CHAPTER

Motor imagery, performance and motor rehabilitation

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Abstract

Motor imagery has been central to adzvances in sport performance and rehabilitation. Neuroscience has provided techniques for measurement which have aided our understanding, conceptualization and theorizing. Challenges remain in the appropriate measurement of motor imagery. Motor imagery continues to provide an impetus for new findings relating to our emotional network, embodied cognition, inhibitory processes and action representation. New directions are proposed which include exploring the physical setting and conditions in which imagery occurs and investigating if short term impairments to the motor system detract from motor imagery ability and the potential application of motor imagery for recovery.

Keywords

Motor imagery, Sport, Rehabilitation, Theory

1 MENTAL IMAGERY: FROM PRACTICE TO THEORY

Mental imagery has been illuminated by the spotlight of neuroscientific methods in recent decades. The development of techniques including brain imaging (PET; fMRI), extracerebral magnetic (MEG) and electric field studies (EEG) has advanced our theoretical and conceptual understanding and application. Mental imagery is broadly construed as a cognitive simulation process by which we can represent perceptual information in our mind in the absence of appropriate sensory input (Munzert et al., 2009). Motor imagery has particular applicability to the sport performance and rehabilitation context (Moran et al., 2012). In this review, we elaborate on the progress in our understanding of the neural basis of motor imagery processes across the

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decades. Our concern will be largely on the conceptual, theoretical and methodological shifts that have occurred rather than focusing on some of the latest innovations where the emerging literature has been subject to recent review (e.g., BCI and motor imagery, Marchesotti et al., 2016).

To explain, we will outline how we have moved through three waves of mental imagery research and how in recent decades motor imagery has gained prominence among the topics of concern to investigators and practitioners. This is a largely a result of the aforementioned methodological advances and recent theorizing. To explain, the first wave of imagery research focused largely on the role of performance enhancement, the study of the mental practice effect (MacIntyre and Moran, 2007). It spanned approximately a century from when William James first expounded on the topic of imagination up until to the 1990s when evidence for the mental practice effect cumulatively led to two supportive meta-analyses (e.g., Driskell et al., 1994; Feltz and Landers, 1983). It is noteworthy that this research phase was extensive with the first published mental practice study, an investigation of free-throw performance in basketball, conducted four decades before the initial systematic review (Vandell et al., 1943). The next stage was comparatively brief and two strands of research developed concurrently. In applied domains, such as sport psychology, researchers sought to understand how imagery was used and applied by performers in everyday sport settings (e.g., Hall et al., 1998). In the 1990s, what was later referred to by the US Senate as the "decade of the brain," because of methodological advances due to innovations in brain imaging research, a multi-disciplinary research program of evidence-based theorizing on specific imagery modalities including, for example, visual, spatial and motor imagery (Jeannerod, 1994; Kosslyn, 1994) challenged the view that mental imagery was unitary construct. The third wave in a zeitgeist of theory driven-research has attempted to combine testing neurally plausible models with interventions utilized both for their applied efficacy (e.g., performance and rehabilitation). Researchers continue to use motor imagery as a window into cognition, action and perception (Munzert et al., 2009). Motor imagery has gained much clarity as a consequence and as we shall discuss, mental imagery research has a long past but only a short history of robust empirical findings, so that many questions remain and new pathways for discovery are emerging.

2 DISENTANGLING MOTOR IMAGERY AND DEFINITIONAL DILEMMAS

The issue of gaining clarity in how we operationalize motor imagery is central to both theorizing and refining its application (Madan and Singhal, 2012a; Moran et al., 2012). Semantic and conceptual challenges have undermined our capacity to clearly conceptualize motor imagery and the varied approaches by researchers have hampered research and limited their inferential power (see Moran et al., 2012 for review). Notably, a consensus has emerged on the utility of the term "motor imagery," which has been used widely for decades (Decety, 1996; Jeannerod, 1994). "Motor imagery" refers to the mental representation of an action without engaging in its actual execution (Madan and Singhal, 2012a; Moran et al., 2012). First, strictly speaking, motor

Table 1 Neurally Dissociable Dimensions of Visual and Motor Imagery

Term	Operational Definition	Source
Motor imagery	Motor imagery is a dynamic mental state during which the representation of a given motor act or movement is rehearsed in working memory without any overt motor output	Collet and Guillot (2010)
Visual-object imagery	This refers to the capacity to generate pictorial images that are vivid, detailed, and include information about surface properties, e.g., color	Blajenkova et al. (2006)
Spatial imagery	Spatial imagery refers to relatively abstract representations of the spatial relations among objects, parts of objects, locations of objects in space, movements of objects and object parts and other complex spatial transformations	Kozhevnikov et al. (2005)

imagery involves the absence of overt motor *output* rather than of overt movement itself. Research suggests that it is possible to form a motor image of one's static position (e.g., in an isometric contraction) *without* the rehearsal of a dynamic movement of one's body (Hashimoto et al., 2010). For example, gripping a basketball in your hand while standing on the free-throw line will entail a degree of motor activation (e.g., postural activation, isometric force to grip the ball) even without any overt movement. The underlying assumption of this definition is that we are confronted with a disembodied account of motor imagery. However, mental imagery is now widely acknowledged as a multi-dimensional, multi-modal construct (Lacey and Lawson, 2013) and as we shall review in this chapter, evidence to suggest that it is artificial to decouple motor imagery from the multisensory components is accumulating. "Mental imagery is not a single function…mental imagery arises from the joint action of numerous systems" (Kosslyn et al., 2010, p. 12). Traditional phenomenological approaches in both the conceptualization and measurement of imagery (e.g., vividness) have been replaced with, for example, the neurally dissociable processes of visual-object imagery, spatial imagery, and motor imagery (see Table 1) and this complexity goes further. If we return to our basketball example, even with the simple example of a closed motor skill, there is a spatial component (e.g., the degree to which the ball is proximal or distal to the subject). And the entropy only increases, as motor imagery typically occurs in conjunction with visual imagery, for example, rather than in isolation. On the other hand, visual imagery is commonly reported without other senses according to self-report studies (Kosslyn et al., 1990). The interaction between visual and motor imagery only blurs this conceptual clarity further.

3 IS MOTOR IMAGERY LIMITED BY VISUAL IMAGERY PERSPECTIVE?

The richness of self-generated visual input during imagery is most aptly demonstrated in the sport and human performance context. Dance has been subject to multidisciplinary neurocognitive science in recent decades (Blasing et al., 2018).

The dynamic movements within this form provide an opportunity for a variety of visual viewpoints during imagery (i.e., whether first or third person) and for metaphorical imagery, which, unlike the imagery of the movement itself, can present other shapes, movements and ideas that may enhance motor performance and emotional expression (Sevdalis and Raab, 2014). Early self-report findings led to an assumption that motor imagery was limited to an egocentric or first-person viewpoint (see Moran et al., 2012). This artifact, termed the "limited perspective problem" in which visual perspective during imagery was conflated with the presence or absence of motor imagery, created further confusion among researchers. Only recently have researchers reconciled this issue, as both neuroscience evidence (Fourkas et al., 2006) and phenomenological studies with elite performers have confirmed the possibility of motor imagery from a third-person perspective or allocentric viewpoint (Callow and Roberts, 2010; MacIntyre and Moran, 2010). Thus the definitional dilemma erroneously linked to visual perspective has been averted to some degree but other confounds remain (Madan and Singhal, 2012a; Moran et al., 2012).

One may predict that this increased level of conceptual clarity provides a solution to the preceding dilemma for researchers and practitioners alike. However, the cognitive simulation technique of motor imagery requires typically conscious activation of brain regions which overlap with those utilized during motor activity. For example, imagery of finger and hand movements demonstrated activation of the supplementary motor area (SMA), the premotor cortex (PMC), the cerebellum but also the primary motor cortex contralateral (cM1) to the imagined movements in fMRI studies (Leonardo et al., 1995; Lotze et al., 1999; Porro et al., 1996; Sabbah et al., 1995). ALE meta-analyses of motor imagery and motor execution similarly reported activation of fronto-parietal, subcortical and cerebellar regions, but inconsistency in the activation of the primary motor cortex (Hardwick et al., 2018; Hétu et al., 2013). Debate over the role of Brodmann area 4 or M1 continues but researchers agree that the neural activation is accompanied by a voluntary inhibition of the actual movement (Lotze and Cohen, 2006). The inhibitory processes have become subject of much debate (Grospetre et al., 2016; Guillot et al., 2012a) but what has received less attention is the often uninhibited "quasi-movements" that are experienced by the imagery (Nikulin et al., 2008). Motor imagery is complex, dynamic and the quasi-movements have been described by practitioners as dynamic motor imagery, despite the obvious conundrum that such imagery is at odds with the agreed definitions of motor imagery. To understand such complexity, it is worthwhile re-visiting the theoretical advances that have precipitated our current knowledge of motor imagery.

4 MOTOR COGNITION AND SIMULATION THEORY

The interface between action observation and motor imagery has been subject to a recent review (Mizuguchi and Kanosue, 2017) and paradigms to unravel the complexity of these interactions have only recently been developed (Vogt et al., 2013). The very premise on which these methodological advances in recent decades have been developed is grounded in the action simulation theory of Jeannerod (1994, 2006; see critique by O'Shea and Moran, 2017). Motor cognition, the field of study that explores how the mind plans, simulates, and produces goal-directed movements, is concerned with the "preparation and production of actions as well as the processes involved in recognizing, anticipating, predicting and interpreting the actions of others" (Jackson and Decety, 2004, p. 259). An important distinction is made between the terms movement and action. "Action" is posited to have both covert stages (action simulation including motor imagery) and overt stages (movement execution), and movement related to when the activation leads to the displacement of a limb in space (i.e., proximal or distal). Within this approach, motor imagery is predicted to (1) be functionally equivalent to action because of consistent evidence for common neurological mechanisms, and (2) involve comparable processes, what is termed structural equivalence (see Borst and Kosslyn, 2008). Motor imagery researchers had learnt from visual imagery research which had piggybacked findings on the neural basis of vision to stimulate new paradigms (Kosslyn et al., 2006). A key discovery, the mirror neuron network, was to hasten the development of paradigms to investigate motor imagery, which had been of less concern to researchers for whom visual imagery was more relevant (Moran et al., 2012).

The discovery of mirror neurons in macaque monkeys stimulated research on the neural basis of action representations in human participants (Rizzolatti et al., 2001). According to Jeannerod (2006), the action continuum predicts that the difference between the simulation of an action and its executed counterpart is one of degree and not one of kind. Consequently, the continuum posits that at one end of the spectrum is an action representation and at the other end is intentional movement. This conceptualization, although not without criticism (Gallese and Sinigaglia, 2011; Glover and Baran, 2017), is of particular interest from an embodied cognition perspective, with implications for psychological science and applied psychology which we shall consider later in this chapter.

Further evaluation of the what is termed *Motor Simulation Theory*, the explanatory account for motor imagery processes, is merited. Although several possible explanations of motor imagery effects have been proposed since the 1930s, none is as comprehensive as that provided by motor simulation theory (Jeannerod, 1994, 2006; see review by O'Shea and Moran, 2017). According to this theory, the motor system is part of a cognitive network that includes such psychological activities as imagining actions, learning by observation, and attempting to understand the behavior of other people. Simulation theory proposes that motor images are "non-executed actions" (Jeannerod, 2004, p. 390). Based on this tenet, Jeannerod (2001) predicted that "motor imagery … should involve, in the subject's motor brain, neural mechanisms similar to those operating during the real action" (pp. S103–S104). This proposition is known as the "functional equivalence" hypothesis (Jeannerod, 1994, 2006) and suggests that motor imagery and motor execution are functionally equivalent because they share a mental representational system. Specifically, they share a motor representation of an intention to act. Whereas this intention is converted into an actual physical movement in the case of overt actions, it is inhibited in the case of imagined actions (Guillot et al., 2013).

According to this theory, motor execution comprises at least two stages of processing: (i) an early covert or mental representational stage which contains action components (e.g., the goal, action plan, motor program and the anticipated consequences of the action); and (ii) a later execution stage whereby the movement is physically completed. During motor imagery, the motor system is held to operate "off-line" (cognitively) via a hypothetical simulation mechanism. This mechanism purportedly drives neural motor systems and functional mechanisms involved in motor execution—except that overt movement is inhibited. In attempting to explain how, for example, motor imagery practice facilitates skill learning. Jeannerod (2001, 2004, 2006) suggests that motor imagery covertly primes the motor system, thereby rehearsing and refining the action execution process. In support of this proposal, transcranial magnetic stimulation research demonstrates that motor imagery induces corticospinal excitability, evidenced by amplitude increase in the motor-evoked potentials incited by the primary motor cortex, which indicates that motor imagery involves an action implementation or simulation stage as well as a purely motor representational stage (Chong and Stinear, 2017; Lebon et al., 2018).

Accounts of motor imagery in the sport context have been developed, based on simulation theory, which provide more detailed knowledge on the implementation of motor imagery (Guillot and Collet, 2008). The former model was an advance upon the descriptive account of imagery functions (Holmes and Collins, 2001) and this model, termed the *Motor Imagery Integrative Model in Sports* (MIIMS), additionally encompasses rehabilitation which was overlooked in previous models. The MIIMS includes specific roles for imagery in rehabilitation and explores the role of environmental factors and individual differences including the level of expertise of the athlete. Consequently, it has a capacity to account for imagery in injury recovery via several mechanisms. Furthermore, it can elucidate the previous qualitative findings on injury recovery (Driediger et al., 2006), provide an explanatory framework to explain recent findings on the use of imagery to enhance flexibility (Guillot et al., 2010), and be linked to neurophysiological explanations of motor imagery (Guillot et al., 2012a). A strong theoretical basis provides a necessary backdrop for hypothesis generation, subsequent testing of the propositions of the model and the exploration of key issues including measurement issues, multi-sensory integration and embodied cognition.

5 MEASUREMENT ISSUES: BEYOND SUBJECTIVE SELF-REPORT

Measuring individual ability in imagery is an important aspect of using motor imagery's relationship with performance enhancement and rehabilitation but remains one of the current challenges in the field (Madan and Singhal, 2012a,b). The concept of mental imagery as a private phenomenological experience created challenges for those interested in objective measurement tools. The classic mental rotation paradigm was the breakthrough which led to an implicit measure of mental imagery

(Shepard and Metzler, 1971). Mental rotation, or the ability to mentally manipulate two- or three-dimensional objects that may be rotated in any direction or translated in space, had been investigated using a variety of inanimate stimuli (e.g., letters or 3-D block figures). Typical findings showed that response times increased linearly with increased differences in angular disparity. In other words, a second-order isomorphism existed, in that physical properties of objects influenced our operations on them in our mental world. Interestingly, "kinesthetic" sensations appeared to be present during mental rotation for some subjects, according to Jackie Metzler (co author with Roger Shepard, 1971). So visual imagery investigations were recognized as potentially involving the motor system. Kosslyn and Sussman later argued that "visual mental images are transformed in part via motor processes" (1995, p. 345). If this were the case, it would have implications for studies that were concerned with the localization of mental rotation processes at a neural level (e.g., Corballis, 1997). One question that emerged was whether the involvement of motor processes in mental rotation was due to a voluntary strategy adopted by participants. A subsequent study employed positron emission tomography (PET) while subjects mentally rotated either their hands or the original 3-D block objects (Kosslyn et al., 1998). The results highlighted that two mechanisms could be applied: "one mechanism that recruits processes that prepare motor movements and another that does not" (Kosslyn et al. 1998, p. 151). Again, we turn to a mental rotation study comparing animate versus inanimate stimuli for answers. Kosslyn et al. (2001a,b) had subjects engage in a familiarization training condition prior to the mental rotation experiment. Participants viewed a 3-D block object being moved by an electric motor (exogenous force) or, in the alternative condition, were required to twist the object with their right hand to orient it (endogenous force). The familiarization process influenced the strategy adopted by participants in the study, and only in the latter condition (endogenous force) was the primary motor cortex activated. Recent studies have also examined mental rotation of human figures, with results indicating an effect of embodiment (Madan and Singhal, 2015). Further evidence is derived from studies comparing athletes' performance on mental rotation of animate versus inanimate figures. If motor imagery is grounded in actual experience of motor skills then the spatial imagery tested in the comparison of the orientation of block figures during mental rotation should not be as strong a predictor of expertise as motor imagery (i.e., animate stimuli). Findings in successive studies support athletes out-performing non-athletes on tests with such embodied figures, with no such differences apparent in their mental rotation of cube stimuli (Jansen et al., 2012). The implications of these findings will be re-visited but it is noteworthy that mental rotations tests have not been widely applied as a measurement tool (e.g., MacIntyre et al., 2002).

Instead the most often used questionnaire to assess motor imagery is the *Vividness in Movement Imagery Questionnaire* (VMIQ; Isaac et al., 1986; Roberts et al., 2008) and newer iterations, all based on rating the phenomenological concept of "vividness." The VMIQ was based off of the *Vividness in Visual Imagery Questionnaire* (Marks, 1973), both involving specific mental imagery instructions followed by a Likert scale corresponding to the vividness of the imagery. The VMIQ involves three sub-scales, evaluating internal visual imagery, external visual imagery, and kinesthetic imagery, each for the same set of imagined actions. Another common questionnaire is the *Movement Imagery Questionnaire* (MIQ; Gregg et al., 2010; Hall and Pongrac, 1983), which involves both enacted actions and imagined actions, with a comparison of vividness for the imagined action (see Cumming and Eaves, 2018 for review).

A limitation of these common questionnaires is the reliance on subjective responses and self-report. Self-report responses can be influenced by numerous biases, but of particular interest to questionnaires of motor imagery is the effect of confidence; athletes are likely to feel more confident in the motor abilities, whereas injured performers are likely to feel less confident due to re-injury anxiety (Hsu et al., 2017) potentially leading to inflated effects of ability on motor imagery responses. This is not to say that athletes might not actually have better motor imagery abilities, but that these self-report responses may exaggerate these group differences. While ability confidence could potentially be measured and corrected for, it is challenging to determine how to account for the impact of confidence on responses to imagery items. A better approach, however, would be to use an *objective* measure to assess motor imagery ability.

Motor imagery ability can be objectively measured if the imagined action can be assessed as being correct or incorrect. For instance, the *Test of Ability in Movement Imagery* (TAMI; Madan and Singhal, 2013, 2014) consists of 10 questions, preceded by a practice question, that each have a list of body movement instructions. Participants are asked to start from a specified starting position and then imagine the instructed actions. This is then followed by the presentation of several body positioning pictures from a third-person perspective in a multiple-choice format, with participants being asked to select the picture that corresponds to the outcome of the listed movement instructions—i.e., there is a correct response. After the initial development of the TAMI (Madan and Singhal, 2013), the scoring method was refined to assign weights to each question based on difficulty to improve sensitivity (Madan and Singhal, 2014). In a large sample ($N=246$; Madan and Singhal, 2015), it was shown that the TAMI relates to different imagery processes than merely mental rotation.

The TAMI is not the only movement imagery questionnaire to use objective tests, there is also the Controllability of Motor Imagery test (CMI) (Naito, 1994; Nishida et al., 1986) and the Tests zur Kontrollierbarkeit von Bewegungsvorstellungen (TKBV; Schott, 2013); however, among other differences, neither of these is in English. A questionnaire designed to examine tool-related motor imagery in apraxia patients, the *Florida Praxis Imagery Questionnaire* (FPIQ; Ochipa et al., 1997), has also been suggested to be useful for evaluating individual differences (McAvinue and Robertson, 2008). Recent work has followed this suggestion and demonstrated useful individual differences with the FPIQ in healthy, young adults (Donoff et al., 2018; Madan and Singhal, 2013; Madan et al., 2018).

An approach which combines both traditions has been developed by Collet et al. (2011). Mental chronometry, self-report inventories, and physiological indices of the autonomic motor system are combined in an index. The flexibility of this system is that the indices can be changed depending on the sport, individual characteristics or the athletes' current status (i.e., injured or functioning). This may be pertinent as loss of function during motor execution may inhibit motor imagery processes as suggested by short term changes in temporal accuracy for imagined movements after exposure to microgravity (Papaxanthis et al., 2003; see also Guillot et al., 2012b). The implications are that the capacity to recover from injury, for example, may be inhibited due to loss of motor imagery ability. One interesting example is the case of IW, who suffered from peripheral neuropathy and developed his spatial imagery but still performs poorly on motor imagery (ter Horst et al., 2012).

6 IS MOTOR IMAGERY UNCOUPLED FROM ACTION?

Researchers have in recent years begun to study what is termed dynamic motor imagery. It refers to incorporating relevant movements during motor imagery to enhance the process (Guillot et al., 2013). These movements have been described as being either synchronous or asynchronous to indicate their overlap with the simulated movement (MacIntyre and Moran, 2010). Traditionally, imagery, by definition, occurred in the absence of movement. Empirical evidence and practice based evidence have questioned this decoupling. For example, both contemporary models of imagery in athletes postulate that movement is possible during imagined action (Guillot and Collet, 2008; Holmes and Collins, 2001). We now focus our attention on this issue. In addition, the motor cognition account questions the artificial decoupling of motor imagery from movement by providing an action spectrum encompassing imagery and motor execution. Morris et al. (2005), in their monograph on the topic of imagery in sport, state that imagery "may be considered as the creation or re-creation of an experience generated from memorial information, involving quasi-sensorial, quasi-perceptual and quasiaffective characteristics, that is under the volitional control of the imager, and which *may* occur in the absence of the real stimulus antecedents normally associated with the actual experience" (p. 19, emphasis added). This definition retains key elements of traditional definitions (e.g., multisensory, conscious experience) but is novel in that it includes the possibility that imagery and action may co-occur. The traditional definitions of mental imagery presuppose that the simulation occurs in the absence of actual perception or movement execution. However, as we discovered with motor imagery in mental rotation, the complexity of these processes means they are not easily dissociable. In the visual imagery research literature, for example, it has been suggested that there is no such thing as immaculate perception (Kosslyn and Sussman, 1995). Thus, visual imagery was seen to be central to perception in providing topdown knowledge that influenced our visual recognition abilities. Indeed, early studies by Perky (1910) attempted to answer the question of the role of imagery in perceptual recognition by projecting a faint illustration of objects during imagery of either congruent or incongruent objects. While debate over the methods continues, the principle that imagery can facilitate visual recognition processes remains. In the motor context, quasi-movements—a term used by Nikulin et al. (2008) to describe volitional movements that are suppressed during motor imagery and thus are neither movement execution nor motor imagery per se—have been recorded. The inhibition of such movements is integral to motor imagery processes (Guillot et al., 2012a). On the basis of self-reports suggesting that athletes often engage in movements while experiencing imagery, sport psychologists have recommended that performers apply dynamic imagery in their imagery practice (Holmes and Collins, 2001). Researchers had noted that athletes engaged in either synchronous movements (e.g., moving the appropriate limbs to simulate the executed skill) or asynchronous movements (e.g., other movements in which, for example, their hand may simulate the carving movement of a surfboard) during imagery (MacIntyre and Moran, 2010). Guillot et al. (2013) conducted a study with 12 elite high-jump athletes to test the hypothesis that movement during imagery would enhance the participants' imagery. Their measure was temporal accuracy—the comparison between duration of simulation and motor execution of the run-up jump and landing for dynamic imagery and motionless imagery. They reported a significant difference between imagery and actual times when participants performed motionless imagery. In contrast, they achieved temporal congruence during dynamic imagery. Furthermore, ratings on the quality of their imagery supported previous quasi-experimental findings (Callow et al., 2006) and qualitative reports. While one can tentatively conclude that the evidence suggests athletes find this beneficial, it requires further study. The implications of these findings go beyond the performance-enhancement role, however, and question the traditional definitions of motor imagery as occurring without any overt motor output. Jeannerod's (1994, 2006) action-simulation model proposes that imagery processes are involved in motor planning (covert process), and this enables the off-line simulation of action. As noted earlier, motor imagery is part of the action spectrum, with other simulation activities on this spectrum including shadow shots (e.g., a low-amplitude post-execution practice swing) and action-observation, which have varying degrees of motor activation, potential for motor output, and visual cognition.

7 DOES MOTOR IMAGERY PROVIDE A WINDOW TO OUR EMOTIONS?

Research using the mental rotation paradigm has recently demonstrated that motor retardation, a symptom of depression, is also evident during motor imagery tasks (Chen et al., 2013). To explain, a slowdown in motor execution has been reported in mental rotation studies that compared differences between the response times for two sets of stimuli. Briefly, in a study with patients with unipolar depression, their mental rotation of animate stimuli reflected slower reaction times in comparison with the latencies for another condition that used inanimate stimuli (e.g., block objects). This raises an interesting question for researchers: Does this impairment reflect our negative emotional state through embodied cognition? Evidence for these effects are accumulating (Bennabi et al., 2014), but research is required with those with less profound emotional distress to explore whether our action system and simulation processes convey mood disturbances across the spectrum (i.e., positive and negative mood). For example, injured athletes compared with those in flow state may differ vastly both in their emotional state and their ability to react to stimuli; the possibility of developing implicit measures of mood state from motor imagery research remains.

8 TO WHAT EXTENT DOES OUR PHYSICAL ENVIRONMENT INFLUENCE MOTOR IMAGERY?

Adam and Galinsky (2012) proposed the concept of enclothed cognition to illustrate the interaction between what we wear and our cognition. They posited that the term enclothed cognition encompassed "the effects of clothing on people's psychological processes" which "depend on both a) the symbolic meaning of the clothes and b) whether people are actually wearing the clothes" (p. 919). The broader environment may indeed have a wider influence on our cognition than has been previously thought. For example, exercise and physical activity in natural spaces—what has been termed green exercise—has distinct effects on our attentional capacity and emotions (Barton and Pretty, 2010). Emerging evidence suggests that even rambling on a forest trail can enhance working memory capacity (a process called attention restoration) relative to the similar physical activity in an urban setting. The differences between urban and rural settings are potentially substantial in terms of visual stimuli, social factors (i.e., whether solitary or social activity), and environmental factors like air pollution and noise, but other factors may also be at play here. Walking is a complex motor behavior with a special relevance in social interactions. By observing walking, people can extract a considerable amount of information, including emotional states and intentions of the agent (Dalla Volta et al., 2015). Natural environments provide a rich sensory experience, often without the threat (e.g., crime) or risk (e.g., traffic) obvious in other settings. Walking supports various psychological mechanisms for reconciliation, including creativity, locomotion motivation, and embodied notions of forward progress (Webb et al., 2017). Another possibility is that the vividness of our memories of these natural experiences (e.g., walk along a beach), mediated by embodied cognition, provides a multisensory episodic procedural memory that gives green exercise its sticky behavior effect (i.e., increased adherence and higher propensity for future engagement).

9 FUTURE PATHWAYS FOR MOTOR IMAGERY RESEARCH

This chapter has highlighted conceptual and theoretical issues that elucidate our understanding of motor imagery. A number of new directions are highlighted in Table 2. Motor imagery, at the nexus of cognition, perception, action and emotion, has the potential to illuminate our cognitive apparatus and guide our conceptualizations and theorizing.

Table 2 Future Directions for Motor Imagery Research

Issue	Potential Domain	Source
Using pupillometry (the measurement of changes in pupil diameter as a function of cognitive processing) to investigate the possible cognitive mechanisms underlying simulation (see O'Shea & Moran, 2018a,b)	However, the following questions remained open: (1) are there differences in the ability to imagine movements in healthy people? (2) To what extent is this function impaired when there is damage to the nervous system	Wondrusch and Schuster-Amft, 2013 Mokienko et al. (2014)
Impairment of motor imagery during injury		
Action observation and motor imagery	Can action observation be used in conjunction with motor imagery interventions to optimize performance and learning	Cumming and Eaves (2018)
Embodied cognition and inhibitory processes	An exploration of the different inhibition processes of elite performers who can couple quasi-movements with motor imagery merits further study using fMRI-targeting the dorso-lateral pre-frontal cortex will enable the role of meta-cognitive processes to be explored	Guillot et al. (2012a)
Physical environment influences	Investigating the context in which imagery occurs could either enhance or detract from the experience, either by mood changes from stressors or calm mood altering stimuli including nature, fMRI could provide information on the activation of emotional networks	MacIntyre et al. (2018)

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