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A Neuroscientific Review of Imagery and Observation Use in Sport

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ABSTRACT. Imagery and observation are multicomponential, involving individual difference characteristics that modify the processes. The authors propose that both imagery and observation function by offering effective routes to access and reinforce neural networks for skilled performance. The neural isomorphism with overt behaviors offers a tempting mechanism to explain the beneficial outcomes of the 2 processes. However, several limitations related to imagery indicate the possibility that imagery may not be as efficacious as the literature would indicate. The authors propose observation-based approaches to offer more valid and effective techniques in sport psychology and motor control.

Keywords: imagery, neuroscience, observation

Imagery continues to be popular among both practitioners and academics in psychology and motor control. The extensive imagery literature base has always supported the inclusion of some form of imagery process in sports mental practice regimes on limited theoretical evidence (e.g., Murphy, 1994). However, what is different in recent texts is the increasing lure of new cognitive neuroscience research to support the neurological efficacy of imagery as a psychological intervention (e.g., Morris, Spittle, & Watt, 2005; Murphy, Nordin, & Cumming, 2007). This neurophysiological approach is welcome to a discipline area that has suffered from a lack of valid mechanism-driven theories.

Researchers have recognized integrating ideas and theories from disparate areas as beneficial for sport psychology and motor control (e.g., Keil, Holmes, Bennett, Davids, & Smith, 2000). With the use of imaging technology (e.g., functional magnetic resonance imaging; fMRI) now available to many neuroscientists, existing knowledge of imagery and observation is vast. However, it is easy to oversimplify one or more of the integrated areas. Such oversimplification can lead to the application of invalid new models in practical fields like sport psychology and motor control.

In the present article, we aim to provide a critical review of the cognitive neuroscience literature related to imagery and observation and, by comparing their neural equivalence with physically executed behavior, argue for their careful use in sport. The review is divided into two main sections. We propose that (a) many individual difference characteristics can modify the neural activity occurring during imagery and observation and (b) researchers and practitioners should consider a number of implications.

INDIVIDUAL DIFFERENCE CHARACTERISTICS AND NEURAL ACTIVITY DURING IMAGERY AND OBSERVATION

Imagery and Observation: Defining the Processes

Before researchers can consider the neural activity associated with imagery and observation, it is important to define the two processes clearly. Morris et al. (2005) discussed the problems with trying to define the imagery process in a sporting context. They suggested that there is a lack of consistency in the features that constitute the process and that “the focus of each definition seems to vary depending on the purpose for which the imagery description is used” (p. 14). Similar problems are evident in the more sparse definitions for observation (McCullagh & Weiss, 2001). Although many reported definitions indicate the possibility, to a greater or lesser extent, of the brain activity that is occurring during the behavior, few researchers have used neuroscience to define the fundamental imagery processes. To reflect the neuroscientific focus of this article and the strong underlying assumption that imagery shares at least some anatomical substrate with physical execution, we refer to this focus in our definition. Therefore, we offer a modified version of Morris et al.’s working definition of *imagery*:

Imagery, in the context of sport, may be considered as the neural generation or regeneration of parts of a brain representation/neural network involving primarily top-down sensorial, perceptual and affective characteristics, that are primarily under the conscious control of the imager and which may occur in the absence of perceptual afference functionally equivalent to the actual sporting experience.

We contrast the definition of imagery with that of *observation*:

Observation, in the context of sport, may be considered as the neural stimulation of a brain representation/neural network involving primarily bottom-up sensorial, perceptual and affective characteristics, that are primarily under the subconscious control of the observer and which may occur in the presence of afference functionally equivalent to the actual sporting experience.

Therefore, imagery at its most basic level is a top-down, knowledge-driven process, whereas observation is more a

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bottom-up and percept-driven process. Of interest here are (a) how much these processes reflect and share neural activity associated with their physical overt behaviors; (b) their ability to influence future behavior; and (c) how researchers, practitioners, and athletes can use them effectively in sport.

Much of what follows in our discussion relates to the terminology of these definitions. We provide evidence to support a distinction between the processes of imagery and observation in terms of their efficacies to access functional cortical and subcortical neural networks. However, we do not propose that imagery and observation compete as interventions; they share many central substrates. Rather, we see their roles as separate but complimentary if we consider some important procedural concerns. Clark, Tremblay, and Ste-Marie (2003) observed similar changes in corticospinal excitability during imagery and observation. We argue that imagery and observation share a number of mental operations and rely on common neural structures (e.g., Grèzes & Decety, 2001). These structures are analogous to some of those that are active during the preparation, anticipation, and, in some cases, actual production of actions. In this way, imagery and observation have the potential to produce a similar outcome: a repetitive Hebbian modulation of intracortical and subcortical excitatory mechanisms through synaptic and cortical map plasticity, similar to those mechanisms observed after physical practice of the same task. We question and review primarily the extent of the modulation.

Imagery Process

In this section, we discuss some of the important aspects of the imagery process. First, we consider imagery characteristics and neural activity. The imagery characteristics are considered through (a) image generation, maintenance, and transformation and (b) spatial perspective, behavior agency, and image modality. Second, we discuss imagery's neural association with physically executed behavior. Third, we examine the process of and concerns for imagery assessment.

Imagery Characteristics and Neural Activity

Image Generation, Maintenance, and Transformation

In our experience, imagery in sport frequently starts with the imager choosing to close his or her eyes. In terms of neurological congruence with the overt behavior, this process instantly modifies the activity across the primary visual cortex sites, and researchers can observe this process through, for example, the desynchronizing of alpha band frequencies (e.g., Andreassi, 2000). Therefore, before the imagery process has even begun, visual aspects of the neural shared circuitry have potentially been compromised.

De Beni, Pazzaglia, and Gardini (2007) described imagery as multicomponential, comprising image generation, transformation, maintenance, and scanning. Traditionally, researchers have considered image generation and maintenance to be parts of the same process, whereas image

transformation has been defined as a special case of image generation (see Kosslyn, 1994). De Beni et al. argued that the neurological structures active during these processes suggest a mutual independence of image generation and maintenance. The detail relating to these procedures is outside of the scope of this article. However, that an image has to be generated, maintained, and transformed reduces the neural equivalence with motor execution and only complicates the simulation–execution debate. Further, De Beni et al.'s study identified for younger participants (M age = 22.0 years, SD = 1.80 years) mean image generation times ranging from 2.2 s for general images to 3.4 s for autobiographical images. With the temporal importance of skilled sports behavior, these latencies would seem problematic, in particular if the imagery script is externally delivered and paced. The temporal problem is accentuated further when the maintenance times are considered. General images were maintained for an average of 3.7 s, and autobiographical images were maintained for 5.2 s. These maintenance times raise concerns about what happens to the image after this time. In a second study, De Beni et al. found that the best way to maintain an image was for the imager to manipulate the visual characteristics through minor transformations. If the process of imagery is to extend beyond a few seconds, the image must be either regenerated or transformed visually. Therefore, it changes from that directed by the initial script and is unlikely to be temporally congruent with the prescribed behavior.

Spatial Perspective, Agency, and Modality

In the sport psychology and motor control literature, three separate image characteristics have tended to be compounded: image spatial perspective, image agency, and image modality. There is considerable evidence that they show different patterns of cortical and subcortical activity both within and across variables (e.g., Farrer & Frith, 2002; Fourkas, Avenanti, Urgesi, & Aglioti, 2006; Maeda, Kleiner-Fisman, & Pascual-Leone, 2002; Ruby & Decety, 2001; Vogeley & Fink, 2003). For example, an image using different visual perspectives can involve different parts of cortex: The right inferior parietal, precuneus (posteromedial portion of the parietal lobe), and somatosensory cortices have been found to distinguish self-produced actions from those generated by others (Ruby & Decety). Although perspective, agency, and modality factors may be related and share some neural properties, they are not the same. Their conflation can complicate the delivery of imagery for the practitioner and confuse the recipient about what he or she is required to image.

Spatial perspective and agency. Jeannerod's (2006) concept of perspective taking supports a close link to agency but without mention of image modality. He stated that "perspective taking is part of the self-other distinction: putting oneself in the place of somebody else implies that the two selves have been identified as distinct from one another" (p. 89). In general, an internal visual spatial perspective (a

first-person visual perspective; 1PP) has been associated with the self as the agent of behavior. But in the situation of mental perspective taking, a 1PP can also allocate agency to another as would be the case if an individual were told to “put yourself in their shoes.” In the case of an external visual spatial perspective (a third-person visual perspective; 3PP), another individual or the self can be seen as the agent. The difference between 1PP and 3PP is that 3PP requires a translocation of an egocentric viewpoint. Vogely and Fink (2003) proposed that egocentric frames of reference can be subdifferentiated and defined with respect to the midline of the visual field, the head, the trunk, or the longitudinal axis of the limb involved in the execution of a certain action. To our knowledge, this level of image detail has not been discussed in sports imagery research and further complicates the image generation problem. If Hebbian plasticity of functional synapses and cortical and subcortical maps is to be the mechanism that researchers use to explain imagery’s effectiveness, clarity of instructions for image perspective and agency requirements throughout the script is important.

The perspective–agency issue in imagery is complicated further by the relative motion of the imaged behavior: In 1PP and 3PP imagery, researchers can see the object or behavior of interest to move, whereas the viewer remains stationary. This relative motion is of particular interest because, as we discuss later, agency of movement is important to the experience of other sensorial modalities. If a 1PP is used, but there is no movement of the self as agent relative to the viewed behavior, it is unlikely that the imager would experience kinesthesia associated with the movement. These issues are important because there is evidence that manipulation of each of the two factors varies the neurological profile as a consequence of the different spatial perspective and agency imagined (e.g., Decety & Chaminade, 2003; Farrer & Frith, 2002; Fourkas et al., 2006; Ruby & Decety, 2001). Assumed understanding of any perspective or agency instructions provided to participants or athletes undertaking imagery may significantly influence the neural activity during the intervention.

Therefore, although there is strong evidence that simulated 1PP and 3PP actions share neural correlates, there is not a complete overlap between self and other representations (e.g., Anquetil & Jeannerod, 2007; Decety & Grèzes, 2006). The evidence from Decety and Grèzes suggested that self-awareness, as well as agency, is important. The junction of the right inferior parietal cortex and the posterior temporal cortex is a key neural locus for self-processing and is critical in distinguishing self-produced actions from other-produced actions (Blanke & Arzy, 2005). Given these areas’ neural links with visual, auditory, somesthetic, and limbic areas, we should ask athletes to image internal self and external self rather than other. However, we should consider the preferred agency perspective, the sense of self-ownership, and the visual cues for self-identification. If a self (internal or external) perspective is undertaken, then it

may be supportable by an extensive cross-modal sensory image of the body that is reinforced through synchronous memorial experiences that are visual, kinesthetic, tactile, auditory, gustatory, and proprioceptive. This complimentary neural activity may be compromised if an other perspective agency is promoted. In case there is a psychological or coaching need to use an other agency, Jeannerod (2006) suggested that “[to] represent the actions of others the best way is to read representations of one’s own actions in a third-person perspective, instead of the usual first-person perspective” (p. 90). This switching of agency, in terms of neurological activity, may be a sensible suggestion as more functional activity is seen for self-agency irrespective of spatial perspective (e.g., Decety & Grèzes). Again, it is rare to find these issues discussed in the sport psychology and motor control literatures.

Spatial perspective and viewing angle. A further confounding variable important to this section is the viewing angle adopted during the imagery behavior. Although this factor was raised by Kosslyn in 1978, it has rarely been discussed in the sport psychology literature and, to our knowledge, has not been considered through empirical study in sport. Both 1PPs and 3PPs can adopt numerous viewing angles, and this may contribute to their effectiveness. If, as Hardy (1997) suggested, an external visual spatial perspective is effective because it provides the performer with additional information about the movements and positions required for performance, then multiple-angled external visual spatial perspective imagery may be more efficacious than that from only a single angle. The concept of viewing angle is likely to be linked to the imagined task. For example, in our applied work, we have recorded the experiences of elite prone shooters, elite gymnasts, and golfers who rotate and transform their external self-images to see side, front-on, and plain views of their bodies to provide performance information. In contrast, these multiple-angled, rotated images have rarely been reported by runners and swimmers with whom we have worked. White and Hardy’s (1995) concept of form-dependent skills linked to external visual imagery may be associated with the use of multiple-angle, rotated images. This idea remains to be tested.

Imagery modality. Behavioral agency and spatial perspective are frequently confounded with image modality, especially movement kinesthesia. As we have discussed, spatial perspective is, primarily, a visual component of the image. When combined with agency and with movement added to the image content, the potential exists to experience kinesthesia and other modalities associated with the movement (e.g., sound).

Some authors (e.g., Collins, Smith, & Hale, 1998; Hale, 1982; Lang, 1985) have argued that a first-person visual spatial perspective combined with a self agency is the most effective in eliciting a multisensory physiological response to an imagery script. Proponents of this 1PP-self imagery have suggested that the kinesthetic component of internal imagery is the critical element of the image content and that

it is exclusive to this perspective, which is assumed to be a result of the specific and more elaborate neural activity in functional motor areas (e.g., Collins et al., 1998). Although this account may be true, there is also evidence that 3PP-self is at least as effective as 1PP-self for the experience of concurrent kinesthetic imagery during visual imagery of certain tasks (e.g., Callow & Hardy, 2004).

Theoretical accounts (e.g., parallel distributed processing models; neural network models) and empirical studies (e.g., Hardy & Callow, 1999; White & Hardy, 1995) support the proposal that kinesthetic imagery can be experienced concurrently with a 3PP, but only where the external agent is the self and for skilled movements (see Callow & Hardy, 2004). Callow and Hardy developed their argument further and stated that “kinesthetic imagery may have spatial and/or visual components” (p. 174). This statement mirrors the position adopted by Jeannerod (1994), who reported that it is difficult to separate visual images of movement from kinesthetic images irrespective of the visual perspective. If neural complexity of the visuomotor representation is important for the experience of concurrent kinesthesis with an external visual spatial perspective, the imager should possess a motor familiarity as well as a visual familiarity with the imaged action.

The Neural Association Between Imagery and Physically Executed Behavior

In sport, imagery practice has tended to promote a multimodal image (e.g., one referring to visual, kinesthetic, auditory, olfactory, and gustatory stimuli). The emphasis on motor imagery, the covert rehearsal of movement, has been particularly common in sport because of the visuomotor-based nature of the behavior and the implicit association of motor imagery with the kinesthetic component of the imagery process. For this reason, we focus on the efficacy of motor imagery as part of a valid intervention technique for sport psychology and compare this with observation of movement. Researchers require discussion to justify the effectiveness of access to functional motor pathways through the generation of motor images.

Do Imagery Processes Activate Primary Motor Cortex?

A question that is central to the shared neural circuitry debate follows: What is the contribution of the contralateral primary motor cortex (cM1) to motor imagery? An unstated assumption in some recent motor imagery studies in sport has been that cM1 is involved in the imagery process. Researchers have also proposed that this activity will enhance future motor tasks because it supports the concept of motor functional equivalence (e.g., Holmes & Collins, 2001).

There is evidence that the supplementary motor area (SMA) and premotor cortex (PMC) are active during movement-based imagery (albeit in areas slightly different from those of motor execution). The areas of activity are consistent with movement selection and preparation but not initiation and execution. Therefore, we have a paradox. Imagery is normally assumed to be performed in the absence of overt movement, and cM1 is

primarily an executional part of the motor system. No activity should be expected in this motor area during the imagination of movements. However, this is not a consistent finding, with as many researchers having reported cM1 activity (e.g., Nair, Purkott, Fuchs, Steinberg, & Kelso, 2003) as those who have not (e.g., Decety et al., 1994). Lotze and Halsband (2006) offered two methodologically grounded explanations for the discrepant results. First, cM1 activation during motor imagery could be present for a much shorter period than such activation during movement execution. Therefore, the methodological technique used to provide the marker of cM1 activity may be important because the temporal resolution of, for example, electroencephalography, is different from that of functional magnetic resonance imaging. Second, Lotze and Halsband suggested that the imagined task may explain the differential access to cM1. Simple motor images, such as single finger flexions and extensions, may access more neuronal assemblies of cM1 in comparison with the inhibited complex, gross motor activities. Lotze and Halsband concluded that cM1's contribution to motor imagery is intensity and threshold dependent. We offer two further considerations to explain the inconsistent findings. First, based on the aforementioned perspective, agency, and modality debates, there is sufficient doubt about the methodological imagery processes to question what the imagers were actually doing. Second, there has been doubt for some time (e.g., Jeannerod, 1994) about the influence of tacit knowledge in the imagery process. Both these issues could explain the variable cM1 access. The primary motor cortex may be involved in motor imagery but much decreased in comparison with motor execution; those neurons that are involved are located more anterior to those active during execution. Claims for complete motor cortex functional equivalence during motor imagery are therefore misleading.

Cerebellar Contribution to the Motor Imagery Process

A similar argument is apparent for activity in the cerebellum during motor imagery. Cerebellar activity during motor execution reflects somatosensory feedback of the movement to allow precise, coordinated spatial and temporal control of the movement. In imagery conditions, this is not necessary but cerebellar activity is still observed. However, in a profile similar to that discussed for cM1, the specific areas of the cerebellum active during movement execution are not the same as those active in motor imagery. The upper parts of the posterior cerebellum are linked to the SMA, and premotor cortex and activity here seems to reflect the inhibition of movement rather than functional equivalent activity specifically related to the imagined behavior. This level of topographic detail is rarely considered in the sport neuroscience literature. It would be incorrect to report functional equivalence of cM1 or cerebellum activation in imagery and execution conditions only on the grounds of activity.

The activity observed in cerebellum and other areas during imagery conditions has typically been reported as evidence for effective motor representational access and used to validate imagery-based interventions (Holmes & Collins,

2001; Murphy et al., 2008). If activity is not functionally related to the physical activity or, as in the case of cerebellar activity, related to inhibitory behavior, the efficacy of motor functional equivalence to explain imagery's effectiveness may need to be reviewed.

Influence of Expertise in the Involvement of Cortical Areas During Imagery

It is important for researchers to place the neural activity in the context of the imager's individual differences. For example, cM1 activity may be less a required neuronal correlate for elite performers. Studies of skilled musicians (e.g., Langheim, Callicott, Matthey, Duyn, & Weinberger, 2002) have shown that cM1 was not active during imagined performance, whereas activity was observed in functional cerebellar, superior parietal, and frontal areas. This topographic profile was interpreted to reflect spatial and temporal components of the skill rather than any tacit motoric control. Therefore, it has been argued that with increasing experience in the skill, the activation sites related to motor imagery may systematically change to reflect a more abstract, less motor-centered internal representation of the behavior (Lotze & Halsband, 2006). If neural functional equivalence is accepted as the main mechanism to support imagery's use, then the development of the process should focus on these abstract and less motoric behaviors for skilled performers and avoid direct motor activity comparisons. Controlling these behaviors in an imagery context is challenging for researchers.

The cM1 shift away from cortical motor sites is supported by further findings from studies of amateur and professional musicians. Lotze, Scheler, Tan, Braun, and Birbaumer (2003) showed that the imagined musical performance of professionals was reflected in significantly lower cerebral activity in comparison with the amateurs' widely distributed activation maps. Again, the superior parietal and cerebellar shift from cM1 was interpreted as more efficient recruitment of sensorimotor engrams during imagery and increased recruitment of temporal processes linked to the temporal information of the task. These interpretations are consistent with skilled behavior in sport and could offer an additional explanation for the inconsistent finding of cM1 activity during motor imagery. Primary motor cortex activity during imagined behavior seems to be a poor marker of image quality and, in skilled performers, may indicate an ineffective process.

In summary, motor imagery and motor execution share some anatomical substrates. However, it is clear that researchers should not simply read gross activity in any given region during imagined and executed behavior as functional equivalence; the specific anatomical topography and the imagery procedure characteristics (e.g., movement inhibition) should determine any interpretation of the activity.

Assessment of Imagery

Four methods have tended to be used to assess imagery ability: (a) subjective, self-report tests, (b) objective tests,

(c) qualitative procedures, and (d) functional imaging techniques. Subjective pencil-and-paper tests, which require participants to form a mental image described in the items of the test, rate specific dimensions of imagery via 5- or 7-point Likert-type scales. The most examined have been the imagery dimensions of vividness (e.g., vividness of visual imagery questionnaire [VVIQ] in Marks, 1973; vividness of movement imagery questionnaire [VMIQ] in Isaac, Marks, & Russell, 1986), controllability (e.g., Gordon Test of Visual Imagery Control; Gordon, 1949), perspective (i.e., watching someone else and watching oneself [VMIQ]; Isaac et al.), and modality (e.g., visual and kinesthetic, Movement Imagery Questionnaire in Hall & Pongrac, 1983; revised version of the Movement Imagery Questionnaire in Hall & Martin, 1997).

Objective tests require participants to solve problems through mental manipulations of stimulus objects (Barratt, 1953) with the answer being checked against externally verifiable criteria. Popular tests include the Minnesota Paper Form Board (Likert & Quasha, 1941) and the Space Relations Test (Bennett, Seashore, & Wesman, 1947).

Qualitative procedures are retrospective reports provided by athletes after performing an imagery experience. Researchers should see these procedures as complimentary to objective and subjective tests. The procedures collect information that is not available through objective and subjective testing (Morris et al., 2005). In sport psychology, information concerning the athletes' imagery process has been proposed through full manipulation checks and debriefs (e.g., Goginsky & Collins, 1996).

To increase understanding of the imagery process and address some of the measurement concerns, Fournier (2000) offered an innovative solution. He proposed using psychomotor films of different contrast and luminosity to assess imagery vividness. Participants were invited to choose the film that best matched the vividness of the imagery experience during the mental simulation of movement. More recently, Fournier, Deremeaux, and Bernier (2008) extended the work with competitive skydivers to include film and image speed, perspective, and color.

Cui, Jeter, Yang, Montague, and Eagleman (2007) recently used functional imaging techniques (e.g., fMRI) to measure mental imagery vividness more objectively. They showed that individual differences in imagery vividness could be assessed objectively by measuring blood flow changes, even in the absence of retrospective reports. They also found a correlation between visual cortex activity and vividness rated on the VVIQ. The findings from this study are exciting, and future researchers using the technique seem likely to be able to provide neurophysiological markers of imagery ability. However, at present, access to imaging facilities remains difficult and expensive.

The tools that researchers have claimed assess imagery skills have raised some concerns. First, subjective and objective tests are unrelated; they do not measure the same abilities (Hall, 1998; Moran, 1993). Most subjective tests

are related to imagery generation or representation abilities. In contrast, objective tests are markers of image transformation or processing, thereby raising questions about the choice and validity of tests in imagery contexts. This concern is supported by Morris et al.'s (2005) claim that "each type of instrument either measures a different construct or assesses orthogonal aspects of imagery ability" (p. 87). Second, items in most of the subjective tests (e.g., in the VMIQ) are not sport-specific, and they confuse movement agency (although this latter issue has been addressed recently by Roberts, Callow, Hardy, Markland, and Bringer's [2008] VMIQ-2). They describe viewing self's and others' actions of daily life, such as walking, running, or bending down to pick up a coin. Therefore, athletes could score poorly on the VMIQ but be high in imagery vividness for their specific sport skills because of the nature and context of the task or because they have ability in only one visual perspective. Moreover, the processes used to assess the vividness of an image may vary across participants (e.g., Belleza, 1995): How is a participant's rating of *perfectly clear and vivid* distinguished from a second participant's rating of *moderately clear and vivid* for a similar imagined experience? Third, studies have shown that verbal reports of cognitive processes and less conscious psychological states are frequently unreliable (e.g., Brewer, van Raalte, Linder, & van Raalte, 1991; Nisbett, & Wilson, 1977). Similarly, retrospective reports may be biased by performance outcome and risk, providing a distorted version of events (Brewer et al.).

Observation Processes

A Mechanism to Support the Observation Process

Researchers do not fully understand the mechanisms that underlie the process of imagery. Until recently, this lack of understanding was also the case for observation, specifically the processes of understanding and imitation of action and intention (Buccino, Binkofski, & Riggio, 2004; Buccino et al., 2004; Wohlschlagel & Bekkering, 2002). However, the recent discovery of mirror neurons (MNs) has provided some evidence to explain these observation-based behaviors.

MNs were first discovered in the ventral premotor cortex of the macaque monkey with single neuron recording (e.g., Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). These visuomotor neurons show special characteristics. They fire when the monkey executes a goal-directed hand movement (Rizzolatti et al., 1996) and also when it observes the same action executed by another monkey or by a human.

Evidence for the existence of similar neurons in humans has been provided by electroencephalographic research (e.g., Calmels et al., 2006; Cochin, Barthelemy, Roux, & Martineau, 1999) and by brain-imaging studies (e.g., Buccino et al., 2001; Grèzes, Armony, Rowe, & Passingham, 2003). These data support the proposal that MNs form the basis of an observation-execution matching system.

This system, also known as the *motor resonance system* or the *MN system*, provides a mechanism to explain how perception of an action can activate a brain representation similar to that used to perform the action (Grèzes et al.). This mechanism shares some similarities with the matched representational access discussed for imagery.

In humans, the MN system acts differently depending on the forms of observed motor behaviors. For example, viewing a grasping action performed by a nonbiological model involves the MN system but is less effective in doing so than watching the same action executed by another human (Perani et al., 2001). The system is active minimally when the observed action is biomechanically impossible to perform (Stevens, Fonlupt, Shiffrar, & Decety, 2000) or when the observed action does not belong to the observer's motor repertoire (Buccino et al., 2004). Similarly, level of expertise also influences the involvement of the MN system (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006). Stronger bilateral parietal and left hemisphere motor cortex activations have been recorded in expert dancers when observing familiar dance movements in comparison with movements that the performers had not experienced physically before, even if they were visually familiar to them. These issues are of obvious importance to the development of the applied use of observation. We discuss this in more detail throughout the article.

The mirror system has been linked to four main functional roles in humans: understanding of action, understanding of intention, imitation, and empathy (Rizzolatti, 2005; Rizzolatti & Craighero, 2004). The involvement of the motor system is proposed as a necessary requirement to understand fully the observed action. The perception of an action without the involvement of the motor system may only provide a superficial description of the action and not allow its thorough comprehension (Rizzolatti). Intention understanding (i.e., why an individual is performing a particular action) is also linked to an activation of the MN system. The intention of a movement can be differentiated from its goal. For example, a child may have a movement goal to pick up a ball. However, the intention may be to throw it or put it in his or her pocket. Iacoboni et al. (2005) showed that observing grasping hand actions in different particular contexts allows the observer to infer different intentions for the actions. Imitation also implies activation of the motor neuron system. Imitation of an action that belongs to the motor repertoire of the observer includes activity in the neural circuitry of the superior temporal sulcus and the frontal and parietal mirror areas (Iacoboni, 2005). In contrast, imitation of a novel action activates the same neural circuitry and also Brodmann's Area 46 (BA 46), associated with the selection of appropriate motor acts. Buccino et al. (2004) also showed that imitation activates areas involved in motor preparation (i.e., dorsal premotor cortex, mesial frontal cortex, and superior parietal lobule). Last, the MN system

is also associated with human empathy (i.e., the capacity to feel the same emotional states that another feels); observing a person laughing or crying generates a similar emotional state in the observer. In such situations, activity is present in the insula and limbic system of the observer (e.g., Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003). In summary, exploiting the MN system properties offers a potentially exciting avenue for accessing the neural circuitry of physical motor control and, therefore, for sport psychology research and practice.

Observation Characteristics and Neural Activity

Because there is no requirement to generate, maintain, or transform an image in observation conditions, this section is brief in comparison with that for imagery. However, it is still necessary to discuss observational perspectives, including specular and anatomic imitation, behavioral agency, influence of procedural instructions that are provided prior to observation, and nature of the task.

Observation Perspective

As with imagery, different observational perspectives also show different neurological profiles (e.g., Chan, Peelen, & Downing, 2004; Jackson, Meltzoff, & Decety, 2006; Maeda, Chang, Mazziotta, & Iacoboni, 2001; Saxe, Jamal, & Powel, 2006). For example, Maeda et al. (2001) used transcranial magnetic stimulation to show that action observation enhances cortico-spinal excitability. They found that observation of a movement increased functional motor output; the degree of modulation was maximal when the observed action was presented from a 1PP. In these studies, visual perspective and modality were combined because dynamic movement were explicit within the visual array. However, the observed hand and finger tasks were simple, fine movements. Recent researchers have tested this differentiation for more form-based, whole-body activities.

The extrastriate body area (EBA) is known to respond to the visual appearance of the human body. Chan et al. (2004) and Saxe et al. (2006) reported that EBA distinguished an egocentric (1PP) view of the self and other people from an allocentric (3PP) view. EBA activity was found to increase significantly for allocentric views relative to egocentric views in the right hemisphere. Jackson et al.'s (2006) fMRI study indicated that a series of simple intransitive hand and foot actions showed greater activity in the sensorimotor cortex when viewed from a 1PP compared with a 3PP. By referring to 1PP and 3PP, we potentially conflate perspective, agency, and modality in an observational context. As with the imagery research, it is important for observational research to be specific in the detail of the observation process if researchers are to gain understanding of the neurological substrate for the observation–execution matching system. However, with regard to visual perspective and behavioral agency, observation-based research shows neural patterning similar to that in imagery studies, suggesting it is at least as effective in accessing meaningful neural networks.

Specular Imitation or Anatomic Imitation?

A potential confounding factor for observation compared with imagery is the concept of specular imitation: observational behavior as if looking into a mirror. For example, when the observed model moves his or her left hand, the observer moves his or her own right hand. This phenomenon is particularly important for younger performers. For example, Wapner and Cirillo (1968) demonstrated that specular responses predominate over nonspecular responses up to approximately 10 years of age.

These findings suggest that imaginary rotation does not take place during observation and that the temporal and spatial characteristics of the skill are more neurally important than ipsilateral matching.

Behavioral Agency

The concept of behavior agency in observation has received some interest (e.g., Chan et al., 2004; Knoblich & Flach, 2001; Patuzzo, Fiaschi, & Manganotti, 2003). In the observation of hand movements, Patuzzo et al. found no specific agency recognition effect on motor system excitability but concluded that this was possibly because of the anonymous nature of the process. By manipulating postural congruency of finger movements, which we argue to be similar to self–other agency, Urgesi, Candidi, Fabbro, Romani, and Aglioti (2006) found that egocentric and allocentric manipulations altered the modulation of abductor digiti minimi, suggesting a detailed functional correspondence between action execution and observation. In a more applied study, Knoblich and Flach presented participants with videos of dart-throwing actions that had previously been performed. They were also shown the same action performed by others. The results indicated that prediction of accuracy of the observed actions was greater when participants observed their own actions. Observation of self-generated actions may be more informative because of the functional similarity of the neural activity to that during motor execution. Behavioral agency can be discriminated by psychophysiological markers and movement prediction. We consider the implications of these findings.

Observation and Motor Cortex

With the concerns for the validity of (motor) imagery mounting, the case for observation of movement must be made. We reviewed cortical and cerebellar activation during imagery and questioned the extent of the primary motor cortex activity for the covert process. In contrast to the imagery literature, a large body of evidence supports the view that perception of action facilitates motor activity in the cortico-spinal (CS) system (e.g., Fadiga, Craighero, & Olivier, 2005). Further, the facilitation is also present while the participant listens to action-related sounds or speech, suggesting that scripted imagery's benefits may, in part, be explicable by this MN–CS system activation. In addition, there is evidence that motor cortex activity also occurs prior to observation of action (Kilner, Vargas, Duval, Blakemore, & Sirigu, 2004).

This anticipatory motor excitation may be important to predictive or priming behavior and a further mechanism that helps to explain the benefits of the technique (see Edwards, Humphreys, & Castiello, 2003). However, there is no evidence to suggest that this anticipatory activity is present in imagery conditions; such activity would be unlikely because the images have to be self-generated.

Importance of Instructions Provided Prior to the Observation Process

The observational neural profile is also sensitive to the instructions that are provided prior to the observation process. Participants can be invited either to (a) observe movement with the purpose of later imitation of it (e.g., Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Iacoboni, Woods, Brass, Bekkering, & Mazziotta, 1999) or that of recognizing it (e.g., Fadiga et al., 1995); or (b) to observe the movement with no specific goal (e.g., Cochin et al., 1999; Hari et al., 1998; Iacoboni et al., 1999; Muthukumaraswamy & Johnson, 2004; Muthukumaraswamy, Johnson, & McNair, 2004; Nishitani & Hari, 2000). The nature of the instructions given to the participants is important and can be differentiated by neural activity. Decety et al. (1997) and Grèzes, Costes, and Decety (1998) have also shown that cortical areas involved in the process of observation are dependent on the instructions given to the participants. For example, Decety et al. (1997) found that the dorsolateral prefrontal cortex and the presupplementary motor area are active when participants receive instructions to observe a movement with the later requirement to imitate it. In contrast, the right parahippocampal gyrus was activated in a situation where there was a requirement to recognize the movement after its observation.

Nature of the Task

The nature of the task (i.e., meaningless action vs. meaningful action) is also important (e.g., Decety et al., 1997; Grèzes et al., 1998). For example, Grèzes et al. showed that observation of goalless meaningful actions elicited some activity in the ventral pathway. However, observation of goalless meaningless actions activated the dorsal pathway. Observation to replicate the action at a later stage involved the dorsal pathway for meaningful and meaningless actions. Because of our understanding of these visual streams, creating a shared understanding of the nature of the task is important for neural activation.

Observation-Based Characteristics

Lotze and Halsband (2006) stated,

The quality of imagery should be controlled as precisely as possible to guarantee a maximal homogenous task over the group of participants of the study but also to have a better understanding of the task performed by the subjects for the interpretation of the data. Therefore a good description of the image which should be produced and a precise imagery training is needed [before the mapping] . . . to train visual imagery, an observation task may proceed the actual imagery task . . . Nevertheless, we have to admit that . . . a precise

control of what the subject actually does during imagery remains an illusion. (p. 389)

Imagery task instructions present a number of construct validity concerns. An identical set of imagery instructions can be provided to two or more participants, yet they do not develop the same imagery experience (Murphy, 1990). In addition, there is evidence that participants do not always follow the directed imagery script (Jowdy & Harris, 1990).

It is our opinion that observation may offer a solution to some of the imagery limitations. Generating an image is not an issue because the visual percepts are provided by the digital information displayed, typically through individualized DVDs, and observed with participants' eyes open. Observation of still photographic action shots can also generate functional neural activity (e.g., Kourtzi, 2004) because the percepts imply motion.

Observation also controls for imagery ability factors because clarity, vividness, and image management (maintenance and rate of exposure) are manipulated through the filming and editing processes. Image transformations and rotations are also more effectively managed through dynamic use of camera angles. Because what performers are actually doing during imagery is unknown, it is the psychologist–imager shared observational image that differentiates observation from imagery; the researcher or practitioner no longer has to accept the debriefed account of the process from the imager. No validated measures of observation ability are currently available, although we are currently studying this omission.

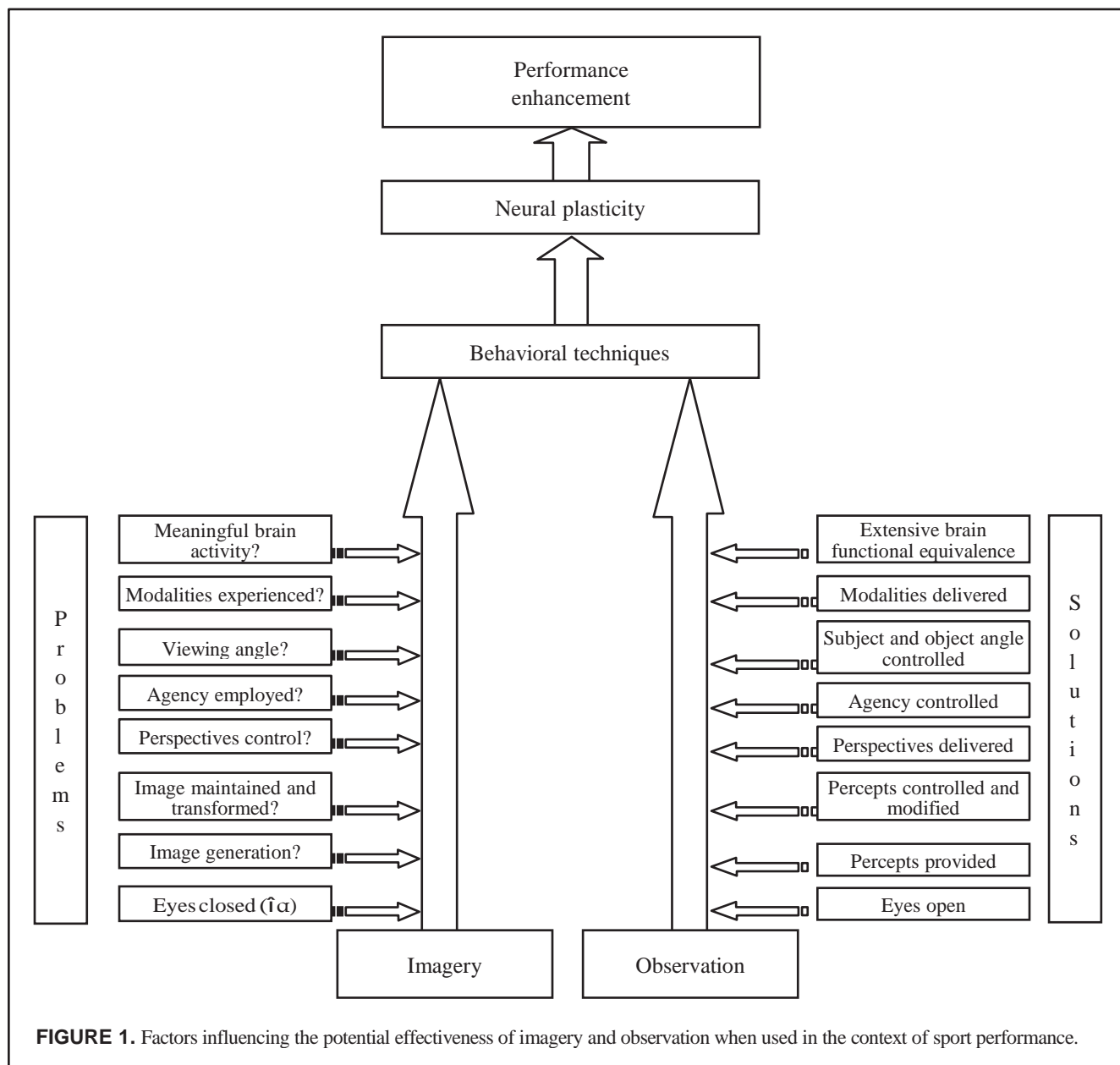
Observation that researchers provide through digital video can offer the viewer every conceivable angle from either 1PP or 3PP and avoids the need for the performer to transform or rotate a transient image.

We believe that many of the imagery outcomes that athletes, coaches, and sport psychologists desire—particularly functional neural activity—can be achieved in a more valid way. More specifically, the modifiers of the neural activity during imagery are better controlled through an observation process than through imagery. A summary of the imagery problems and observation solutions is provided in Figure 1.

IMPLICATIONS FOR RESEARCHERS AND PRACTITIONERS

Application of Observation-Based Intervention in Sport

The lack of control of imagery content and characteristics has raised concerns about the interventions' ubiquitous use. Many athletes have difficulty in generating, maintaining, and transforming mental images. Those who can form and control images use a combination of perspectives, agency, and modalities and often switch from one perspective to another without conscious awareness (Orlick & Partington, 1988). Athletes frequently do not see themselves but imagine others (e.g., teammates, opponents, sporting heroes)



and do not generate mentally whole sport scenario with high degrees of vividness. They also tend to speed up, slow down, or freeze their imagined behavior. Therefore, they cannot control their images and despite effortful attempts, they fail to image or omit part of their routine or movement. These modifications to an image compose different neural processes and lead to methodological bias in imagery research and practice.

The MN system offers a mechanism and the reviewed research provides evidence to support the application of observation-based interventions in sport. Given the focus of this article, we argue that observation affords practitioners and researchers greater control over some of the fundamental characteristics to optimize neural functional equivalence with overt behavior. Imagery also has the potential to

achieve this outcome but with less assurance that the athlete will conduct it in the prescribed way.

Imagery, Observation, and Social Context

Regardless of how good a psychologist's imagery script may be, the exact content and context in the imager's brain may be radically different from that prescribed. Frequently in sport, the visual emphasis of imagery is on the motor behavior of the performer, with little or no regard for the social context in which the imagery is taking place. We argue that this may compromise the neural functional equivalence with the task, especially in areas associated with affect (e.g., anterior insula, medial prefrontal cortex, amygdala). Some psychologists have tried to prime the imagined environment with photographs, but this may not

be sufficient to fully describe the behavior, which can be differentially affected by the same stimuli. In Lewin's early work in social psychology (1938, 1951), he implied that the same stimulus can acquire a different valence (affective charge) depending on the perceiver's goals. Further, he stated that the effect of a given stimulus on the perceiver depends on the stimulus constellation, or properties of the stimulus, and the state of the perceiver. Therefore, whatever the imagined stimulus, its meaning and interpretation is derived from the context in which the image is set. Recreating the social context under the constrained conditions of imagery and observation is difficult and challenging. However, the control afforded by observation-based intervention techniques would suggest that this may be a more effective medium to manage social context than is imagery. The experimental and applied imagery research, with its focus on rigorous methods and internal validity, necessarily sacrifices external validity and thereby loses the social context of the image content. This suggests that researchers and practitioners should test their experimental paradigms for behavioral effects before implementing them in interventions. For example, in a case study of one of our performers, the performer reported a strong dislike of 3PP imagery because he perceived that it isolated him (as the viewer) from the activity and he "felt separate from the group activity" as he tried to "watch" the performance. This changed response of self is similar to one reported by Williams, Cheung, and Choi (2000). They found that the anterior cingulate cortex and the right ventral prefrontal cortex (areas active during studies of physical pain) were activated in observers who felt socially rejected because of the visual content of the display. Social context in this example profoundly affected neural correlates of behavior and modified the required neural equivalence.

If researchers and practitioners are to use central brain mechanisms to explain imagery and observation processes in sport, we must ensure that contextual information is included in imagery scripts and observation percepts. Further, the performers' understanding of the context is also important to infer optimal neural activity. Clear, unambiguous instructions relating to the image or observation content are important to optimize equivalence with the execution neural profile.

Advantages of Observation Use in Sport

The advantages of use of observation in sport are several. First, using observation in a learning framework to support more traditional physical training sessions could also be a useful intervention. Training supported in this way could decrease physical training loads, training fatigue, and, potentially, injury. In light of Calvo-Merino et al.'s (2005) and Calvo-Merino et al.'s (2006) results, we recommend using models that have skill expertise similar to that of the observer to promote more optimal motor representations access. An observer should possess a visual familiarity and a motor familiarity with the observed action.

Second, observing parts of team plays, such as offensive and defensive strategies or exchange of actions between two opponents, could allow athletes to anticipate the actions of others more effectively (i.e., opponents or partners). If the MN system is fundamentally concerned with movement prediction, then where and how others move have obvious relevance for sporting interactions. Understanding other's actions in terms of movement kinematics allows performers to make predictions about their behavior goals; performers can infer the intentions behind movements and judge whether movements are intended. In these cases, the MN system could be depicted as the neural substrate of the capacity to understand an action, intention, or the state of mind of others.

Third, in sports rehabilitation, athletes may recover more quickly after viewing diverse and repeated sport video sequences. Observation of relevant sport sequences could allow cortical structural changes, reorganization, and reinforcement in the motor architecture. Used alongside more traditional manual therapies, observation may prime the neural structures supporting the rehabilitation of the more peripheral anatomy. Although gaining some support in clinical settings (e.g., Pomeroy et al., 2005), these ideas remain to be tested empirically in sporting contexts.

DISCUSSION

The content of written imagery scripts are typically devised by coaches, sport psychologists, or other consultants. These scripts offer, at best, a generic content for groups of athletes and do not take into account the numerous individual differences discussed in the sections above. These scripted programs are not meaningful to an athlete because they rarely offer real-life situations that the athlete experiences daily. In our experience, this leads to poor adherence, reduced trust, and rapid withdrawal from the imagery program.

In many imagery research studies, the instructions provided to the participant-athletes are limited. Similarly, the goal of the mental simulation of the skill is rarely specified. Therefore, the generated mental images are likely to display different characteristics.

We have reviewed a comprehensive section of the neuroscience literature relating to imagery and observation research. The evidence suggests that many factors can contribute to the effectiveness of the processes. Researchers and practitioners in sport psychology should be aware of the influence of these factors to optimize the validity and efficacy of their studies or practice. However, the ease of use, greater control over procedure, and more effective access to functional brain areas indicate that observation should be used in preference to imagery.

We have not exhausted the factors that are likely to influence neural activity during imagery and observation or considered practical delivery issues relating to individual differences in age, gender, amount and duration (imagery or observation dosage), intervention adherence strategies,

motivation to undertake the intervention, outcome goals, external encouragement, and many other psychosocial factors. As brain-imaging techniques become more readily available, future social neuroscientists will provide answers to many of these issues.

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