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A review and critical analysis of how cognitive neuroscientific investigations using dance can contribute to sport psychology

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Whether watching Michael Jackson moonwalk or Savion Glover tap dance, it is striking how skilfully some people can move their bodies. The emerging field of cognitive neuroscience has produced important advances in understanding the control and perception of complex action. Here we outline the merits and limitations of neuroscience methods for studying psychological states and how they might inform sport psychology research. To do so, we review studies that have used dance paradigms, as well as summarize a debate regarding the utility of brain-based measurements for studying human cognition. Our central argument is twofold. First, the origins of studying dance with cognitive neuroscientific methods do not stem from a desire to inform dancers or instructors how to influence performance. Rather, dance is a useful tool to investigate the neurocognitive mechanisms that mediate the perception of complex action and development of expertise. In other words, neuroscientists were initially interested in ways that dance could be used to study elementary links between action and perception. Second, biological-level descriptions should not hold a privileged status over any other measure of a psychological state, and we urge consideration of the limits of brain-based methods when using cognitive neuroscientific approaches to understand the psychology of sport.

Keywords: cognitive neuroscience; mirror system; dance; observation; motor simulation; learning; action observation network

Introduction

When the legendary tap dancer Savion Glover takes the stage, the rate at which his feet accelerate to produce a dizzying cascade of polyrhythms too quick for the eye to follow serves as a stark reminder of the human capacity to produce exquisitely precise, coordinated and complex movements. Whether performing a double triple time step in tap dance, a slam dunk in basketball or an iron cross in gymnastics, one cannot fail to recognize movement expertise. While it is easy to recognize expert performance, it is less clear what cognitive and brain systems underpin such expertise. Using neuroimaging research on dance as a test case, the current article aims to evaluate how cognitive neuroscientific methods can advance understanding of action and perception links at brain and behavioural levels.

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Over a decade ago, Keil, Holmes, Bennett, Davids, and Smith (2000) argued that sport psychology and motor behaviour research required a common language to provide a framework for interpreting research in human behaviour. The core principle of their argument put forward that multiple lines of evidence should be integrated and modelled together when investigating psychological processes. More specifically, Keil and colleagues emphasized the importance of using human brain imaging techniques to investigate possible neural substrates of psychological states. The hope was that neuroimaging measurements would complement traditional behavioural measures more common to the field of sport psychology. In the current article, we critically analyse this viewpoint, presenting the merits and limitations of brain imaging techniques for researchers interested in the psychology of sport.

To do this, we train our lens on the nascent field of cognitive neuroscience, with a particular focus on studies using dance paradigms. Many other researchers have considered links between action and perception across myriad sporting domains, including golf, football, gymnastics, canoeing, skiing and many others (see Moran, 2009; Moran, Campbell, Holmes, & MacIntyre, 2012; Moran, Guillot, Macintyre, & Collet, 2012; Yarrow, Brown, & Krakauer, 2009). Here, however, we focus on studies combining dancers or dance paradigms with cognitive neuroscientific approaches. We hope to demonstrate that dance is a rich subfield to explore within cognitive neuroscience due to its utility to those interested in the learning and perception of complex, whole-body action. Cognitive neuroscience research using dance did not originate from a desire to inform the way dancers and dance instructors approach their work or to understand how audiences appreciate dance as a performance art. Rather, at its inception, neuroscientists were interested in studying the brains and bodies of dancers as they have an extraordinary skill set, which can be investigated to address core questions of how perception and action are organized. Only later have questions of dance instruction and aesthetics come into focus.

The current article is divided into three main sections. First, to build a neuroscientific framework and historical context, we begin with a brief review of research that paved the way for modern cognitive neuroscientific investigations into action and perception links. This is achieved by outlining how research into the mirror neuron system has contributed to our understanding of human motor cognition. In the second section, we provide an up-to-date overview of studies that have used a dance paradigm (and/or dancers as participants) with a neuroscientific technique to address a question about action and perception links. The main objective of this section is to highlight how brain imaging or neurostimulation methods may be used to study how we learn or become experts in a particular kind of complex action (dance). In the third section, we turn to the limits of cognitive neuroscience methods and analyse a debate that concerns what brain-based data can contribute to the understanding of human cognition. Our main point is that biological or brain-based descriptions should not hold a privileged status over any other measure of a psychological state. Maps of brain activity that relate to different cognitive tasks might make a novel contribution to the literature in some cases, but such maps are not necessary or sufficient to constrain theories of cognition (Coltheart, 2006; Henson, 2005). Thus, we urge any researcher from the brain and behavioural sciences to avoid 'brain-mapping for brain-mapping's sake', where the only aim of an investigation is to find out *where* in the brain is active during a particular psychological state. As such, caution is crucial when making inferences about cognitive function from brain imaging data. Finally, we

conclude with a summary and some suggestions for future directions in the endeavour of using cognitive neuroscientific approaches to address questions relevant to further understand the psychology of sport.

Cognitive neuroscience of action learning and understanding

In this section, we explore how neuroimaging tools and the naissance of cognitive neuroscience are helping to illuminate fundamental questions in sport science in new and exciting ways. One question that is of particular interest to psychologists, sport scientists and neuroscientists is the remarkable plasticity of the human brain to integrate different types of physical and perceptual experiences in order to learn new movements. Such abilities are quite pronounced in professional sports competitors and dancers, whose livelihoods depend on rapid and adept movement perception, reproduction and refinement.

With the advent of cognitive psychology in the late nineteenth century, William James introduced the idea that action and perception might in some manner converge or overlap (James, 1890). This idea gained traction in the mid-twentieth century, when a number of laboratories began to use neurophysiological means to investigate the brain's ability to use perceptual information to shape movement. It was during this time that information processing explanations, proposing complex transformations from perception to the organization and execution of action, gathered momentum (Massaro & Friedman, 1990; Mountcastle, Lynch, Georgopoulos, Sakata, & Acuna, 1975; Sanders, 1967, 1983; Welford, 1968). In the mid-1970s, Mountcastle and colleagues began the first investigations into putative neurophysiological mechanisms linking action and perception (Mountcastle, 1975; Mountcastle et al., 1975; Yin & Mountcastle, 1977). In these seminal studies, Mountcastle and colleagues used single-unit recording techniques to track the activity of neurons within posterior parietal areas of the macaque cerebral cortex while the animals performed simple behavioural acts in response to sensory stimuli. In one such study, Mountcastle and colleagues determined that neurons in the parietal cortex respond to visual cues associated with the performance of specific actions (Mountcastle et al., 1975). These researchers concluded that this region of the parietal cortex is a likely candidate for cross-modal convergence of perception and action, and established the foundation for the next several decades of further inquiry into how these modalities interact (Andersen et al., 2004).

In the 1990s, research into the interface between action perception and production experienced an extraordinary surge in interest that was sparked by the discovery of so-called mirror neurons found within the ventral premotor cortex of the macaque monkey. These neurons fired in a similar manner both when a monkey performed an action as well as when it observed another monkey or human perform the same action (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). A similar firing pattern when perceiving or performing actions was subsequently observed in the inferior parietal lobule (IPL) (Fogassi et al., 2005), which suggested that perceiving others' actions engages a similar fronto-parietal circuit to executing actions.

One dominant explanation of these response profiles is tied to the notion of motor simulation (Jacob & Jeannerod, 2005; Jeannerod, 2001). The concept of motor simulation is consistent with other forms of mental simulation, which involve the re-enactment of

mental processes associated with previously experienced states (Barsalou, 2008). Such states can be perceptual, motoric or introspective. Hence, motor simulation is an instance of a more general concept of mental simulation (Jacob & Jeannerod, 2005). Many researchers implicitly or explicitly hold that the mirror system is a key neural substrate for processes of motor simulation (e.g. Decety & Grezes, 1999, 2006). In addition, motor simulation accounts of action comprehension have proposed that perceiving and understanding another's action might involve the observer's brain simulating observed movements using their own motor system (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Fadiga et al., 1999; Grafton, Arbib, Fadiga, & Rizzolatti, 1996; Rizzolatti, Fogassi, & Gallese, 2001). Thus, it is argued that through a process of motor simulation, action comprehension occurs by engaging specific parts of the motor system that would be used to perform the same action that is being observed (Rizzolatti et al., 2001).

Interest in mirror neurons has sparked hundreds of studies and an ongoing debate among researchers regarding the specific parameters, scope and limitations of a possible action simulation system within the human brain (Gallese, Gernsbacher, Heyes, Hickock, & Iacoboni, 2011; Gallese & Sinigaglia, 2011). While an exhaustive review of the past two decades of research performed in this domain is beyond the scope of this article (for reviews, see Grosbras, Beaton, & Eickhoff, 2012; Molenberghs, Cunnington, & Mattingley, 2012; Rizzolatti & Sinigaglia, 2010), what a burgeoning corpus of research demonstrates is that neural tissue found within parietal and premotor cortices of the human brain is engaged when actions are performed or when they are observed. This work has given rise to the notion of a human mirror system, which comprises multiple cortical regions and shows evidence of behaving in a similar manner to individual mirror neurons found within non-human primate brains (Molenberghs et al., 2012).[1]

The implications of a neural link between perception and action are broad-reaching and have been explored by scientists from disciplines and perspectives beyond neurophysiology and cognitive neuroscience, including the sport sciences, cognitive psychology, philosophy and occupational therapy (Braun, Beurskens, Borm, Schack, & Wade, 2006; Goldman, 2009; Guillot & Collet, 2010; Jacob, 2008; Johnson-Frey, 2004; MacIntyre, Moran, Collet, & Guillot, 2013; Moran et al., 2012; Yarrow et al., 2009). Keil and colleagues have outlined several ways in which research on the human mirror system might inform and advance theoretical models for understanding psychological processes in a sporting context (Keil et al., 2000). As one example, they discuss the paradox of the popularity of imagery in sports science research, and the lack of empirically testable theoretical models for the efficacy of such imagery interventions. An important implication is that the reasons underlying the success or failure of a particular imagery intervention are not well understood, and thus might be more difficult to replicate or improve without strong theoretical underpinnings. However, with the advent of functional neuroimaging methods, sports science researchers can now glimpse some of what happens inside expert movers' brains as they watch or imagine different actions. Such methods can add a biological level of description to complement established behavioural evidence, which together may aid in the construction of more detailed, empirically testable models of imagery (Moran et al., 2012).

In the following section, we turn our attention to a particular subfield that has been active for nearly a decade in exploring the impact of action expertise on the perception and production of complex movements. Cognitive neuroscience research using dance is helping to illuminate how an observer's experience impacts perception, enjoyment and learning of new movement. These findings and their implications are considered below.

Insights into action and perception links from cognitive neuroscientific approaches using dance paradigms

The pioneering research on mirror neurons in monkeys and subsequent neuroimaging work with humans have made large strides in addressing how action observation, imagery and execution interact at a biological level. However, attempting to measure sport-specific movements, especially in ecologically valid (i.e. sporting) environments can prove difficult. Importantly, however, it is not impossible. Numerous carefully considered experiments highlight the potential for sport science questions to be addressed, at least in part, by neuroscientific methods. With this being said, it is important to keep in mind that the bulk of research on the neural correspondence between action and perception in general, and the action observation network (AON) specifically, has focused on small, constrained movements of the hands and fingers (see Grosbras et al., 2012; Rizzolatti & Sinigaglia, 2010). However, a small but growing number of laboratories have expanded their research foci to explore the neural underpinnings of complex actions that involve coordination of the entire body, such as actions involved in dance and sporting contexts (Bläsing et al., 2012; Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005; Cross, Hamilton, & Grafton, 2006; Yarrow et al., 2009; Zentgraf et al., 2005).

Here we highlight the utility of cognitive neuroscientific findings that have used experimental paradigms involving dance performance and/or perception (Table 1), which at first might seem rather removed from the simple hand actions that are most commonly studied. We argue that dance provides an excellent means to study the interaction between action and perception at brain and behavioural levels for three main reasons. First, for most of us, daily life requires the efficient coordination of the entire body, not just the fingers and hands. Dance provides a variety of paradigms for studying whole-body coordination. Second, dance is generally not object-directed, and thus enables the study of 'pure' movement (or movement for movement's sake), where the goal of an action is the movement itself (rather than opening a bottle, tying a shoelace, etc.). Finally, by studying a motor behaviour that requires the coordination of multiple effectors, as a field we are better placed for understanding a broader range of motor behaviours, from the simple to the complex.

One of the key research programmes involving dance and populations of expert dancers has addressed questions of how motor expertise impacts the brain during the perception or production of dance (e.g. Brown, Martinez, & Parsons, 2006; Calvo-Merino et al., 2005; Cross et al., 2006; Orgs, Dombrowski, Heil, & Jansen-Osmann, 2008). One of these studies explored whether it is possible to track the emergence of motor expertise (Cross et al., 2006). In this experiment, the researchers followed an ensemble of expert contemporary dancers as they learned a complex 30-minute contemporary dance piece across an eight-week rehearsal period. The dancers were invited into the laboratory for six consecutive weeks where their brain activity was recorded with functional magnetic resonance imaging (fMRI) as they watched and imagined themselves performing short segments of choreography from the dance piece they were learning, as well as kinematically similar dance movements that were never seen or rehearsed in the studio. Across the rehearsal period, dancers unsurprisingly became more adept at physically performing the choreography they rehearsed in the studio each day. However, the most interesting finding to emerge from this longitudinal study was that as dancers became more adept performers, activity within two core regions of the AON – the left IPL and the left ventral premotor cortex – showed increased activity the better a dancer was at

Table 1. Summary of empirical studies using dance paradigms to investigate brain-based questions of action and perception links

Authors & Date	Methodology	Dance Style Studied	Population	Primary Research Question	Innovative Element(s)	Major Finding
Brown et al. 2006	PET	Tango	10 M/F Amateur tango dancers	Are the mechanisms controlling complex sensorimotor processes, such as dance, the same ones as those that underlie elementary processes, such as ankle rotations?	This was the first study to examine performance of the foot/leg actions of dance while undergoing functional neuroimaging	Dance recruits similar sensorimotor processes as those recruited for elementary actions, such as ankle rotations and finger tapping. Specifically, the cerebellum was implicated with entrainment to a musical beat, whereas the putamen was engaged with regular and predictable movements more than irregular movements. Finally, medial superior parietal cortex was involved with the spatial guidance of leg movements, in terms of proprioceptive information.
Calvo-Merino et al. 2005	fMRI	Classical ballet; capoeira	10 ballet & 9 capoeira experts; 10 non-dancers. All male	Is the brain's system for action observation precisely tuned to the individual's acquired motor repertoire?	Using acquired motor skills, the authors investigate the influence of an individual's motor repertoire on neural systems for action observation.	Premotor, parietal and posterior temporal cortices showed greater BOLD responses when participants observed dance actions that were within their motor repertoire compared to kinematically similar dance actions that were not in their motor repertoire. Thus, the extent to which action

Table 1 (*Continued*)

Authors & Date	Methodology	Dance Style Studied	Population	Primary Research Question	Innovative Element(s)	Major Finding
						observation engages premotor, parietal and posterior temporal cortices depends on an individual's motor expertise.
Calvo-Merino et al. 2006	fMRI	Classical ballet	24 M/F professional ballet dancers	Is activation of regions within the action AON representative specifically of motor knowledge or of a more general knowledge of an action (e.g., visual knowledge)?	Using male and female ballet dancers and presenting them with videos of male specific and female specific moves, the authors can dissociate motor and visual knowledge (as dancers have motoric knowledge only for their gender-specific moves but will have had equal visual exposure to both types of moves).	Having controlled for visual familiarity, the authors show activation in premotor, parietal and cerebellar cortices that is specific to motor representation. They provide support for the idea that motor-related areas simulate the observed action as AON activity is not only representative of visual knowledge of an action but also physical knowledge.
Calvo-Merino et al. 2008	fMRI	Classical ballet	6 Male non-dancers	How does variation in aesthetic responses to dance movements correlate with neural activation?	First fMRI study of the brain correlates associated with aesthetic appraisal of dance	Used group-average subjective responses, brain activation differed only for the variation in the 'liking-disliking' aesthetic dimension. Medial visual cortices & right premotor cortex showed higher activation for liked

Table 1 (*Continued*)

Authors & Date	Methodology	Dance Style Studied	Population	Primary Research Question	Innovative Element(s)	Major Finding
						movements compared to disliked. Stronger activation was seen for whole body movements, and an aesthetic network for movement was suggested.
Calvo-Merino et al. 2010	rTMS	Static dance-like body postures (postures from classical ballet and some hybrids postures combining classical ballet with other dance styles)	16 M/F non-dancers	What are the neural mechanisms underlying aesthetic appreciation of body perception?	First study to use a method that intervenes with brain activity (repetitive transcranial magnetic stimulation; rTMS) to study aesthetic evaluation.	rTMS of extrastriate body area (EBA) and ventral premotor cortex (PMv) modulates aesthetic evaluations such that EBA stimulation blunts and PMv stimulation enhances aesthetic sensitivity. Thus, the authors suggest that EBA and PMv are complementary components of a network responsible for aesthetic perception of bodies and propose a two-route model of body processing.
Cross et al. 2006	fMRI/ training	Contemporary dance	10 M/F expert contemporary dancers	How do brain regions engaged in action observation and perception change as complex movements transition from	Longitudinal study tracked brain activity across 6 weeks of the rehearsal process; used dancers' ratings of performance ability in neuroimaging analyses	Activity within PMv and IPL in the left hemisphere increases parametrically with increasing performance ability; also of note that neural responses within the action AON become more

Table 1 (*Continued*)

Authors & Date	Methodology	Dance Style Studied	Population	Primary Research Question	Innovative Element(s)	Major Finding
				unlearned to well-embodied?	to explore which brain regions' activity profiles increase with increasing expertise	finely tuned as expertise increases, authors interpret this to mean the better you are at performing an action, the more you simulate that action when watching others perform it
Cross, Kraemer, et al. 2009	fMRI/ training	Video game dance (step sequences in StepMania, an open source version of the popular video game *Dance Dance Revolution*™)	16 M/F non-dancers	How are physical and observational learning of complex, whole-body action sequences represented at brain and behavioural levels?	Pre- and post- training scan sessions; used a video game paradigm with a step pad, which enabled objective quantification of dance ability; observational learning component was implicit (participants were not specifically instructed to learn via observation; just watch)	While physical training resulted in the best learning (as measured by video game scores), passive observation resulted in performance scores on a post-training test that were intermediate between physically practiced and unpractised scores; after training, a subset of AON regions (left IPL and right premotor cortex) did not discriminate when watching dance sequences that were learned via physical practice or observation, providing evidence for neural overlap between both kinds of learning within these brain regions

Table 1 (*Continued*)

Authors & Date	Methodology	Dance Style Studied	Population	Primary Research Question	Innovative Element(s)	Major Finding
Cross, Hamilton, et al. 2009	fMRI/ training	Video game dance (step sequences in StepMania, an open source version of the popular video game *Dance Dance Revolution*™)	16 M/F non-dancers (Additional analysis of Cross, Kraemer, et al. 2009)	Is the AON tuned to learn from/respond to only human actions, or might these brain regions also respond to symbolic, non-human cues for motor learning?	Addressed the human-specificity of the AON, and also how different components of this network might contribute to different parts of action observation and the learning process	Individual components of the AON respond to experience and observing the human form; bilateral superior temporal sulcus (STS) preferentially responded to stimuli where a human form was present while right PMv responded most to videos that participants had physically practiced (regardless of presence of human form); this suggests dissociable components for motor planning and observing others' actions within the AON
Cross et al. 2010	fMRI	Static contortion postures	18 M/F non-dancers	How do body-sensitive brain regions respond to body postures within an observer's repertoire compared to those beyond their abilities (contorted postures)?	Used a repetition suppression design to localize these representations independent of viewpoint	EBA & fusiform body area were reported as more responsive to contorted postures, suggesting greater processing demands for more difficult/impossible postures. Reduced activity was reported within the AON & fusiform gyrus for repeated postures, independent of viewpoint.

Table 1 (*Continued*)

Authors & Date	Methodology	Dance Style Studied	Population	Primary Research Question	Innovative Element(s)	Major Finding
Cross et al. 2011	fMRI	Classical ballet/ contemporary dance	22 M/F Non-dancers	How is observers' aesthetic evaluation of dance related to their perceived physical ability to reproduce the movements they watch?	First study to address the interaction between physical ability and aesthetic evaluation.	Participants report liking movements more that they perceive as being difficult to physically perform. The interaction between liking and physical ability is represented within occipitotemporal and parietal regions of the AON.
Cross et al. 2012	fMRI	Club dancing/ robotic break-dancing	45 M/F non-dancers (split across 2 independent experiments)	How do form (human vs. robot) and motion (rigid vs. fluid) cues interact and impact action perception within the AON?	2 experiment study that used stop-motion cinematography to precisely animate a robotic action figure to emulate human dance moves; first study to directly address contribution of form and motion cues to whole-body action perception	Core regions of the AON were reported to respond more robustly to robotic, rigid movements, independent of the form of the dancer (robot or human). The findings call into questions whether the AON does indeed respond preferentially to familiar movements, and the authors suggest a nonlinear relationship between familiarity and AON activity.
Fink et al. 2009	EEG	Imagery (improve dance vs waltz) and creative thinking task	15 professional M/F ballet and contemporary dancers and 17 M/F novice	How does EEG alpha activity compare between professional and novice dancers on a free-associative dance improvisation task, waltz	Studied not only movement-related tasks, but also creative thinking to see whether/ how a high degree of physical expertise	In the creative thinking task, expert dancers showed stronger alpha synchronization in posterior (i.e. centroparietal, parietotemporal and

Table 1 (*Continued*)

Authors & Date	Methodology	Dance Style Studied	Population	Primary Research Question	Innovative Element(s)	Major Finding
			dancers who had only completed a basic course in dancing	task, and creative thinking (alternate uses) task?	impacts cognition in alternative domains	parietooccipital) brain regions than novice dancers. This is likely indicative of differences in qualitative information processes. In the improvisation task, dancers exhibited more right-hemispheric alpha synchronization in parietotemporal and parietooccipital areas than novices. No differences were seen in the waltz task. Similar patterns of alpha synchronization in the improvisation and creative thinking tasks suggests they are due to creativity in general.
Grosbras et al. 2012	fMRI & rTMS	Contemporary dance	16 M/F non-dancers	Which brain areas play a causal role in emotion processing during dance observation?	Applied rTMS over previously-identified brain regions involved in emotional responses to dance in order to make causal inferences	Emotional responses correlated negatively with activity in right posterior parietal cortex and rTMS over this area enhanced emotional responses to dance segments eliciting positive emotions
Grossman et al. 2013	fNIRS			In young infants' brains, how are form and	Used identical stimuli as Cross et al. (2012) and	The infant brain was found to be sensitive to form and

Table 1 (*Continued*)

Authors & Date	Methodology	Dance Style Studied	Population	Primary Research Question	Innovative Element(s)	Major Finding
		Club dancing/ robotic break-dancing	15 M/F 4-month old infants	motion cues processed when the observer has very limited visual experience and no physical experience with the types of actions being observed?	infant-friendly brain imaging methods to address the ontogeny of action perception in the human brain	motion cues in a remarkably similar way to the adult brain. Motor properties of movements the infants are unable to perform are processed in premotor areas, while left posterior temporal regions appear to code for congruent form/motion pairings, just as was reported in the fMRI study with adults (Cross et al. 2012).
Hänggi et al. 2010	DTI	Classical ballet	10 Female ballet dancers and 10 non-dancer age-matched control subjects	How do grey matter and white matter volumes, fractional anisotropy, and mean diffusivity values compare between professional ballet dancers and healthy controls?	First study to look at structural brain alterations resulting from long-term intensive dance training.	Major reductions in grey and white matter volumes were reported in dancers compared to controls in brain regions involved in motor control processes, including premotor/supplementary motor areas, the basal ganglia, the corticospinal tracts, corpus callosum and internal capsules – findings contrast with many others that show positive correlations between grey/ white matter density/volume and motor/cognitive

Table 1 (*Continued*)

Authors & Date	Methodology	Dance Style Studied	Population	Primary Research Question	Innovative Element(s)	Major Finding
						performance – perhaps suggests more pruning back of neural hardware to essential synapses, dendrites and axonal connections with increasing expertise?
Jola et al. 2011	TMS/MEPs	Classical ballet	4 M/F non-dancers	How do different forms of salient emotional events in a live performance evoke specific modulations of brain activity? How does cortical excitability changes over a long continuous time-course (2.5 hours)?	First study to bring neurophysiological procedures into a theatre setting – participants were stimulated with TMS while watching a dress rehearsal of Sleeping Beauty performed by the Scottish Ballet. Also made comparisons between qualitative and quantitative data.	Emotional responses build up and change in terms of their valence and arousal as a show unfolds. The authors observed a decrease of cortical excitability over time that could either indicate subjects' adaptation to the procedure and the consequent effects of muscle relaxation or changes in their emotional and cognitive engagement when watching dance.
Jola et al. 2012	TMS/MEPs	Classical ballet, Indian dance, non-dance (acting)	Experienced ballet or Indian dance spectators, or novice dance spectators	In experienced dance spectators, is there evidence for effector-specific resonance when watching different movement styles? (i.e., more arm resonance when watching arm movements vs. more	Used TMS in conjunction with live dance performance to examine effects in the most ecologically-valid performance context possible	Visual experience, as well as the fantasy subscale of the Interpersonal Reactivity Index, modulated motor resonance in the arm muscles dependent on the performance style; for example, corticospinal excitability enhanced in arm

Table 1 (*Continued*)

Authors & Date	Methodology	Dance Style Studied	Population	Primary Research Question	Innovative Element(s)	Major Finding
				hand resonance when watching hand movements)?		muscles when ballet spectators watched ballet compared to Indian dance.
Jola and Grosbras 2013	TMS/MEPs	Classical ballet, Indian dance, non-dance (acting) live and video sequences	20 M/F non-dancers	How does observation of live compared to filmed performance affect muscle motor activity?	Systematically compared physiological responses when watching live dance to video-recorded dance	Higher simulation (Motor Corticospinal Excitability – MCE) in arm muscle groups was found for live compared to video performance, modulated by type of performance (when watching live performance, larger MCE response for Indian dance). Greater subjective enjoyment was reported for live compared to video performance. Performance-sensitive MCE evidence for muscle simulation when observing live dance.
Jola et al. 2013	fMRI	Unedited 6.5 minute "padam" section of a Bharatanatyam performance (classical Indian dance) with music	12 M/F naïve observers unfamiliar with Indian dance and with no musical training	Is enhanced activity in audio, visual and audiovisual (AV) brain areas (e.g. superior temporal gyrus; STG) synchronized over time across subjects when they are presented with multisensory stimuli?	Used free viewing of a longer, more natural dance stimulus and Intersubject Correlation (ISC) analysis, enables analysis of fMRI data whilst presenting more natural, long duration, complex,	Brain activity was significantly correlated across subjects in areas functionally relevant for auditory (e.g., Heschl's gyrus), visual (e.g., lingual gyrus) and multisensory processing (e.g., STG). But no synchronization found in higher order areas

Table 1 (*Continued*)

Authors & Date	Methodology	Dance Style Studied	Population	Primary Research Question	Innovative Element(s)	Major Finding
					multidimensional audiovisual stimuli	(e.g., areas implicated in cognition, action, and emotion tasks), suggesting that by presenting an unfamiliar dance, correspondence between subjects' is constrained to a sensory level.
Miura et al. 2010	fMRI	Humanoid robot dance, human dance, moving objects (mosaics)	49 M/F participants (dance experience not reported)	What are the neural effects of motion smoothness and intersubjective variability in attitudes about art during dance observation?	Used a humanoid robot named QRIO as dance performer to regulate appearance and movements and measured functional connectivity related to interindividual differences in self-reported attitudes	Higher activity was reported in brain areas sensitive to motion and body cues for smooth actions, and AON activity was modulated by intersubjective variability in personal attitudes toward art
Ono et al. 2013	fNIRS	Video game dance (step sequences in StepMania, an open source version of the popular video game *Dance Dance Revolution*™)	26 M/F participants with various levels of video game experience (10 frequent players; 4 occasional	How is sensory input (visual and auditory cues) processed in areas of multimodal integration to achieve accurate motor performance during dance video game play?	Measured cortical activity when participants are actually dancing in a video game context; correlated individual performance scores with hemodynamic response to better understand how physical experience	Focusing analyses on the middle temporal gyrus (MTG) and the frontopolar cortex (FPC), the authors found that performance accuracy positively correlated with activity in the MTG and suppression of the FPC. Authors suggest MTG is critical for integrating visual

Table 1 (*Continued*)

Authors & Date	Methodology	Dance Style Studied	Population	Primary Research Question	Innovative Element(s)	Major Finding
			players, 12 naïve subjects)		modulates cortical activity	and auditory rhythmic cues while FPC provides top-down control to compensate for insufficient integration by MTG
Orgs et al. 2008	EEG	Contemporary dance	10 M/F expert contemporary dancers and 10 M/F non-dancers	Is event-related desynchronization (ERD) in the alpha and beta frequency bands during action observation sensitive to expertise with the observed movement?	First study to use EEG to investigate the influence of expertise on alpha / beta-ERD during action observation	Dance expertise specifically modulates alpha / beta-ERD during observation of familiar vs. unfamiliar movements.
Tachibana et al. 2011	fNIRS	Video game dance (step sequences in StepMania, an open source version of the popular video game *Dance Dance Revolution*™)	7 M/F non-dancers in fNIRS task; 8 M/F naïve dancers in behavioural task	How is brain activity in regions that receive signals from more than one sensory modality impacted while performing a "dance" video game with three different difficulty levels?	First study to measure cortical surface brain activity while participants stand up, bear weight, and actually "dance"	Authors focused their analyses on two brain regions, the superior parietal lobule (SPL) and the superior temporal gyrus (STG) – found greater activity in right SPL the more difficult the dance task was, general engagement of bilateral SPL and STG during the difficult task, and only engagement of bilateral STG during the simpler tasks

performing a particular sequence. The authors interpreted this as evidence that the better one is at performing a particular action, the more that action is simulated or embodied, as evidenced by increased parietal/premotor activity tracking with increased performance ability (Cross et al., 2006).

Another example of using populations of expert dancers to explore the neural signature of physical expertise was the seminal study by Calvo-Merino and colleagues, which investigated how highly specialized physical training in one dance style (classical ballet or capoeira) influenced perception of the familiar dance style compared to the unfamiliar dance style (Calvo-Merino et al., 2005). The authors reported that when trained ballet dancers watched ballet, or when trained capoeira dancers watched capoeira, greater activity was seen throughout the AON compared to when ballet dancers watched capoeira or capoeira dancers watched ballet. The authors took this finding as evidence that years of physical practice shape action simulation processes that occur within sensorimotor cortices. In other words, extensive physical practice fine-tunes the sensorimotor cortex to respond to movement that is familiar.

One final early dance brain imaging experiment that warrants discussion is the highly innovative study by Brown and colleagues, who had participants actually 'dance' while lying supine within a positron emission tomography scanner. Their aim was to investigate the core elements of tango dancing (entrainment, metre and step patterns) by having participants physically perform the foot patterns on an inclined surface while having their brain activity measured (Brown et al., 2006). Brown and colleagues report activation within a broad network of AON regions when executing complex foot sequences, and involvement of striatal and cerebellar components when more complex rhythmic sequences were performed. The activation of these brain regions is consistent with those regions activated by dance observation (Calvo-Merino et al., 2005) and dance imagery (Cross et al., 2006). Importantly, this study by Brown and colleagues (2006) provided the first evidence that actual performance of complex dance steps (albeit in a modified, neuroimaging context) shows strong overlap with observation.

Another area in which dance paradigms have helped to illuminate neural processes involved in linking action with perception is the domain of how observational and physical experience compare when learning or perceiving complex motor skills (Calvo-Merino, Grezes, Glaser, Passingham, & Haggard, 2006; Cross, Kraemer, Hamilton, Kelley, & Grafton, 2009). Cross and colleagues sought to specifically address how observational learning compares to physical practice in terms of behavioural performance and neural responses (Cross, Kraemer, et al., 2009). The authors accomplished this by implementing a one-week training study with novice dancers who learned novel dance sequences in a video game context. Using a within-subjects design, all participants learned six sequences via physical practice and passively observed six different sequences during five consecutive days of training. Immediately before training began and after it concluded, participants' brain activity was recorded with fMRI while they watched and listened to the music videos of all the dance sequences from the physically practised and watched conditions, as well as from a third, untrained condition. Based on the wealth of behavioural data showing evidence for learning by observation (e.g. Feltz, Landers, & Raeder, 1979; Hodges & Williams, 2007; Hodges, Williams, Hayes, & Breslin, 2007; McAuley, 1985), the authors hypothesized and found that observational experience is associated with a performance advantage compared to untrained sequences.

Of greater interest for this particular study, however, was how the brain was impacted by physical compared to observational experience. The fMRI data revealed that physical

and observational learning appeared to impact two core regions of the AON in a similar manner. Responses within the left IPL and right premotor cortex were quantifiably more similar when observing danced and watched sequences compared to untrained sequences. This was among the first brain-based evidence to suggest that mere observation of an action has the potential to build a similar neural representation of that action as physical practice (Cross, Kraemer, et al., 2009), which added to prior behavioural support for a common neurocognitive representation of performed and perceived actions (e.g. Badets, Blandin, & Shea, 2006; Bandura, 1986; Hodges et al., 2007).

Naturally, the take-home message from the study by Cross, Kraemer, and colleagues (2009) is not that observational learning is identical to physical practice when it comes to building action representations within the brain. Rather, the results suggest that the parts of the brain that are active during physical training might be active in a similar manner when actions are passively observed, and this activity appears to be related to some degree to the efficacy of learning by observation. When examining how watching others in action changes an observer's physical abilities, studies using dance (as well as other skilled full-body actions such as gymnastics and contortion) have advanced our understanding of how observation impacts motor regions of the brain (e.g. Calvo-Merino et al., 2006; Cross, Mackie, Wolford, & Hamilton, 2010; Cross, Stadler, Parkinson, Schutz-Bosbach, & Prinz, 2013; Jola, Abedian-Amiri, Kuppuswamy, Pollick, & Grosbras, 2012).

While some evidence suggests that visual experience alone is not enough to meaningfully impact the AON (Calvo-Merino et al., 2006), other research suggests that even when an individual observes movements that he or she could not possibly physically perform, extensive visual experience of these actions is associated with the emergence of neural representations within sensorimotor regions (Cross et al., 2013; Jola, Pollick, & Grosbras, 2011). Jola and colleagues have recently performed a number of innovative studies that have used transcranial magnetic stimulation (TMS) to further explore the impact of visual experience on dance perception (Jola et al., 2011), as well as how the context in which one observes an action impacts how sensorimotor brain regions respond when watching a complex action (Jola et al., 2012; Jola & Grosbras, 2013). In this work, Jola and colleagues measure motor evoked potentials (MEPs) within arm, hand or finger muscles when participants watch different kinds of dance, such as classical ballet or Bharatanatyam (a type of classical Indian dance). The idea behind this approach is that cortical excitability (measured by stimulating the motor cortex with TMS while simultaneously recording MEPs in the hand or arm) should increase when watching action compared to non-action viewing events. Furthermore, cortical excitability should be greatest when watching actions that are visually familiar or aesthetically pleasing, and such excitability is taken as an index of motor simulation (or, as Jola et al. (2011) describe it, 'watching somebody else performing an action induces internal "rehearsal" of the action observed in the mind of the spectator in a muscle-specific manner' (p. 380)).

Another finding Jola and colleagues report is that visually experienced ballet spectators with no physical experience dancing ballet but who frequently attend ballet performances show greater MEP amplitudes in arm muscles when watching ballet compared to Bharatanatyam (Jola et al., 2011). A notable feature of this research group's approach is their drive to push neuroscientific measures of action observation into ever-more ecologically valid contexts. As evidence of this, they have used the same TMS combined with MEP recording approach on four experienced ballet spectators while they watched a 2.5-hour dress rehearsal of the Scottish Ballet performing *Sleeping Beauty* with full costumes, music and lighting in a theatre setting (Jola et al., 2011). While the small

number of participants prohibited the authors from running full statistical analyses, this approach nevertheless sheds light on how sensorimotor activity changes across a long viewing epoch, as well as how individual differences in spectators' affective responses relate to sensorimotor activity. Considered together, results from studies that combine neurostimulation with MEP recordings demonstrate the utility and increased ecological validity of an approach to study not only how we are able to coordinate our entire bodies to perform complex movements, but also how different experiential backgrounds and observational contexts impact perception.

Another methodological approach that has proved valuable in exploring the underlying neural dynamics of complex action observation using dancers is electroen-cephalography (EEG; Fink, Graif, & Neubauer, 2009; Orgs et al., 2008). Compared to fMRI, EEG enables much more precise measurement of the temporal engagement of brain systems. In the first study to employ such measures to investigate the impact of a highly skilled motor repertoire on action perception, Orgs and colleagues (2008) assessed the event-related desynchronization (ERD) of the EEG signal. ERD within certain frequency bands during action observation is thought to be an indirect measure of sensorimotor cortical engagement in action simulation processes (Muthukumaraswamy, Johnson, & McNair, 2004). Orgs and colleagues, set out to test whether ERD was sensitive to expertise in contemporary dance. To do so, they showed dancers and non-dancers two types of upper body action stimuli: dance movements and everyday actions. Among the dancers, observation of dance movement resulted in significant ERD, while no such ERD was observed among the non-dancers. By contrast, when watching everyday actions there were no differences in ERD values between dancers and non-dancers. The authors interpret this as further evidence of motor experience impacting how sensorimotor brain regions respond when watching others in action. Moreover, they were the first to show that looking at the temporal dynamics of brain activity between expert and novice movers can provide another avenue for understanding the relationship between action and perception (Orgs et al., 2008).

A final set of studies that warrants discussion in this section, less in terms of the research questions being addressed and more for methodological novelty and innovation, is work by Tachibana, Ono and colleagues (Ono et al., 2013; Tachibana, Noah, Bronner, Ono, & Onozuka, 2011). These investigators have sought to advance the use of functional neuroimaging in complex action *performance* contexts, and have so far performed a pair of studies using functional near infrared spectroscopy (fNIRS) while participants played dance video games. The authors aimed to investigate how different elements of performance and participants' prior experience shape neural responses during action execution. Like EEG, fNIRS involves wearing a cap with a number of sensors that covers the surface of the scalp. Unlike EEG, however, and akin to fMRI, fNIRS measures the blood oxygen level dependent (BOLD) response of the brain. Compared to fMRI, the spatial resolution of fNIRS is inferior, and it is also difficult to measure neural activity beyond surface cortical regions. With these limitations in mind, however, it is still the only available technology that enables measurement of the BOLD signal while participants stand and move all their limbs while playing a dance video game. By corroborating previous results from other techniques that have measured brain activity during action observation only (and manipulated physical experience separately), these two studies serve as proof of principle that fNIRS can be used to study perception–action links using dance performance. The benefit of this approach is the added flexibility that

fNIRS provides for measuring brain activity during action execution, especially for whole-body movements.

Of course, the findings and approaches outlined above extend well beyond dance learning, observation and expertise. A cursory search of the literature reveals that cognitive neuroscientific measures have been applied to a variety of highly skilled actions in sporting domains, including shooting (Baeck et al., 2012), basketball (Abreu et al., 2012; Aglioti, Cesari, Romani, & Urgesi, 2008), gymnastics (Cross et al., 2013; Zentgraf et al., 2005) and archery (Kim et al., 2011), to name a few examples. As a whole, we suggest that the theoretical models and neuroimaging tools borrowed from the neuroscience community can fortify and accelerate sports science research, but only if the concepts are applied carefully and conservatively, and the tools used appropriately (as with every other kind of cross-disciplinary endeavour). The challenge for research into the relationship between action perception and production is to determine the explanatory power and generalization of the network of brain regions engaged by action perception and performance and its relationship to motor skill and new action learning. It is the hope of researchers in this field to eventually explore applications for the recovery of function after injury and improved learning and teaching practices, especially in the sports sciences.

A critical analysis of cognitive neuroscience and the study of psychological processes

Our goal in this section is to review the main debates surrounding the application of different cognitive neuroscience techniques discussed in the previous section to the study of psychological processes. This section of the review is necessarily selective. We restrict ourselves to fMRI, TMS and EEG, the main methodologies encountered in the previous sections. There are other neuroscientific techniques, such as studies of brain lesions, that have interesting applications to the study of cognition (e.g. Rorden & Karnath, 2004) but these are beyond the scope of this review. Similarly, it is not possible to discuss all possible applications of the three methodologies of interest. We acknowledge that recent developments to neuroimaging techniques including, connectivity analyses (e.g. Friston, 2011), multivoxel pattern analysis and classification approaches (e.g. Norman, Polyn, Detre, & Haxby, 2006) and real-time fMRI (e.g. deCharms, 2008) hold significant potential for informing research into sport psychology questions. Similarly, further relevant applications of EEG include neurofeedback and performance enhancement (e.g. Thompson, Steffert, Ros, Leach, & Gruzelier, 2008). However, consideration of each of these issues is beyond the scope of the current review. Instead, our aim in the following paragraphs to provide an introduction to some of the main issues with each of the major techniques discussed in the previous section.

Currently, lively debate continues surrounding the extent to which fMRI can contribute to an understanding of psychological processes (e.g. Bechtel, 2002; Coltheart, 2006; Henson, 2005; Page, 2006). Henson (2005) has argued that imaging data comprise another dependent variable for psychologists. The relevance of functional imaging data to psychological-level theory depends upon assuming what Henson labels systematic function-to-structure mapping in the brain: the assumption that there is some systematic mapping between *which* psychological processes are currently engaged and *where* activity is changing in the brain.

This assumption supports two types of inferences made from imaging data. The first Henson (2005) labels function-to-structure deduction. This is the context- and theory-specific inference made from a single experiment. 'If (experimental) conditions C_1 and C_2

produce qualitatively different patterns of activity over the brain, the conditions C_1 and C_2 differ in at least one function, F. The definition of "qualitatively" … entails a reliable statistical interaction between conditions C1 and C_2 and at least two brain regions R_1 and R_2' (p. 197).

The second Henson (2005) labels structure-to-function induction. 'If condition C_2 elicits responses in the brain region R_1 relative to some baseline condition C_0 and region R_1 has been associated with function F_1 in a different context (e.g. in a comparison of condition C_1 vs. C_0 in a previous experiment), then F_1 function is also implicated in condition C_2' (p. 198). This is a context-independent inference that nevertheless requires stronger assumptions than the previous type of inference, relying on the validity of previous studies. Henson (2005, 2006) cites a number of examples or studies that have used these inferential strategies to inform underlying cognitive mechanisms.

Page (2006) raises a number of issues with these inferential strategies. In relation to 'function-to-structure deduction', he argues that it is essential to clarify how cognitive functions are to be individuated. In order for a functional decomposition to make firm predictions about activity patterns detectable by fMRI, psychological models would have to be specified not merely in terms of the neural hardware with which the function is thought to be implemented, but also in terms of the spatial distribution of that hardware in the brain. If cognitive theories fall short of this level of specification, it is not at all clear how information about the spatial distribution of neural activation can be used to constrain the theory.

The logic of 'structure-to-function induction' involves inducing the implication of F_1 from activation in R_1. However, Page (2006) notes that the activation of a given region in an fMRI scan might legitimately imply functional engagement, functional disengagement, or some modulation in between. A further possibility is that in C_2, neural hardware in R_1 attempts to implement processes associated with F, but for various reasons fails to generate a response that affects the to-be-explained behaviour. This could then result in activation in R from which the implication of F_1 could be incorrectly inferred. So we need to be clear about what can legitimately be inferred from a particular pattern of activation. Multiple interpretations are possible.

A final use for fMRI that merits discussion here is the project of localization: using neuroimaging methods to relate particular functions to particular parts of the brain. Page (2006) observes that a large number of imaging papers go to great lengths to establish the locus of a particular function, without specifying how this is meant to contribute to the advancement of psychological theory. In one of the first articles to address this issue, Fodor (1999) argued for a need to distinguish between the question of *whether* mental functions are neurally localized in the brain and the question of *where* they are neurally localized in the brain. Indirectly, of course, the location of a particular function may be relevant. For example, Bechtel (2002) suggests if it were found that brain activity associated with two cognitively identified processes that are linked in cognitive models are *not* linked in brain activity then we may consider revising the cognitive model. The point is that cognitive theory is not advanced by the localization of function *per se* (Page, 2006). This means that the theoretical ramifications of the localization of a particular function need to be spelled out in advance (see Slotnick, Thompson, & Kosslyn, 2005).

It is salutary to remember that neuroimaging data are inherently correlational (Poldrack, 2011), which limits inferences of causality. One of the strengths of TMS is that it can contribute to an understanding of which regions are necessary for a cognitive

process and which are epiphenomenal, because brain activity can be directly manipulated as an independent variable (Sack & Linden, 2003).

Nevertheless, although in principle TMS can be used as a technique to investigate causality, the effect of TMS on task performance can be difficult to interpret (Miniussi & Thut, 2010). For example, performance on the same cognitive task can be shown to be facilitated or inhibited (e.g. Rossi & Rossini, 2004). Interpretation of a null result is complicated by the fact that, if task performance is unaffected by TMS, this could mean that stimulation actually had no effect or that the stimulation was simply insufficient (Miniussi & Thut, 2010). More complex explanations for null results have also been discussed in the literature (e.g. Sack, Camprodon, Pascual-Leone, & Goebel, 2005; Sack & Linden, 2003). A further issue is that although a specific cortical area may be targeted, TMS may affect remote cortical and subcortical areas (Paus et al., 1997; Sack & Linden, 2003), thus compromising the spatial specificity. As a result, this means that TMS-induced changes in behaviour could also be ascribed to secondary effects on areas connected to the stimulated site (Miniussi & Thut, 2010; Sack & Linden, 2003).

Turning to EEG, it has been noted that, in common with fMRI, it only identifies correlational links between brain activity and behaviour (Miniussi & Thut, 2010). As a result, the functional significance of an event related potential (ERP) is somewhat opaque. Luck (2005) illustrates this by contrasting ERP recordings with reaction time (RT) paradigms requiring a button press. When a button press is recorded, Luck argues that we have a clear understanding of what that signal means. If the RT in condition A is 30 ms longer than that in condition B, it seems legitimate to infer that the time required to encode, process and act on the stimuli was 30 ms longer in condition A than in condition B. On the other hand, if the peak latency of an ERP component is 30 ms later in condition A compared with condition B, Luck notes that a much longer chain of assumptions and inferences is required.

A growing number of papers have discussed statistical issues with the analysis and interpretation of EEG data (Kilner & Friston, 2010; Kilner, 2013; Maris & Oostenveld, 2007). These are a consequence of the complex and multi-dimensional nature of EEG data. Kilner (2013) notes that one way of reducing the complexity and dimensionality is to average the data to produce a single value per subject. He argues that this method is robust and valid providing that the time windows and electrodes/sensors over which the data are averaged have been chosen independently (e.g. from an independent data set or from an orthogonal contrast). Nevertheless, Kilner observes that it is common practice for the selection to be based on where the effect of interest is greatest. Kilner presents the results of a simulation, demonstrating that this leads to an increased risk of reporting false positives and concludes, therefore, that it should not be used as part of EEG analysis.

To end this section, we discuss an issue that is common to all three approaches. A number of authors have addressed the so-called 'seductive allure' of cognitive neuroscience. Henson (2005) argues that 'there is real danger that pictures of blobs on brains seduce one into thinking that we can now directly observe psychological processes' (p. 228).

This phenomenon has also been investigated empirically. McCabe and Castel (2008) found that articles summarizing cognitive neuroscience research were judged to be more credible if they were accompanied by brain images compared with other sorts of visual images such as bar charts or even topographical maps of EEG recordings. However, the effect does not appear to be limited to brain images. Weisberg, Keil, Goodstein, Rawson and Gray (2008) reported that the presence of explanatorily irrelevant neuroscience

information encouraged non-scientists to judge explanations of psychological phenomena more favourably. Mausfield (2012) has analysed the current dominance of cognitive neuroscience, arguing that it emerges from, along with other factors, our desire to reduce highly abstract mental phenomena to 'real' objects such as neurotransmitters or brain areas. The danger here, of course, is that neuroscientific techniques are prioritized over other types of investigation. We hope that by drawing attention to the techniques' limitations as well as their strengths, we have presented a balanced perspective whose central tenet maintains that no single research technique holds privileged status with respect to the study of cognitive processes.

Summary and conclusion

In the present article, our overarching objective was to highlight the utility and scope of the considered application of cognitive neuroscience techniques to questions of interest to sport psychologists. We have emphasized how cognitive neuroscientific approaches might inform research into the links between action and perception, with a particular focus on studies that feature dance learning and expertise. Our motivation for this stems from the fact that a number of elegant studies using dancers and dance paradigms are contributing valuable knowledge to our understanding of what it means to be a movement expert at the neural level, as well as how different learning techniques impact brain and behaviour.

Based on this review, two main aspects are worth recapping for researchers interested in the application of cognitive neuroscientific techniques to investigate the psychology of sport. First, each experiment stemmed from a more general question regarding neurological constructs of action cognition. They were not focused on studying dance *per se*, nor were they asking 'where in the brain does process *X* occur?' In other words, dance was used as a tool to probe neurocognitive processes rather than dance being an end in itself. Therefore, we hope that researchers remain mindful that the generation of appropriate research questions, which are tailored to the method chosen, is essential if results are to be informative.

Second, although brain-based approaches continue to gain popularity and ubiquity, such techniques should be used cautiously and any results should categorically *not* be considered superior to behavioural or other methodological approaches. We urge researchers to consider Morton's framework of causal modelling (Morton, 2004; Morton & Frith, 1995). Morton argues that (neuro)biology is only one piece of the puzzle to be considered alongside many other pieces in order to construct the fullest understanding of a psychological construct or process. This means that researchers who primarily use neuroscience methods would benefit from considering knowledge gained from other approaches to understanding psychological states, such as experimental psychology and neuropsychology. Equally, researchers who rely upon behavioural methods should take into account knowledge gained from neurobiological approaches to understanding psychological states. With this in mind, it is our view that with careful planning and considered application, a number of techniques from the cognitive neurosciences have the potential to significantly drive forward research using complex action, not simply to investigate links between action and perception, but in a number of other domains of sport psychology, such as motivation, performance under pressure and skill transfer.

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Note

1. In the present review, we prefer to extend our focus slightly beyond the classic mirror system to also include parts of the brain involved primarily in action perception. This network of brain regions, comprising classic frontoparietal mirror system regions, as well as occipitotemporal brain regions engaged by watching others in action, is known as the action observation network (AON), and its properties are central to much of the research discussed herein.

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