Motor Cognition and Neuroscience in Sport Psychology

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Abstract

Advances in technology have allowed research in cognitive neuroscience to contribute significantly to the discipline of sport psychology. In most cases, the research has become more rigorous and has directed current thinking on the mechanisms subserving a number of psychological theories and models of practice. Currently, the three most common neuroscience techniques informing sport and exercise research are electroencephalography, transcranial magnetic stimulation and functional magnetic resonance imaging. In this review, we highlight and discuss the contributions to sport psychology that have been made in recent years by applying these techniques, with a focus on the development of expertise, motor cognition, motor imagery and action observation.

Highlights

- Recent advances in neuroscience have benefitted sport and exercise psychology
- Integral to research in neuroscience is a good understanding of measurement techniques
- Research supports combined imagery and action observation interventions

Introduction

The considerable advances in neuroscience and digital technology over the past 30 years have had a substantial and positive impact on sport psychology research and practice. The ability to demonstrate functional brain activity during sporting performance and whilst engaged in psychological interventions has been important in promoting the efficacy of the discipline, albeit in most cases through cross-sectional studies. Cognitive neuroscience has now been able to provide sport psychologists with the ‘evidence’ for the “neural reorganizations that occur with expertise [that] reflect the optimization of the neurocognitive resources to deal with the complex computational load needed to achieve peak performance”[1 p.1].

Moore’s Law’s predictions for growth in digital electronics have seen important improvements in neuroimaging techniques, brain activity recording, and non-invasive electrical stimulation of the brain. These gains, alongside the decreasing cost of computing power, have allowed many sport and exercise psychology laboratories to host an array of complex, increasingly mobile and wireless technology that could not have been envisaged even 20 years ago. Many laboratories now include multi-channel, light-weight mobile electroencephalography (EEG), wireless electromyography (EMG), and single and paired-pulse transcranial magnetic stimulation (TMS) equipment. In addition, sport and exercise psychologists are collaborating more regularly with their mainstream psychology and cognitive neuroscience department colleagues to use functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG) to study brain activity in sport and exercise psychology research.

Unfortunately, however, with the ubiquity of neuroscience technology comes an uncomfortable allure and fascination with neuroscience research that can seem to make any psychological finding more important, even when the presented neuroscience is almost irrelevant to the logic of the study [2]. This is a concern for sport and exercise psychology and researchers should be careful not to include neuroscientific approaches in an attempt to inflate the importance of their research or to overemphasize the meaning of their data.

One area that has had to wrestle with the recent technical and popularity challenges in cognitive neuroscience is motor cognition. Defined as the study of the mechanisms involved in movement thought, planning, intention, organization, perception, understanding, learning, imitation and attribution (modified from Jeannerod, [3]), motor cognition has been important for sport and exercise psychology because it “acknowledges the inextricable link between cognition and action…and highlights the importance of bodily knowledge and kinesthetic processes in the study of mental activity” [4 p.421]. Jeannerod’s list has an obvious attraction for sport psychologists and the field has had an even greater lure in recent years following the neuroscientific evidence in support of a proposal for a putative human mirror neuron system (hMNS). The suggestion that a hMNS is the neuronal substrate underlying this array of functions has, however, been increasingly questioned [5, 6] and even been presented as “the most hyped concept in neuroscience” [7 p.1]. Sport and exercise psychologists need to be cognizant of the hyperbole surrounding cognitive neuroscience, motor cognition and the hMNS if they are to research and practice effectively in motor learning.

In the following sections, we present recent evidence to support the continued but cautious use of three techniques that purport to provide evidence for neuroscientific mechanisms that underlie the modulation of some of the cognitive processes and common behaviors seen in the sport and exercise psychology literature.

Electroencephalography (EEG)

Electroencephalography (EEG) records voltage fluctuations in the electrical activity of the brain through electrodes attached to the scalp. In sport psychology EEG has, historically, been the subject of criticism (see Hatfield et al. [8]). In the sports-based research of the 1980s and early 1990s, EEG montages tended to be limited to small electrode arrays and signal analysis was often restricted to spectral power in the single frequency of interest; typically overall alpha power (i.e., 8-13Hz) conflating the known behavioral differences between upper and lower frequency alpha power. Therefore, whilst the good temporal resolution allowed accurate measurement of cortical activity, the poor spatial resolution and partial analysis may have limited any meaningful interpretation of the data.

The psychological meaning of any event-related frequency change has been based on the generally accepted topographic function of the cortex immediately below the electrode(s) of interest. For example, alpha power increase, or event-related synchronization (ERS), at electrode site T3 was referred to as reduced auditory processing, whilst a decrease in power, or event-related desynchronization (ERD), could be explained by an increase in ‘self-talk’. Today, with more dense electrode arrays, more detailed analyses and the contribution from concurrent imaging techniques, it is accepted that the neural substrate of skilled performance is more extensive than previously reported. Fortunately, some of the recent research has learnt from the early ambitious studies. Di Fronso et al. [9*], for example, using a 32-channel montage, have identified the neural markers underlying optimal and sub-optimal pistol shooting performance, and used the ERS and ERD data as evidence to support the neural efficiency hypothesis [10] and the reinvestment theory [11] of skilled motor performance.

Other EEG components of interest to sport and exercise psychology include the movement-related cortical potential (MRCP) and event-related potentials (ERPs). The MRCP is a low-frequency negative shift in the electroencephalographic recording that occurs approximately 2 seconds before voluntary movement onset. Its components, the readiness potential and the negative slope (aka 'early' and 'late' Bereitschaftspotential respectively), are thought to reflect the cortical processes involved in movement planning and preparation. As such, the MRCP has been seen as a useful marker of motor learning [12] since, like the ERS shown in the Di Fronso et al. [9*] study, reductions in the slopes of both components may reflect the greater neural efficiency that accompanies motor skill acquisition. In a related study, Rietschel et al. [13] have recently shown that the ERP, P3 (an index of the involuntary orienting of attention), increased in amplitude over practice trials to offer evidence that attentional reserve increases with motor skill acquisition.

Taken together, we propose that these three markers of skill improvement indicate a reduction in cerebral cortical activation. This reduced cognitive load accompanying expertise is consistent with the claims of the current attentional theories in sport psychology (e.g, Processing Efficiency Theory [14] and Attentional Control Theory [15]. EEG methodologies, therefore, continue to offer a valid approach for sport and exercise psychologists. The increasing opportunities to investigate sporting behavior in ecologically-valid environments with mobile, wireless systems suggests this area of research remains fruitful.

Transcranial Magnetic Stimulation (TMS)

Delivering transcranial magnetic stimulation (TMS) to motor cortex elicits a motor evoked potential (MEP) response in the corresponding muscle on the contralateral side of the body. The amplitude of the MEP, measured using surface EMG, provides a marker of corticospinal excitability at the time of stimulation. Recently, this technique has been used to explore some of the theoretical claims from motor cognition and motor simulation, especially the effects of motor imagery (MI; see [16*]) and action observation (AO; see [17]) interventions on activity in the corticospinal system. It is now accepted that MI and AO interventions facilitate corticospinal excitability in comparison to various control conditions and that activity in an extended hMNS may explain some of this facilitation. This has been demonstrated in recent sports-related tasks for both AO [18, 19] and MI [20, 21] with the implicit assumption that the increased corticospinal activity during these simulation conditions in some way supports motor learning and the development of expertise. We would argue that this association is not yet fully established.

In this field of research, MI or AO interventions that elicit the largest MEP response are often assumed to be the most effective in delivering enhancements in motor performance and (re)learning. For example, informed by the work of Vogt et al. [22], several recent TMS experiments have demonstrated that corticospinal excitability is increased when participants engage in kinesthetic imagery synchronous with AO, in contrast to independent MI or AO [e.g., 23-25*]. This has resulted in claims that simultaneous AO and MI interventions may offer sport and exercise psychologists more optimal delivery methods for performance and learning than the traditional independent MI and AO approaches. Future research should investigate these claims. In a similar study, Wang et al. [21] have reported MEPs of larger amplitude when elite badminton players imagined serving whilst holding their racquet, compared to imagery when the racquet was absent. It is possible, therefore, that holding implements associated with movement execution during imagery may make such interventions more effective, and would be consistent with the central tenets of Holmes and Collins' PETTLEP model [26] where haptic afference was suggested to facilitate MI generation.

Whilst intuitively appealing, an underlying assumption with this research paradigm is that an elevated MEP response during certain AO or MI conditions would be facilitative to motor skill performance. Although plausible, it should be noted that successful performance in high-level sport is usually characterized by reduced cortical activity [e.g., 9*]. TMS research may, therefore, only reflect the conscious and focused attentional processes associated with skill learning and not necessarily the more autonomous and 'intentive' brain activity of the skilled performer described by Shaw [27]. Sport psychology researchers and applied practitioners should be cautious in interpreting greater MEP responses during AO or MI as 'better' until further evidence of the neural substrate for skill learning and motor performance is provided. Similarly, Hétu et al. [28] have cautioned against generalizing data from TMS action observation research and suggested that it will be critical to first "identify individuals who are more prone to respond to action observation interventions" (p.10) and to "distinguish 'good' from 'bad' observers [to] potentially optimize the use of action observation" (p.10) as an intervention technique.

Functional Magnetic Resonance Imaging (fMRI)

Functional magnetic resonance imaging (fMRI) is a neuroimaging technique that detects changes in cerebral blood flow, which are then interpreted as a marker of neural activity. Staying with our motor cognition theme, experiments using fMRI have shown some commonality between the areas active during the execution of movement and those active during motor imagery [29] and action observation [30]. Possibly more important however, multi-voxel pattern analysis techniques have shown that it is possible to distinguish areas in which increased activity is seen to be unique to each behavior [31]. In a comprehensive review of online and offline performance gains following motor imagery practice, Di Rienzo et al. [32* p.1] also demonstrate the “compelling evidence that motor imagery promotes motor learning”. In line with the discussion in the TMS section above, the finding that action observation and motor imagery activate similar and distinct motor regions of the brain is important for practice in sport and exercise psychology and, in recent years, has seen an increased interest in their combined use [see 22]. Instead of contrasting the respective benefits of MI and AO, optimal training gains might be anticipated through their combined and simultaneous use because of the greater shared neural activity. For example, recent fMRI experiments have explored the effects of the simultaneous combination of AO and MI of kicking [33] and balance [34] tasks. These studies indicate that AO with concurrent MI elicits increased activity in brain regions involved in motor execution of the same task compared to independent AO [33] or both independent AO and MI [34].

It is important to note that the increased activity detected by fMRI techniques could represent an increase in neural mechanisms that are either facilitatory or inhibitory to movement production. As such, we encourage researchers to consider combining fMRI with other measurement techniques, such as EEG or TMS, to provide a clearer understanding of the fMRI activity.

From the MRCP research discussed in the EEG section above, it is well-established that, compared to novices, expert performers seem to exhibit reduced and more ‘efficient’ cortical activity related to movement preparation and execution [e.g., 35, 36]. In addition, successful athletic performances are characterized by reduced cortical activity prior to and during movement execution than less successful performances [9*]. In support of the findings from these approaches, Costanzo et al. [37] used fMRI to demonstrate that this neural efficiency in experts may extend beyond motor preparation and execution. Specifically, they reported that in comparison to non-athletes, athletes with experience of performing successfully in stressful competitive situations exhibited reduced activity in pre-frontal brain regions associated with regulation of emotions when processing pictures of emotional stimuli related to their sport (e.g., injury). The authors argued that this reduced activity in processing emotional stimuli may preserve processing resources required for attentional and motor processes, allowing these athletes to cope and manage their performance during the stress of competition.

Conclusions

The use of advanced neuroimaging and brain activity recording technology in motor cognition and cognitive neuroscience continues to inform thinking in sport and exercise psychology. The findings from recent research have significant implications for practice, especially in the area of motor learning. However, as the opportunities to use this technology become more available, it remains important for researchers to be mindful of the electrophysiological limitations of the methods when reporting their findings and for practitioners to constrain their work to the evidence from methodologically rigorous studies.

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