied awareness and regulation via implicit learning and real-time feedbacks – has been used in such application field to improve the consciousness of neurophysiological signals of internal sensations and implicit processes, as well as to train intentional regulation of those responses and of correlated mental states in order to enhance mental focus, concentration, and relaxation (Jiménez Morgan & Molina Mora, 2017; Mirifar et al., 2017).

2. Neuroempowerment in sports: applied examples

To complement above-reported remarks and ground them to real-life experience, we will now briefly refer to applied examples of neurocognitive empowerment protocols dedicated to both higher macro-levels and finer-grained micro-levels of mental processes involved in sport performance, which have been specifically developed to optimize athletes' performance in different sport disciplines, highlighting a threefold focus on individual, dyadic, and collective performance.

2.1 Stress management, focusing, and individual peak performance

The ability to focus attention only to stimuli that are relevant to current goals, while minimizing the processing of interfering information notwithstanding their perceptual or affective salience, is considered a key aspect of optimal performance and a valuable trans-disciplinary trait in athletes. In addition, the ability to reorient the psychophysiological arousal that accompanies competition and pre-competition phases to boost mental focus and physical readiness is a further key to peak performance.

This first exemplification regards a two-week intensive protocol combining embodied awareness (EA) practices and wearable neurofeedback training, originally devised to investigate the effects of neurotechnology-enhanced empowerment on neurocognitive efficiency and stress management in athletes (see Crivelli, Fronda, & Balconi, 2019). A total of 50 participants completed the neurotechnology-enhanced empowerment protocol or an active control protocol based on relaxation practices, and underwent pre- and post-training neuroassessment sessions including psychometric, neuropsychological, cognitive, and psychophysiological testing. Relevant to the present discussion, athletes who trained by combining EA with wearable neurofeedback specifically showed a consistent profile of improved neurocognitive reactivity and executive control, as marked by both behavioural (i.e., reaction times, false alarms) and electrophysiological markers (i.e., N2 event-related potential) of neurocognitive efficiency, besides decreased perceived stress levels.

2.2 Interpersonal synchronization and dyadic performance

The ability to synchronize with other co-agents grounds on a set of social skills that encompasses joint attention, implicit/intentional imitation, time and content synchronization (Delaherche et al., 2012). Such ability is extremely relevant in dyadic sports such as synchronized diving or dancing.

This second exemplification builds on the concept of interoceptive attentiveness (IA) (see Balconi & Angioletti, 2022) as potential precursor of interpersonal synchronization. Indeed, IA is relevant for motor synchronization since interoceptive processes inform motor coordination with the social partner and joint motor planning (Farmer & Tsakiris, 2012). Eighteen participants here completed an interpersonal synchronization task framed with a social goal (e.g., to synchronize to perform better as a dyadic team), while focusing or not on IA (specifically, on breathing). Task-related hemodynamic activity over prefrontal areas was collected via functional Near-Infrared Spectroscopy (fNIRS). Notably, study outcomes showed that intentionally focusing attention on interoceptive sensations linked to breathing increased the activation of

prefrontal areas during a synchronization task with an explicit social frame stressing the role of collaborative dyadic performance, and that such "boosting" effect can be quantified.

2.3 Teamwork and collective efficacy in team sports

Self-awareness, self-regulation, and social understanding are the foundation for the capacity to effectively conduct joint activities and manage group efforts, which – in turn – are critical precursors of the capacity to create collective efficacy when sharing goals and actions with other inter-agents, such as in team sport. Enhancing those capacities in athletes may potentially enhance both individual and team performance, which rely on effective social attunement, it being with companions or opponents.

This third exemplification concerns a combined metacognitive and neurocognitive empowerment protocol targeted at collective efficacy and social understanding/regulation abilities of team sports athletes (Crivelli & Balconi, 2019). Ten basketball athletes took part in pilot testing and were randomly attributed to experimental or active control groups. The experimental protocol consisted in 14 daily wearable neurofeedback sessions devised to train embodied awareness, and four metacognitive practice sessions based on self-reflection tasks devised to foster the ability to recognize and regulate affective reactions in self and others, take others' perspective, and understand others' motives and behaviour. The active control group only completed the metacognitive practices and relaxation. Psychometric and psychophysiological testing, as well as ecological assessment on the field, was implemented to investigate training effects. Besides expected improvements in neurocognitive efficiency, the analysis of individual and collective performance during ecological team cooperation exercises highlighted an improvement in the experimental group of athletes as for their effectiveness in collective actions in the real game setting (basketball court) and positive reaction to group mistakes.

3. Conclusions

In this work we have discussed the potential and the background of applying neuroscientific models and techniques for neurocognitive empowerment in sport science and practice. Then, three brief cases were referred to as exemplifications in which applied neuroscience protocols combining the use of neurotechnologies (namely, wearable neurofeedback and fNIRS) and traditional mental training techniques (among which embodied awareness

practices, controlled breathing, and metacognitive practices) were used to improve individual and joint performance in individual and team sports. While such cases only represent initial examples of frontier applications of sport neuroscience, they also hint at the practical potential of implementing targeted neurotechnology-based protocols for peak performance.

Indeed, among the future goals of research and practice in sport and exercise neurosciences, one of the hottest challenges concerns how to introduce neurocognitive fitness – besides psychological and physical ones – into the assessment and empowerment routines for athletes. Neurocognitive fitness can be defined as the individual level of efficiency and efficacy in activating and using neural/cognitive resources to reach optimal performance, matching task requests and any additional surcharges imposed by environmental and situational factors (Crivelli & Balconi, 2022). Notably, each of its three main components – self-awareness, self-regulation, and executive control – can become target for empowerment. Self-awareness skills, as an example, can be honed both by exercising self-observation and attentiveness to modulations of physiological activity via mindfulness and bio-/neuro-feedback practice, and by training with embodied awareness practices focusing on interoception and proprioception. The ability to share joint attention on common internal sensations, for example by synchronizing breathing and intentionally paying attention on such shared experience, might represent a way to improve a core precursor of effective motor synchronization and co-regulation, up to shared agency and collective efficacy (Crivelli & Balconi, 2010, 2017). Again, the ability to co-regulate and the degree of interpersonal syntonization during shared tasks can, to date, become a specific target for neuroassessment thanks to the development of the hyperscanning paradigm. Hyperscanning – allowing for simultaneous recording and integrated analysis of physiological activity in two or more co-agents involved in a shared task or experience – can, indeed, complement traditional behavioural analysis on motor synchronization with implicit physiological markers of effective attunement between co-agents. This would, for example, allow for exploring the impact on interpersonal syntonization of different communication and team leadership styles. Finally, even executive control and strategic use of mental resources can become targets for improvement in sports via combined neurofeedback (or non-invasive brain stimulation, such as transcranial direct current stimulation) and cognitive training. In fact, being executive control a core precursor of optimal cognitive functioning, its empowerment can positively affect the efficiency of tactical planning, flexible adaptation of athletic gestures and actions, focusing, and control of environmental distracters during competition, among other critical skills for athletes.

Funding

No funding to declare.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical statement

This paper does not involve primary research with human subjects, animals, or sensitive data. As such, formal ethics approval was not sought for this study. All sources cited and discussed in this paper adhere to appropriate ethical standards and guidelines established within their respective fields.

Data accessibility

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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