

1 Motor Cognition and Neuroscience in Sport Psychology

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1 **Abstract**

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

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1 **Highlights**

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

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1 **Introduction**

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

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

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

7 One area that has had to wrestle with the recent technical and popularity challenges
8 in cognitive neuroscience is motor cognition. Defined as the study of the mechanisms
9 involved in movement thought, planning, intention, organization, perception,
10 understanding, learning, imitation and attribution (modified from Jeannerod, [3]), motor
11 cognition has been important for sport and exercise psychology because it “acknowledges
12 the inextricable link between cognition and action...and highlights the importance of bodily
13 knowledge and kinesthetic processes in the study of mental activity” [4 p.421]. Jeannerod’s
14 list has an obvious attraction for sport psychologists and the field has had an even greater
15 lure in recent years following the neuroscientific evidence in support of a proposal for a
16 putative human mirror neuron system (hMNS). The suggestion that a hMNS is the neuronal
17 substrate underlying this array of functions has, however, been increasingly questioned [5,
18 6] and even been presented as “the most hyped concept in neuroscience” [7 p.1]. Sport and
19 exercise psychologists need to be cognizant of the hyperbole surrounding cognitive
20 neuroscience, motor cognition and the hMNS if they are to research and practice effectively
21 in motor learning.

22 In the following sections, we present recent evidence to support the continued but
23 cautious use of three techniques that purport to provide evidence for neuroscientific

1 mechanisms that underlie the modulation of some of the cognitive processes and common
2 behaviors seen in the sport and exercise psychology literature.

3 ***Electroencephalography (EEG)***

4 Electroencephalography (EEG) records voltage fluctuations in the electrical activity of
5 the brain through electrodes attached to the scalp. In sport psychology EEG has, historically,
6 been the subject of criticism (see Hatfield et al. [8]). In the sports-based research of the
7 1980s and early 1990s, EEG montages tended to be limited to small electrode arrays and
8 signal analysis was often restricted to spectral power in the single frequency of interest;
9 typically overall alpha power (i.e., 8-13Hz) conflating the known behavioral differences
10 between upper and lower frequency alpha power. Therefore, whilst the good temporal
11 resolution allowed accurate measurement of cortical activity, the poor spatial resolution
12 and partial analysis may have limited any meaningful interpretation of the data.

13 The psychological meaning of any event-related frequency change has been based
14 on the generally accepted topographic function of the cortex immediately below the
15 electrode(s) of interest. For example, alpha power increase, or event-related
16 synchronization (ERS), at electrode site T3 was referred to as reduced auditory processing,
17 whilst a decrease in power, or event-related desynchronization (ERD), could be explained by
18 an increase in 'self-talk'. Today, with more dense electrode arrays, more detailed analyses
19 and the contribution from concurrent imaging techniques, it is accepted that the neural
20 substrate of skilled performance is more extensive than previously reported. Fortunately,
21 some of the recent research has learnt from the early ambitious studies. Di Fronso et al.
22 [9*], for example, using a 32-channel montage, have identified the neural markers
23 underlying optimal and sub-optimal pistol shooting performance, and used the ERS and ERD

1 data as evidence to support the neural efficiency hypothesis [10] and the reinvestment
2 theory [11] of skilled motor performance.

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

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

22 ***Transcranial Magnetic Stimulation (TMS)***

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

14 In this field of research, MI or AO interventions that elicit the largest MEP response
15 are often assumed to be the most effective in delivering enhancements in motor
16 performance and (re)learning. For example, informed by the work of Vogt et al. [22], several
17 recent TMS experiments have demonstrated that corticospinal excitability is increased when
18 participants engage in kinesthetic imagery synchronous with AO, in contrast to independent
19 MI or AO [e.g., 23-25*]. This has resulted in claims that simultaneous AO and MI
20 interventions may offer sport and exercise psychologists more optimal delivery methods for
21 performance and learning than the traditional independent MI and AO approaches. Future
22 research should investigate these claims. In a similar study, Wang et al. [21] have reported
23 MEPs of larger amplitude when elite badminton players imagined serving whilst holding

1 their racquet, compared to imagery when the racquet was absent. It is possible, therefore,
2 that holding implements associated with movement execution during imagery may make
3 such interventions more effective, and would be consistent with the central tenets of
4 Holmes and Collins' PETTLEP model [26] where haptic afference was suggested to facilitate
5 MI generation.

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

20 ***Functional Magnetic Resonance Imaging (fMRI)***

21 Functional magnetic resonance imaging (fMRI) is a neuroimaging technique that detects
22 changes in cerebral blood flow, which are then interpreted as a marker of neural activity.
23 Staying with our motor cognition theme, experiments using fMRI have shown some

1 commonality between the areas active during the execution of movement and those active
2 during motor imagery [29] and action observation [30]. Possibly more important however,
3 multi-voxel pattern analysis techniques have shown that it is possible to distinguish areas in
4 which increased activity is seen to be unique to each behavior [31]. In a comprehensive
5 review of online and offline performance gains following motor imagery practice, Di Rienzo
6 et al. [32* p.1] also demonstrate the “compelling evidence that motor imagery promotes
7 motor learning”. In line with the discussion in the TMS section above, the finding that action
8 observation and motor imagery activate similar and distinct motor regions of the brain is
9 important for practice in sport and exercise psychology and, in recent years, has seen an
10 increased interest in their combined use [see 22]. Instead of contrasting the respective
11 benefits of MI and AO, optimal training gains might be anticipated through their combined
12 and simultaneous use because of the greater shared neural activity. For example, recent
13 fMRI experiments have explored the effects of the simultaneous combination of AO and MI
14 of kicking [33] and balance [34] tasks. These studies indicate that AO with concurrent MI
15 elicits increased activity in brain regions involved in motor execution of the same task
16 compared to independent AO [33] or both independent AO and MI [34].

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

22 From the MRCP research discussed in the EEG section above, it is well-established
23 that, compared to novices, expert performers seem to exhibit reduced and more ‘efficient’

1 cortical activity related to movement preparation and execution [e.g., 35, 36]. In addition,
2 successful athletic performances are characterized by reduced cortical activity prior to and
3 during movement execution than less successful performances [9*]. In support of the
4 findings from these approaches, Costanzo et al. [37] used fMRI to demonstrate that this
5 neural efficiency in experts may extend beyond motor preparation and execution.
6 Specifically, they reported that in comparison to non-athletes, athletes with experience of
7 performing successfully in stressful competitive situations exhibited reduced activity in pre-
8 frontal brain regions associated with regulation of emotions when processing pictures of
9 emotional stimuli related to their sport (e.g., injury). The authors argued that this reduced
10 activity in processing emotional stimuli may preserve processing resources required for
11 attentional and motor processes, allowing these athletes to cope and manage their
12 performance during the stress of competition.

13 **Conclusions**

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

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24 **pistol shots, perceived control, accuracy, and hedonic tone, and cortical activity data**
25 **(32-channel EEG). ERD-ERS analysis supported the notion that optimal-automatic**

- 1 **performance experiences were characterized by a global ERS of cortical arousal**
2 **associated with the shooting task, whereas suboptimal controlled states were**
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4 **participants were instructed to observe finger-thumb opposition movement**
5 **sequences: (i) passively; (ii) with the intent to imitate the observed movement; or (iii)**
6 **whilst simultaneously and actively imagining that they were performing the**
7 **movement as they observed it. Corticospinal excitability was facilitated most during**
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