6 Mental imagery, action observation, and skill learning

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Introduction

One of the most remarkable capacities of the mind is its ability to simulate sensations, actions and other types of experience. As Crisp, Birtel, and Meleady (2011) proclaimed recently, "the ability to envisage a world different from that which we know is one of the defining characteristics of human experience" (p. 261). To illustrate a mundane application of this process, if you close your eyes, you should be able to "see" yourself throwing a bright yellow tennis ball up in the air (a visual mental image) and then "feel" yourself bouncing it (a kinaesthetic or "feeling-oriented" mental image). For over a century, researchers have investigated the construct of mental imagery or the cognitive simulation process by which we can represent perceptual information in our minds in the absence of appropriate sensory input (Munzert, Lorey, & Zentgraf, 2009). More recently, another mental simulation process that has attracted attention from cognitive neuroscientists and sport psychologists is "motor imagery" (sometimes called "movement imagery"; Holmes, Cumming, & Edwards, 2010) or the mental rehearsal of actions without any overt motor output (see review by Moran, Guillot, MacIntyre, & Collet, 2011). Research on motor imagery is important in psychology because it provides an empirical window on consciousness and movement planning, rectifies a relative neglect of non-visual types of mental imagery, and has practical implications for skill learning and skilled performance in special populations (e.g., elite athletes).

Perhaps not surprisingly, mental simulation processes such as motor imagery are crucial to success in sport. This claim is supported by anecdotal, descriptive, and experimental evidence. At the anecdotal level, for example, consider the remarkable imagery skills of Michael Phelps, the 14-times Olympic gold medal winner in swimming (see Figure 6.1 below).

Explaining his psychological preparation for swimming competitions, he revealed that "I can visualize how I want the perfect race to go. I can see the start, the strokes, the walls, the turns, the finish, the strategy, all of it" (Phelps, 2008a, p. 8). Furthermore, he highlighted his reliance on kinaesthetic imagery when he said that

swimmers like to say that they can "feel" the water . . . I didn't have to fight the water. Instead, I could feel how I moved in it. How to be balanced. What might make me go faster or slower. (Phelps, 2008b, p. 10)

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Figure 6.1 Photograph of Michael Phelps, the 14-times Olympic gold medal winner in swimming.

At the descriptive level, Taylor, Gould, and Rolo (2008) showed that imagery use was one of the strongest predictors of athletic success in a sample of US Olympians. Finally, at the experimental level, Caliari (2008) found that table tennis players who participated in a mental imagery intervention program to rehearse a stroke symbolically (the forehand drive) improved significantly relative to those in a control group. Clearly, mental imagery training can facilitate the learning and performance of sport skills (Weinberg, 2008). Not surprisingly, the value of using mental imagery to rehearse actions and movements has been acknowledged in other fields of skilled performance. For example, in medicine, motor imagery training can enhance surgical performance (Arora et al., 2010, 2011) and is helpful in facilitating upper-limb recovery after stroke (e.g., Braun, Beurskens, Borm, Schack, & Wade, 2006; Nilsen, Gillen, & Gordon, 2010).

In the present chapter, we explore the role of mental imagery (and the related cognitive process of observation; see Holmes & Calmels, 2008, 2011) in skill learning and skilled performance in sport. We begin by explaining the nature, characteristics (including neural substrates), and measurement of mental imagery. Next, we shall summarize the effects of "mental practice" (a systematic form of covert rehearsal in which people imagine themselves performing an action without engaging in the actual physical movements involved) on skill learning and skilled performance in sport. We then consider the neuroscience of "action observation":

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the fact that, when we watch someone performing an action that lies within our motor repertoire, our brains simulate performance of that action and sketch recent research findings on the relationship between imagery, action observation, and skill learning. Finally, we outline some potentially fruitful new directions for research on mental imagery, observation and skill learning in sport.

Mental imagery: nature, characteristics, and measurement

According to researchers, mental imagery has at least three key characteristics: it is multi-sensory, can be classified into different types, and shares certain neural substrates and cognitive mechanisms with other mental processes. As Hardy, Jones, and Gould (1996) proposed, mental imagery is "a symbolic sensory experience that may occur in any sensory mode" (p. 28). Therefore, we have the capacity to imagine "seeing," "hearing," "tasting," "smelling," and "feeling" simulated actions and experiences. As imagery is multi-sensory in nature, different types of mental imagery have been identified. However, imagery researchers in sport psychology and cognitive neuroscience differ considerably in their postulated typologies of imagery. For example, some sport psychology researchers have developed typologies based on intended functions of imagery. Martin, Moritz, and Hall (1999) distinguished between "motivation general - mastery" (e.g., imagining staying focused after making an error in a competition), "motivation general – arousal" (e.g., imagining the stress and/or excitement associated with competition), "motivation specific" (e.g., imagining achieving a personal best or winning a medal), "cognitive general" (e.g., imagining a game plan for a competitive event), and "cognitive specific" (e.g., mentally practicing a skill) imagery. By contrast with this functional approach, cognitive neuroscientists have adopted a mechanistic typology: distinguishing between the visual, spatial and motor imagery processes that are postulated to underlie the imagery experience. In this regard, Kozhevnikov, Kosslyn, and Shepard (2005) have postulated two distinct cognitive systems that encode and process visual information in different ways. Object-based imagery represents the shape and color information of objects, whereas spatial imagery represents location information. More recently, "motor imagery" processes or the "covert simulation of movement" (Holmes, 2007, p. 1) have begun to attract research attention in neuroscience.

Historically, motor imagery processes have been measured using standardized psychometric tests (e.g., the Vividness of Movement Imagery Questionnaire, VMIQ; Isaac, Marks, & Russell, 1986), qualitative procedures (Moran & MacIntyre, 1998), psychophysiological techniques (e.g., Guillot, Collet, et al., 2009) and chronometric tools (i.e., those in which the time-course of information-processing activities is used to draw inferences about cognitive mechanisms; see review by Guillot & Collet, 2005). In an effort to combine these measures, Collet, Guillot, Lebon, MacIntyre, and Moran (2011) proposed a formula by which a novel "motor imagery index" (MII) can be calculated using a combination of six specific component scores. These scores include self-estimations of imagery quality, psychometric assessment of imagery vividness, three psychophysiological indices (derived from electrodermal and cardiac recordings), and estimation of the difference between

actual and imagined duration of movement execution. According to Collet et al. (2011), the MII is especially helpful to imagery researchers in sport psychology. It is flexible and relatively easy to calculate because most of its components (specifically, the qualitative, psychometric, and chronometric ones) do not require any specialist measurement equipment.

The second notable feature of mental imagery is that although it is unobservable, it can be measured indirectly through individual variations in such dimensions as "vividness" (i.e., apparent realism, clarity, or richness) and "controllability" (i.e., the ease with which a given mental image can be manipulated by the person who generates it) (Moran, 1993). Over the past century, these two dimensions of imagery have been targeted by psychologists in their attempt to measure individual differences in people's use of, and ability in, imagery (see Morris, Spittle, & Watt, 2005). For example, the vividness of an image can be assessed using self-report scales in which people are asked to comment on certain experiential aspects of their mental representation. In this regard, Roberts, Callow, Hardy, Markland, and Bringer (2008) developed the Vividness of Movement Imagery Questionnaire - 2 (VMIQ-2). This test consists of 12 items and assesses the ability to form mental images of various motor tasks (e.g., running, kicking a stone) and then to rate the resultant images on a Likert-type scale from 1 ("perfectly clear and vivid") to 5 ("no image at all"). The VMIQ-2 displays impressive factorial validity and acceptable concurrent and discriminate validity. The controllability dimension of a mental image can be measured objectively by requesting people to complete tasks which are known to require visualization abilities. For example, in the "Group Mental Rotations Test" (GMRT; Vandenberg & Kuse, 1978), people are required to make judgments about whether or not the spatial orientation of certain three-dimensional target figures matches (i.e., is congruent with) or does not match (i.e., is incompatible with) various alternative shapes. MacIntyre, Moran, and Jennings (2002) reported moderate positive correlations between scores on this latter test and finish position among a sample of canoe-slalom world cup competitors.

The third important aspect of mental imagery concerns its neurological substrates. Specifically, researchers have shown that motor imagery shares some neural pathways and mechanisms with like-modality perception (Farah, 1984; Kosslyn, 1994) and with the preparation and production of movements (Decety & Ingvar, 1990; Jeannerod, 1994, 2001). In short, there are close parallels between perceiving, imagining, and motor control (planning and executing actions). Recognition of these parallels led to the "functional equivalence" hypothesis (e.g., Finke, 1979; Jeannerod, 1994; see review by Moran et al., 2011) or the proposition that cognitive simulation processes (e.g., imagery) share, to some degree, certain representations, neural structures, and mechanisms with like-modality perception and with motor preparation and execution processes. For example, neuroimaging studies show that mentally simulated and executed actions rely on similar neural representations and activate many common brain areas such as the primary motor cortex, supplementary motor area, premotor areas, and cerebellum (de Lange, Roelofs, & Toni, 2008; Munzert et al., 2009). Similarly, a meta-analysis by Grèzes and Decety (2001) revealed that motor imagery, movement execution, and action observation activate

overlapping foci in the supplementary motor area, dorsal pre-motor cortex, supramarginal gyrus, and superior parietal lobe. As Macuga and Frey (2012) have recently pointed out, however, there has been no satisfactory direct test of the functional equivalence hypothesis because of the failure to study motor imagery, movement execution and action observation processes within a single paradigm.

Mental practice

As explained earlier, the term mental practice (MP; also known as symbolic rehearsal or covert rehearsal) refers to the systematic use of mental imagery to rehearse an action in one's imagination without engaging in the actual physical movements involved. For over a century, the effects of MP on skilled performance have been investigated by researchers in psychology. To illustrate, James (1890) claimed rather counterintuitively that, by anticipating experiences imaginatively, people actually learn to skate in the summer and to swim in the winter. The typical experimental paradigm used to study MP effects involves a comparison of the pre- and postintervention performance of four groups of participants: those who have engaged only in physical practice of the skill in question (the physical practice group, PP); those who have mentally practiced (the mental practice group, MP); those who have alternated between physical and mental practice (PP/MP); and, finally, participants in a non-practice control condition. After a pre-treatment baseline test has been conducted on a designated skill, participants are randomly assigned to one of these conditions (PP, MP, PP/MP, or control). Normally, the cognitive rehearsal that occurs in the MP treatment condition is guided by a mental imagery script that describes the motor actions to be executed in clear and vivid detail (see Morris et al., 2005). After this MP intervention has been applied, the participants' performance on the target skill is re-tested. If the performance of the MP group is significantly superior to that of the control group, then a positive effect of mental practice is deemed to have occurred.

Empirical findings on mental practice

Scientists interested in imagery have established a number of conclusions about the efficacy of mental practice (see reviews by Driskell, Copper, & Moran, 1994; Schuster et al., 2011). These conclusions may be summarized as in Table 6.1.

First, MP can improve the learning and performance of a variety of motor skills. These skills include self-paced activities such as golf putting (Bell et al., 2009; Ramsey, Cumming, & Edwards, 2008) and the high-jump (Olsson, Jonsson, & Nyberg, 2008) as well as skills involving a partner and anticipation, such as the service return in tennis (Robin et al., 2007). Mental practice interventions have also been applied successfully to enhance performance in music (Johnson, 2011), dance (Bolles & Chatfield, 2009), and medical surgery (Arora et al., 2011). Second, there is evidence (see Driskell et al., 1994) that MP, when combined and alternated with physical practice, tends to produce superior skill learning to that resulting from either mental or physical practice conducted alone. In stroke rehabilitation,

Empirical finding	Illustrative authors (year)	Skill/task in question	Conclusion
1	Bell, Skinner, & Fisher (2009)	Golf putting	MP improves skill learning and skilled performance
	Ramsey, Cumming, & Edwards (2008)	Golf putting	
	Robin et al. (2007)	Service return in tennis	
2	Malouin, Richards, Durand, & Doyon (2009)	Rising and sitting movements after stroke	MP combined and alternated with physical practice (PP) produces better outcomes than PP alone
3	Smith, Collins, & Holmes (2003)	Strength performance on a finger strength task	MP can improve performance on tasks involving physical strength
	Reiser, Büsch, & Munzert (2011)	Strength performance in bench pressing, leg pressing, triceps extension, calf raising	
4	Arvinen-Barrow, Weigand, Thomas, Hemmings, & Walley (2007)	Use of specific types of mental imagery	Expert athletes tend to use mental imagery for skill rehearsal more frequently than do relative novices
5	Goss, Hall, Buckolz, & Fishburne (1986)	Acquisition of various movement patterns	Imagery ability mediates the relationship between MP and performance

Table 6.1 Empirical findings on mental practice (MP): selected studies

mental practice combined with physical practice yields better outcomes in movement recovery than does physical practice alone (Malouin, Richards, Duran, & Doyon, 2009; Page, Levine, & Leonard, 2007). In attempting to explain the mechanisms underlying such mental practice effects in rehabilitation settings, Welfringer, Leifert-Fiebach, Babinsky, and Brandt (2011) postulated that motor imagery training facilitates activation of pre-motor circuits in the damaged hemisphere with consequent stimulation of associated sensory cells. Third, although Feltz and Landers (1983) concluded that mental practice is more effective for the improvement of cognitive rather than motor components of sport skills, there is research evidence that MP can increase physical strength performance (Smith, Collins, & Holmes, 2003; Reiser et al., 2011). Fourth, the expertise level of the performer appears to moderate the effects of mental practice on performance. For example, Driskell et al. (1994) concluded that expert athletes tend to benefit more from MP than do novices, regardless of the type of skill being practiced (either cognitive or physical). Also, Arvinen-Barrow, Weigand, Thomas, Hemmings, and Walley (2007) found

that elite athletes tend to use mental imagery more frequently for skill rehearsal than do novice counterparts. However, these last authors cautioned that there has been considerable inconsistency among imagery researchers in the way in which the skill level of participants has been dichotomized (i.e., elite versus novice). Finally, there is some evidence (e.g., Goss, Hall, Buckolz, & Fishburne, 1986) that imagery ability (or a person's capacity for forming "vivid, controllable images and retaining them for sufficient time to effect the desire imagery rehearsal"; Morris, 1997, p. 37) mediates the relationship between MP and motor skill performance. To summarize, numerous researchers have indicated that mental practice can enhance skill learning and skilled performance in athletes. As Munroe-Chandler and Morris (2011) have noted, however, relatively little research has been conducted on the efficacy of imagery in improving strategic aspects (e.g., developing game-plans) of sporting performance. Nevertheless, the distinction between skill and strategy is not completely clear-cut. For example, MacIntyre and Moran (2007b) argued that the attempt to decouple skills from strategies is often difficult because of the continuous nature of executed movements in sport.

Validation of mental practice research

Although there is an abundance of research on the efficacy of MP, there is at least one unresolved question – a validation issue – that afflicts this field. Specifically, how do we know that people who claim to be using imagery when engaged in mental practice are actually doing so? In other words, how can we validate people's subjective reports about their imagery experiences? One way of addressing this issue is to use custom-designed manipulation checks or verification procedures that attempt to assess the ease and accuracy with which participants adhered to the imagery instructions/script (see Cumming & Ramsey, 2009). An alternative solution to this validation problem comes from research on the mental travel chronometry paradigm (Guillot & Collet, 2005). According to the functional equivalence hypothesis, imagined and executed actions rely on similar motor representations and activate some common brain areas (e.g., the pre-motor and primary motor cortices). Consequently, there should be a close correspondence between the time required to perform simulated actions *mentally* and that required for *actual* performance. This hypothesis has been corroborated empirically (Guillot & Collet, 2005; Guillot, Louis, & Collet, 2010). Moran and MacIntyre (1998) validated the veracity of canoe-slalomists' imagery reports by comparing the congruence between the imagined time and the real time required by these athletes to navigate their courses in competition. More recently, a review by Guillot, Hoyek, Louis, and Collet (2012) concluded that elite athletes are typically more accurate than novices in estimating the imagined duration of executed actions.

Theories of mental practice

In general, four main theories have been postulated to explain MP effects; the neuromuscular model (e.g., Jacobson, 1932), the cognitive or symbolic approach (e.g.,

Denis, 1985), the bio-informational theory (e.g., Lang, 1979) and, most recently, the PETTLEP approach (Holmes & Collins, 2001). According to the neuromuscular model, mental practice effects are mediated by faint activity in the peripheral musculature (Moran, 2012). Advocates of this theory postulate that there is a strong positive relationship between the muscular activity elicited by imagining a given skill and that detected during actual execution. Unfortunately, there is mixed empirical support for this hypothesis. For example, whereas Guillot et al. (2007) discovered electromyographic (EMG) activity during motor imagery, Gentili, Papaxanthis, and Pozzo (2006) failed to do so. Next, according to the cognitive approach mental practice facilitates the coding and rehearsal of key elements of the skilled task. In contrast with neuromuscular accounts of mental practice, cognitive (or symbolic learning) models attach little importance to what happens in the peripheral musculature of the performer. They focus on the possibility that mental rehearsal strengthens the brain's central representation or cognitive "blueprint" of the skill being imagined (Roosink & Zijdewind, 2010). Although this approach has a plausible theoretical rationale, it is challenged by evidence that mental practice can improve people's performance of strength tasks, which, by definition, contain few cognitive components. Another problem for symbolic theorists is that they find it difficult to explain how mental practice can enhance the performance of expert athletes, who, presumably, already possess well-established blueprints or motor schemata for the movements being imagined. Bio-informational theory has at its core the interaction of three different factors: the environment in which a given movement is performed ("stimulus" information such as "feeling" the soft ground as one imagines teeing up a ball in golf), what is felt by the performer while the movement occurs ("response" information such as feeling a slow, smooth practice swing on the imaginary tee-box), and the perceived importance of this skill to the performer ("meaning" information such as feeling slightly anxious because other people are watching as one prepares to drive the ball). Of these factors, the response information is especially significant because it reflects how a person would *actually* react in the real-life situation being imagined. Therefore, bio-informational theorists postulate that imagery scripts that are heavily laden with response propositions should elicit greater mental practice effects than those without such information. The bio-informational approach has been influential in highlighting the value of "individualizing" imagery scripts so that they take account of the personal meaning that people attribute to the skills or movements that they wish to rehearse. Finally, the most recent theoretical approach to mental practice is known by the acronym PETTLEP (Holmes & Collins, 2001). In this model, P refers to the athlete's Physical response to the sporting situation imagined, E is the Environment in which the imagery is performed, T is the imagined Task, T refers to Timing (i.e., the pace at which the imagery is performed), L is a Learning or memory component of imagery, E refers to the Emotions elicited by the imagery, and P designates the type of visual imagery Perspective used by the practitioner (i.e., whether he or she imagines the movement from a "first-person" perspective, imagining/seeing oneself performing a given action, or from a "third-person" perspective, imagining/seeing either oneself or someone else performing the action). The PETTLEP model proposes that, when

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used to enhance performance, imagery interventions should replicate not only athletes' sporting situation but also the emotions that they experience when performing their skills. Although the predictions of the PETTLEP model have not been tested extensively to date, available empirical results are generally supportive. Smith, Wright, Allsopp, and Westhead (2007) compared the use of PETTLEP imagery training with traditional mental practice techniques and with physical practice in developing gymnasts' jump skills. The PETTLEP group improved its proficiency in these skills, whereas the traditional imagery group did not.

Motor imagery, action observation, and skill

So far, we have provided evidence to support the effectiveness of motor imagery as an intervention technique for improving skill acquisition. Because few researchers have adequately addressed the validation problem (i.e., the issue of how we know for sure that people who *claim* to be using imagery when engaged in mental practice are actually doing so), some psychologists (e.g., Holmes & Calmels, 2008, 2011; Holmes et al., 2010) have turned to action observation as either a possible replacement for, or an adjunct to, mental imagery. Many of the factors that have been examined as moderators of the relationship between imagery and skilled performance have become popular in observation research. For example, intervening variables such as visual perspective, movement agency (self or other), viewing angle (allocentric or egocentric position relative to the action), task type (e.g., form-based versus perceptually driven; see Holmes & Calmels, 2011), and timing issues (e.g., real time, slow motion, or speeded) have been studied by action observation investigators. Holmes and Calmels (2011) postulated that observation, when delivered through video-based media, can offer solutions to many of the challenges encountered when delivering imagery interventions, such as increased control over image content.

Let us now summarize some emerging findings about the efficacy of observation interventions in sport settings and how best to integrate them with imagery approaches. To begin, mental skills training through the practice of action observation, just as we have described for motor imagery, can improve sporting performance (e.g., Ram, Riggs, Skaling, Landers, & McCullagh, 2007; Ramsey, Cumming, & Edwards, 2008). A clue to the likely mechanisms underlying these effects comes from the discovery that action observation and motor imagery processes share certain neural representations (see Conson, Sarà, Pistoia, & Trojano, 2009; Holmes et al., 2010). For example, these two processes tend to elicit activation in the primary and premotor cortex, supplementary motor area, cerebellum, and basal ganglia. Many of the cortical circuits that are activated when people execute actions are activated when people observe someone else executing these actions. A degree of interpersonal motor resonance between observer and executer (activation of the two motor systems), or intrapersonal resonance between visual and motor areas, during skill learning has been postulated. Such resonance may provide support for the idea that these shared motor regions are important for action recognition, goal recognition, and action anticipation through the simulation of the observed (or imagined) action (see Uithol, van Rooij, Bekkering, & Haselager, 2011). In this

sense, the "shared" motor resonance translates the observed action into a general understanding of the action; the more familiar the observed action, the greater the motor resonance that can be seen in fMRI and transcranial magnetic stimulation (TMS) studies. As we have explained earlier, this abstract idea of linking several cognitive processes (e.g., motor imagery, action observation, and motor control) has been termed "functional equivalence" in the literature (e.g., the PETTLEP model; Holmes & Collins, 2001). Proponents of the PETTLEP approach have suggested that imagery and action observation can be optimized by including practice-related characteristics such as holding task-specific equipment or adopting task-relevant positions to perform the imagery or observation.

Recently, researchers using TMS has demonstrated that observing another person's actions can modulate the excitability of this shared corticospinal system (see Loporto, McAllister, Williams, Hardwick, & Holmes, 2011). This effect may reflect increased pre-motor activity, seen as increases in motor-evoked potential (MEP) amplitude. This increase in activity may occur because observation not only influences activity in cortico-cortical connections from pre- to primary motor cortex but also contributes to skill learning. This network has been proposed to form part of the human action observation network: a network of pre-motor and parietal areas similar to the mirror neuron system - a brain region that is postulated to underlie people's ability to infer the goals and intentions of others by observing and imitating their actions - found in primates (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992). Transcranial magnetic stimulation is an effective, non-invasive method of stimulating the brain and peripheral nervous system and provides researchers with a useful approach to examine the central mechanisms underlying movement imagery and action observation. For example, MEP amplitude during action observation and motor imagery of finger-thumb opposition was compared with imagery ability as measured using the VMIQ-2 (Williams, Pearce, Loporto, Morris, & Holmes, 2012). Significant increases in MEP amplitude were recorded during the experimental conditions with a significant correlation between imagery MEP change and imagery ability, leading the authors to propose that corticospinal activation during imagery seems to be strongly related to imagery ability. This last finding suggests that individual differences in imagery ability (e.g., vividness) need to be controlled for if neurological mechanisms are to be elicited in support of skill learning.

In addition to the TMS evidence for a neural mechanism to support action observation as part of the skill acquisition process, electroencephalography (EEG) enables suitable measurement of changes in cortical activity that may be associated with motor skill learning and performance. In this regard, recent research provides further support for the utility of the action observation network. In two detailed studies of action execution and observation, comparisons between simple and complex movement conditions displayed a number of significantly similar synchronization patterns across the two conditions (Calmels, Hars, Holmes, Jarry, & Stam, 2008; Calmels, Holmes, Jarrry, Lévèque, Hars, & Stam, 2006). Although they did not yield an identical match of EEG cortical indicators between observation and execution conditions, the preceding studies provide support for a postulated central action-execution matching system that might be important for skill acquisition.

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Researchers have suggested that, before voluntary movement production, there is an increase in electrical activity in motor areas of the brain known as the movementrelated cortical potential (MRCP) (see Figure 6.2).

A component of the MRCP, the Bereitschaftspotential (BP, or "readiness potential"), is a negative slope that occurs just before movement onset (see Shibasaki & Hallett, 2006). The BP is followed by a steeper gradient negativity; the negative slope. The final component is the motor potential, which is concomitant with movement onset. The amplitude and onset times of these components vary depending on the physical and psychological characteristics of the forthcoming movement (Birbaumer, Elbert, Canavan, & Rockstroh, 1990). The MRCP seems, therefore, to reflect the cortical activity involved in planning and preparing to perform voluntary movements (Shibasaki & Hallett, 2006). Also, there are recorded differences in the MRCP amplitude and onset times between expert and novice performers (e.g., Wright, Holmes, Di Russo, Loporto, & Smith, 2011); expert performers show smaller-amplitude and later-onset MRCP profiles than novices. The experienced performers are able to plan and perform the task with a reduced cortical activity compared with novices. The phenomenon is termed neural efficiency, and the differences are attributed to long-term training by the expert group. This profile has been shown in expert and novice pistol shooters (Fattapposta et al., 1996), and kendo martial art performers (Hatta, Nishihira, Higashiura, Kim, & Kaneda, 2009). Wright et al. (2011) have also reported, in a group of novice guitarists, that the MRCP profile can be trained to reach that of an experienced group in as little



Figure 6.2 A schematic representation of the movement-related cortical potential (MRCP). Time 0 ms on the horizontal axis indicates the point of movement onset. The pre-movement components, termed the readiness potential (RP) and the negative slope (NS), are thought to reflect the cortical activity involved in planning and preparing to perform voluntary movement.

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as 5 weeks. Studies are ongoing in our own laboratories to investigate whether or not observation and imagery are able to contribute to modifications of the MRCP profile. What is not yet known, however, is if the reduced MRCP activity is commensurate with altered activity elsewhere (e.g., in the basal ganglia and cerebellum). In future, research that attempts to combine EEG with fMRI may be able to address this unresolved issue.

New directions for research on imagery and action observation

At least five new directions may be identified for future research on imagery and action observation processes. First, little is known as yet about athletes' "metaimagery" processes: their beliefs about the nature and regulation of their own imagery skills (see MacIntyre & Moran, 2010; Moran, 2002). This scientific neglect of what athletes know about their own imagery processes is surprising in view of the abundance of anecdotal insights into imagery that are available from sports performers. More generally, however, there is evidence that people's intuitive theories about their own mental imagery processes are often inaccurate. Denis and Carfantan (1985) discovered that a majority of participants (undergraduate students) in their study regarded as implausible the mental practice effect (see earlier in this chapter): the idea that systematic use of mental imagery could enhance the performance of motor skills. Unfortunately, although some researchers (e.g., MacIntyre & Moran, 2007a, 2007b; Munroe, Giaccobi, Hall, & Weinberg, 2000) have asked sport performers to indicate why, where, how, and when they use mental imagery, there has been little progress in developing either a psychometric test or a coherent theory of meta-imagery processes in athletes. Clearly, these unresolved issues require research attention. In a related vein, it is interesting to note that Pearson, Rademaker, and Tong (2011) have recently investigated people's metacognitive insights into their own visual imagery processes.

Second, research is needed to investigate the use of chronometric methods (mentioned briefly earlier) to validate athletes' reports of their imagery experiences. If imagined and executed actions rely on similar motor representations and activate certain common brain areas (e.g., the parietal and prefrontal cortices, the pre-motor and primary cortices), the temporal organization of imagined and actual actions should be similar, leading to a close correspondence between the time required to *mentally* perform a given action and that required for its *actual* execution.

Third, although imagery researchers in sport psychology (e.g., Morris et al., 2005) have typically advocated that athletes should use all of their sensory modalities in their simulation of action, the efficacy of this multi-modal approach has not yet been evaluated comprehensively. In order to address this unresolved issue, future research could use diary studies with elite athletes to determine the extent to which multi-modal images are generated.

Fourth, research is required on the relationship between action observation, motor imagery, and action execution. In this regard, a potentially promising line of inquiry concerns the study of eye movements. Such movements not only provide objective tools for studying online cognitive processing in imagery and action

observation but could also be used to draw inferences about the shared neural network system that underlies these activities. McCormick, Causer, and Holmes (under review) used the classic "reach and grasp" task design (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995) to demonstrate similarities in visual fixation times and number of visual fixations across motor imagery and observation conditions. These authors also investigated visual perspective with the "reach-grasp-place" being shown in the first- and third-person perspectives. Some differences in the dependent variables between perspectives were evident in both observation and imagery conditions, providing further support for a shared neural representation between observation and imagery processes. Another potential use of eye-movement data in imagery research is to elucidate the extent to which eye-hand coordination during *imagined* movements is similar to that which occurs during *actual* (i.e., physically executed) movements. Heremans et al. (2011) investigated the role of eye movements during motor imagery training. They found that, although eye movements elicited during imagery did not affect the temporal parameters of trained hand movements (reaching task), they did help to achieve maximal gains in movement accuracy and efficiency. These findings were most pronounced in conditions with high accuracy demands. Additional research is required to establish the implications of these findings for motor imagery training.

Finally, an exciting and potentially fruitful new direction concerns the development of methodologies for the investigation of the unique neural mechanisms underlying motor imagery, motor execution, and action observation. Macuga and Frey (2012) devised an fMRI paradigm in which these three processes were examined using a task involving people's performance on a repetitive bimanual fingertapping test. There was only partial support for the hypothesis that imagery and action observation processes activate the same neural representations subserving execution of the same action. Clearly, such results challenge researchers in this field to differentiate between distinctive and overlapping neural mechanisms underlying motor imagery, motor execution, and action observation processes.

In conclusion, the present chapter investigated the nature and implications of the relationship between mental imagery, action observation, and skill learning and skilled performance. We began with a brief introduction to the nature, neural substrates, and measurement of mental imagery. After that, we summarized research findings on the effects of mental practice on skilled performance and suggested some ways in which the veracity of people's reports on their imagery processes could be validated objectively. Then, following clarification of the neuroscience of observation, we outlined some key research findings on the relationship between observation, imagery, and skill learning. The final section of the chapter sketched some new directions for future research on imagery and action observation processes.

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