2 Expertise and the Mental Simulation of Action

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INTRODUCTION

What makes expert performance different from novice skill execution? At first glance, one might suggest that the answer is simple. It is the quality of overt behavior that separates exceptional performers from those less skilled. We can all point to many real-world examples of such performance differences—just try comparing any professional athlete to his or her recreational counterpart. Although actual performance is one component that differentiates experts from novices, overt performance outcomes are only part of the key to understanding skill learning, performance, and expertise. That is, skill-level differences not only are reflected in one's *on-line* task performance (i.e., the real-time unfolding of skill execution and its corresponding performance outcomes), but also are reflected *off-line*, in situations in which individuals are not overtly acting. In the current chapter, we focus our attention off-line on the mental simulation of action in an attempt to shed light on expertise differences in action perception, representation, and production. Such knowledge not only informs the question of what makes an expert different from his or her novice counterpart but also makes salient the robust and widespread influence that mental simulation has on our understanding and representation of information we encounter—even in situations in which individuals have no intention to act.

CHAPTER OVERVIEW

We begin by drawing on the literature in sport psychology, motor learning and control, and cognitive neuroscience to explore how the *explicit* ability to mentally simulate one's own action might differ as a function of one's motor skill level. This type of mental simulation is often termed *motor imagery* and has been defined as reenacting movements without overt execution (Decety, 1996a, 1996b; Decety & Stevens, Chapter 1, this volume). We first outline the cognitive and neural substrates of motor imagery and then consider (a) how motor imagery differs as a function of one's skill level and (b) the implications motor imagery carries for on-line performance and its outcome.

We next turn to recent work in cognitive psychology and cognitive neuroscience investigating how the perception of stimuli in one's environment can prompt *automatic* and *covert* mental simulation of action in the perceiver—even though the perceiver has no intention to act. This type of simulation, often termed *motor resonance*, is the process by which action observation activates the same neural substrates as those recruited when a perceiver performs an action by themselves (Prinz, 1997; Schütz-Bosbach & Prinz, 2007; Zwaan & Taylor, 2006). The conception of motor resonance is supported by monkey and human work demonstrating that overlapping neural regions (e.g., premotor and motor cortex) are involved in the observation and production of action (Decety & Grezès, 1999; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996). Such findings have been taken to suggest that our motor system not only plays a central role in planning actions to be executed, but also participates in the representation and understanding of actions as well (Garbarini & Adenzato, 2004).

The idea that both observing and planning actions share a common neural substrate suggests that merely thinking about action may call on motor-based neural processes. That is, higher-level cognitive processes not directly involved in motor production such as language comprehension

(Zwaan & Taylor, 2006) may be rooted in the mental simulation of action. We ask how this may differ as a function of one's expertise performing the action in question. Together, the work presented in this chapter suggests that a complete understanding of high-level performance not only requires consideration of on-line performance differences across the learning continuum, but also consideration of skill-level differences in the off-line mental simulation of action.

EXPERTISE AND THE EXPLICIT MENTAL SIMULATION OF ACTION

As mentioned, the *explicit* ability to mentally simulate an action without overt execution is often termed motor imagery (Decety, 1996a, 1996b). What is the relationship between motor imagery and execution itself? According to psychophysiology and neuroscience work of the past several decades, there is a *functional equivalence* between action execution and the mental simulation of action (e.g., see Decety & Grezès, 1999; Jeannerod, 1994). That is, motor imagery and execution share common neural substrates (Decety, 1996a; Jeannerod & Frak, 1999). For example, when individuals are asked to imagine themselves writing, increases in regional cerebral blood flow (rCBF) are seen in prefrontal brain regions, the SMA (supplementary motor area), and the cerebellum—similar to the activation patterns found during actual writing movements (Decety, Philippon, & Ingvar, 1988).

Added support for the notion of imagery/action equivalence comes from work demonstrating that the duration of mentally performed movements often does not significantly differ from physically executed movements. For example, mentally performing graphic tasks, such as drawing a cube or writing a sentence, is underlain by similar temporal organization as when actually performing such actions (Decety & Michel, 1989). The time used to mentally simulate moving one's hand or arm to match the orientation depicted in a presented hand stimulus has also been shown to mimic actual execution time (Parsons, 1994). Temporal congruence between imagined and executed actions is not merely limited to specific effectors but has been demonstrated at the whole-body level as well. In a recent chronometric comparison of actual and imagined movements in elite gymnasts, Calmels, Holmes, Lopez, and Naman (2006) found that the overall time to perform versus image a complex gymnastic vault did not significantly differ. This was true whether the vault was imaged from an internal (first-person) or external (third-person) perspective (in this volume, see also Kosslyn & Moulton, Chapter 3, and Libby & Eibach, Chapter 24).

Despite these similarities between motor imagery and action production, there are differences between mentally simulated and overt movement as well. For example, in the above-mentioned Decety and Michel handwriting study (1989), primary motor area (M1) activation was found in actual but not imagined writing. In fact, several studies have found that motor imagery and actual performance show overlapping activity in premotor and SMAs but not in primary motor cortices (see Guillot & Collet, 2005). This suggests that actual and imaged movements overlap most specifically in terms of the planning and programming of behavior rather than behavior execution (Decety, 1996a, 1996b). This is consistent with the notion that motor imagery and physical performance share common processes at higher, cognitive levels of the motor control hierarchy but differ at the level at which performance outcomes actually occur (MacKay, 1989).

EXPERTISE AND MOTOR IMAGERY

To the extent that motor imagery recruits at least some of the same cognitive and neural processes involved in actual execution, it follows that those with particularly specialized bodily experiences ought to mentally simulate actions differently than those without such experiences. That is, experience performing particular actions should be reflected in the mental simulation of action sequences in one's domain of specialization. Support for this notion can be found at both a behavioral and neurophysiological level.

In the chronometric comparison of imaged versus executed springboard dives, Reed (2002) found differences between motor imagery and physical performance that were dependent on skill expertise. Specifically, unlike novices and experts, intermediate divers tended to image their dive sequences significantly slower than they performed them. Reed suggested that such temporal differences in imaged and actual dives may reflect schematic differences in skill representation. Whereas novices have sparse dive knowledge and experts' knowledge may be automatized such that it is relatively closed to explicit introspection and report (Beilock & Carr, 2001; Beilock, Wierenga, & Carr, 2002), intermediate divers may be slowed during imagery by large amounts of dive-relevant knowledge that is represented in a nonautomated form.

Recent neuroimaging work shows that patterns of neural activation also differentiate motor imagery in expert and novice athletes. Using functional magnetic resonance imaging (fMRI), Milton, Solodkin, Hlustik, and Small (2007) compared neural activity while six professional golfers and seven novice golfers (who had less than 2 years of golfing experience) mentally simulated their preshot routines. Results showed that novices primarily activated posterior limbic and basal ganglion (BG) regions of the brain when mentally simulating their preshot routine. BG activation may be indicative of the effortful simulation of shot-related processes and procedures that are not yet fully automatized in novices (see Packard & Knowlton, 2002, for a review of the role of the BG in motor learning). The authors interpreted the posterior limbic activation in the posterior cingulate (PC) to reflect the filtering out of nonrelevant task information (for a review of the role of the PC in sensory monitoring, see Vogt, Finch, & Olson, 1992). Greater PC activation for novices relative to experts, then, may indicate that novices' preshot simulations may fail to successfully block out details less central to the motor-planning components of the action about to be performed. Experts, on the other hand, showed greater activity than novices in regions more closely related to precise visuomotor simulation, namely in the superior parietal lobe (SPL), left dorsal premotor (left PMd) and occipital (OCC) cortices. These regions are part of a broader action-simulation network (Rizzolatti, Fogassi, & Gallese, 2001), and their greater recruitment during experts' preshot routines suggests that part of what experts do in shot preparation is mentally simulate the specific motor sequence about to be performed. Taken together, these data indicate that expert and novice golfers recruit qualitatively different neural networks during preshot routines, and that this may reflect differences in the content of the mental simulation of the actions about to be produced.

MOTOR IMAGERY AND PERFORMANCE

Regardless of the above-mentioned skill-level differences in motor imagery, if the mental simulation of action relies on at least some of the same neural substrates as on-line execution—and this is true whether one is a novice or experienced performer—then manipulating the way in which individuals image execution should have an impact on performance outcomes, just as if performance execution itself were similarly manipulated.

Novice sensorimotor skill execution is thought to be attended in a step-by-step fashion. In contrast, well-learned skills are believed to be based on more automated control structures that run largely outside of explicit attentional control (Beilock & Carr, 2001; Jackson, Ashford, & Norsworthy, 2006; Maxwell, Masters, & Eves, 2000). As a result, when attention is distracted away from primary skill execution, novel skill execution that depends on explicit attentional control suffers. In contrast, attention prompted to a component process of execution disrupts the proceduralized processes of skilled performers. Work in golf putting (Beilock, Bertenthal, McCoy, & Carr, 2004), baseball batting (Gray, 2004), and soccer dribbling (Beilock, Carr, MacMahon, & Starkes, 2002) showed that when individuals are asked to perform a secondary task (e.g., monitor a series of tones for a specified target tone) that distracts attention away from primary skill execution (e.g., dribbling a soccer ball through a series of cones as fast as possible), novice performance is harmed while skilled performance is not. However, when individuals are asked to pay attention to component processes of execution (e.g., in soccer dribbling, the side of the foot that most recently contacted the ball), skilled performance is harmed and novice skill execution is spared.

These skill-level differences carry implications for how limitations in the time available for the setup and execution of one's skill will have an impact on performance. For example, because attention takes time to deploy (Posner & Snyder, 1975; Shiffrin & Schneider, 1977), conditions that limit the ability to explicitly monitor and adjust skill execution parameters (e.g., limited performance time) should benefit the proceduralized performance of experts. Conditions that encourage explicit attentional control (allowing as much performance time as desired) should aid novice performance based on declarative knowledge that must be explicitly controlled in real time. And, indeed, we have found support for this assertion. Beilock et al. (2004) had novice and skilled golfers execute a series of golf putts under speeded conditions in which individuals were told to putt as fast as possible (while still being accurate) or under conditions in which time constraints were not an issue. Although novices performed better under unlimited execution time in comparison to speed conditions, skilled golfers showed the opposite pattern.

We tested whether the above-mentioned expertise differences might occur not only by manipulating on-line performance but also by manipulating the motor imagery that precedes execution as well. Beilock and Gonso (2008) had novice and skilled golfers first *image* and then *execute* a series of golf putts on an indoor putting green under both speeded and nonspeeded imagery and putting instructions. For the speeded condition, participants were told to perform the putt/image as quickly as possible without sacrificing accuracy. In the nonspeeded condition, participants were explicitly told they had as much time as needed to complete the putt/image. When imaging their putts, participants stood over the ball with the club in their hand and pressed a button on the club (connected wirelessly to a computer) to indicate when they began and ended their image. When actually putting, an experimenter recorded (with a stopwatch) the time participants took to complete each putt. Timing results demonstrated that individuals followed instructions in both the putting and imagery conditions, putting and imaging faster under speeded relative to nonspeeded instructions.

Subsequent putting accuracy was then assessed as a function of imagery condition (i.e., speeded vs. nonspeeded imaging) and as a function of actual on-line performance condition (i.e., speeded vs. nonspeeded putts). This 2 (imagery instruction: speeded, nonspeeded) × 2 (putting instruction: speeded, nonspeeded) experimental design allowed for an assessment of the effect of different imagery conditions on actual putting execution independent of the conditions under which the putting task was performed. Likewise, this design also allowed for an assessment of the impact of different putting instructions on actual performance outcomes independent of the particular imagery condition that preceded putting.

Regardless of imagery instructions, novices should perform at a higher level (i.e., putt more accurately) under the nonspeeded putting instructions relative to the speeded putting instructions. This is because the former condition should provide more of an opportunity to explicitly monitor and control execution processes. In contrast, experts should putt more accurately under the speeded relative to the nonspeeded putting instruction condition as the speeded condition should prevent experts' attention from being devoted to skill processes and procedures best left outside conscious control. As mentioned, previous work in our lab has confirmed these predictions regarding the manipulation of actual performance time (see Beilock et al., 2004). In terms of imagery instructions, if imagined and executed actions do share overlapping neural substrates (Decety, 1996a), and imaging an action serves to recruit and fine-tune the motor processes used during actual action execution (similar to the processes involved in motor resonance), then manipulating imagery speed should have the same impact on subsequent putting accuracy as manipulating putting execution itself. As can be seen in Figure 2.1, this is exactly what occurred.

Novices putted less accurately (i.e., a higher putting error score) following either putting *or* imagery instructions in which speed was stressed. Skilled golfers showed the opposite pattern for *both* putting and imagery instructions. Critically, there was no Expertise × Putting instruction × Imagery instruction interaction. In other words, the impact of the imagery instructions on subsequent putting performance did not depend on the type of instructions given for the execution of the putt itself and vice-versa. Thus, manipulating either imagery or putting time appears to

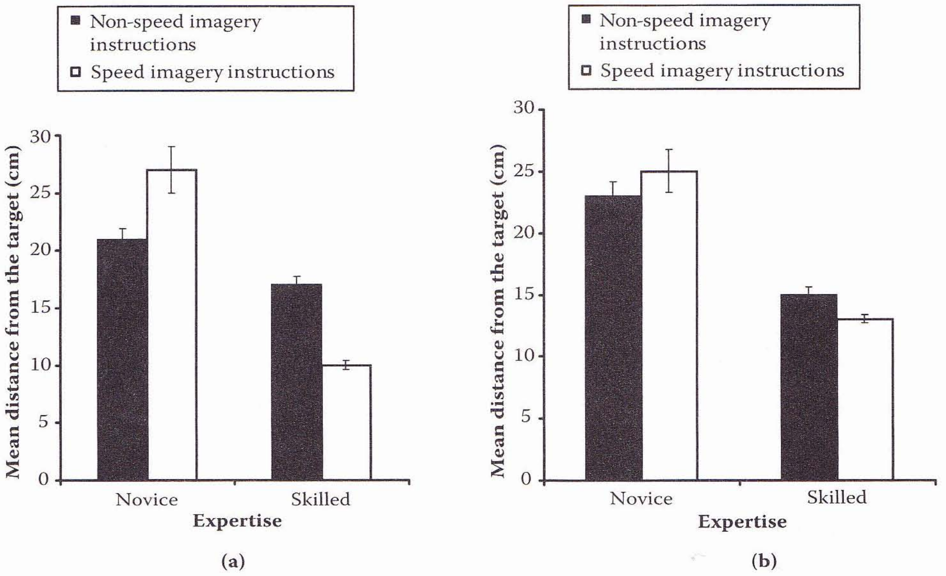


FIGURE 2.1 (a) Mean distance (cm) from the center of the target that the ball stopped after each putt following the nonspeed and speed putting instructions for the novice and skilled golfers. (b) Mean distance (cm) from the center of the target that the ball stopped after each putt following the nonspeed and speed imagery instructions for the novice and skilled golfers. Error bars represent standard errors. (Reprinted from S. L. Beilock and S. Gonso, *The Quarterly Journal of Experimental Psychology*, 2008.)

have similar yet independent effects on overt performance outcomes in a manner dependent on an individual's level of golf expertise.

One might wonder whether the impact of motor imagery on golf putting performance could be accounted for by imagery-induced alterations in putting time. That is, did individuals merely putt faster following speeded imagery instructions, which in turn impacted their performance outcomes? Putting time (defined as the time from when individuals put the ball on the starting position to ball contact) did not differ as a function of whether putts occurred after speeded imagery or nonspeeded imagery, ruling out the possibility that the impact of imagery on putting performance outcomes was merely due to imagery-induced alterations in putting time.

EXPERTISE AND COVERT MENTAL SIMULATION

In the preceding section, we explored the cognitive and neural substrates governing the *explicit* mental simulation of action (often termed motor imagery) and asked how this may differ as a function of skill level. We also considered the implications of functional equivalence between imagery and action in terms of skill-level differences in the impact of motor imagery on performance. In this next section we move beyond explicit or overt motor imagery and instead examine expertise differences in the automatic and covert mental simulation of action—even when there is no intention to act. Such work demonstrates that motor skill expertise carries implications beyond the playing field, having an impact on phenomena as diverse as language comprehension and one's preferences for particular objects they encounter in their environment.

LANGUAGE COMPREHENSION

Rather than our representations of objects and events, we read about being limited to amodal or propositional code that is arbitrarily related to the concepts it represents, language comprehension appears to be interconnected with the sensorimotor experiences implied by the text one reads or the words one hears spoken. Support for this assertion comes from a number of different findings. For example, when individuals make sensibility judgments about sentences by pushing a button that is either close to or far away from their bodies, the sentence's implied action direction interacts with the direction of the response (Glenberg & Kaschak, 2002). For instance, reading the sentence "Close the drawer" increases the time needed to respond with a movement directed toward the body (the opposite direction of the implied action) relative to a response involving movement directed away from the body (the same direction as the implied action). Similarly, sensibility judgments of sentences such as "Can you squeeze a tomato?" are facilitated when participants are primed with an associated hand shape (a clenched hand) relative to an inconsistent hand shape (a pointed finger; Klatzky, Pellegrino, McCloskey, & Doherty, 1989). Reading about performing a motion-directed act (e.g., "Eric turned down the volume") has also been shown to activate motor plans associated with actually producing this action (a counterclockwise hand movement; Zwaan & Taylor, 2006). This interaction between the actions implied by language and motor behavior performed concurrently with comprehension has been taken to suggest that language comprehension is interconnected with the systems involved in the understanding and planning of actions (Barsalou, 1999; Glenberg & Kaschak, 2003).

Converging evidence from cognitive neuroscience supports this idea. For example, reading action words associated with the leg and arm (e.g., "kick," "pick") activates brain areas implicated in the movements of these body parts (Hauk, Johnsrude, & Pulvermüller, 2004), and reading action-related sentences such as "I bit the apple" or "I kick the ball" activates the same areas of premotor cortex as those activated during the actual movement of mouth and leg effectors, respectively (Tettamanti et al., 2005). A recent study using transcranial magnetic stimulation (TMS) suggests that activation of the motor substrates governing the actions one reads about (i.e., motor resonance) is actually an important component of comprehension rather than a superficial by-product. Pulvermüller and colleagues (Pulvermüller, Hauk, Nikolin, & Ilmoniemi, 2005) found that when stimulation was applied to arm or leg cortical areas in the left hemisphere, lexical decisions to words denoting arm or leg actions were, respectively, facilitated. This finding suggests that these motor-related cortical areas play an important role in understanding linguistic descriptions of body-relevant actions.

To the extent that our comprehension of action-related language is grounded in the systems that support action execution, then those who have experience interacting with the objects and performing the actions they read about may represent this information very differently than those who do not have such experience. Despite demonstrations of motor resonance in language comprehension, little work has explored whether differences in motor skill expertise augment or attenuate these motor resonance effects. In a series of studies, we have been exploring this issue by examining differences in how novice and expert athletes represent both everyday and sport-specific objects and actions they read about.

In a first experiment, Holt and Beilock (2006) had ice hockey experts and novices read sentences describing hockey and nonhockey situations. The nonhockey situations depicted everyday objects and individuals (e.g., "The child saw the balloon in the air"). The hockey situations were hockey specific (e.g., "The referee saw the hockey helmet on the bench"). A picture of a target object was presented after each sentence. Participants judged as quickly as possible whether the target was mentioned in the preceding sentence. The target either matched the action implied in the sentence (match) or did not (mismatch) (see Figure 2.2). The correct response to all target items, whether matches or mismatches, was always "yes." Filler items that were not mentioned in the preceding sentence required a "no" response and were used to equate the number of yes and no responses across the experiment. Although the correct response to all target items was always yes, the action orientation of some items (i.e., matches) corresponded more closely to the action implied in the sentence that preceded these items than the action orientation of other items (i.e., mismatches). Building on the initial logic and work of Zwaan and colleagues (see Stanfield & Zwaan, 2001; Zwaan, Stanfield, & Yaxley, 2002), we hypothesized that if individuals mentally represent per-

Non-hockey sentence **Picture**

Scenario 1:

(A) The child saw the balloon in the air. (A)

(B) The child saw the balloon in the bag. (B)

Scenario 2:

(A) The woman put the umbrella in the air. (A)

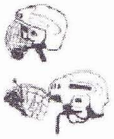
(B) The woman put the umbrella in the closet. (B)

Hockey sentence **Picture**

**Scenario 1:*

(A) The referee saw the hockey helmet on the player. (A)

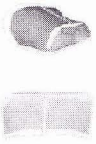
(B) The referee saw the hockey helmet on the bench. (B)



***Scenario 2:*

(A) The fan saw the hockey net after the player slid into it. (A)

(B) The fan saw the hockey net after the puck slid into it. (B)



*Helmet has different configuration depending on whether or not it is on a player.

**Net is either knocked over or upright depending on who or what collides with it.

FIGURE 2.2 Examples of experimental stimuli. Picture A serves as a "match" for Sentence A and a "mismatch" for Sentence B. Picture B serves as a "match" for Sentence B and a "mismatch" for Sentence A. (Reprinted from "Expertise and Its Embodiment: Examining the Impact of Sensorimotor Skill Expertise on the Representation of Action-Related Text," L. E. Holt and S. L. Beilock, 2006, *Psychonomic Bulletin & Review, 13,* 694–701.)

ceptual qualities and action possibilities of the information they comprehend linguistically, then responses should be facilitated for matches relative to mismatches.

We predicted that both novice and expert hockey players would show the match-mismatch effect (i.e., responding faster to items that matched the action implied in the preceding sentence versus items that did not) for *nonhockey* objects and individuals because both novices and experts presumably have the same amount of knowledge and experience interacting with such everyday items. This result would replicate Zwaan et al.'s (2002) work in which only common objects were examined. However, if experience has an impact on the mental simulation of actions one reads about, then individuals with hockey expertise should show the match-mismatch effect for the hockey-specific items, while hockey novices should not.

Both novice and expert hockey players were able to understand the sentences they read (as indicated by high accuracy levels). In addition, participants responded faster to everyday items that matched the action implied in the preceding sentence versus those that did not, suggesting that participants' representations contained information about the sensorimotor qualities of the objects and individuals they read about. However, only those with hockey knowledge and experience showed this effect for the hockey scenarios. This finding is consistent with the hypothesis that a highly specific set of motoric experiences (e.g., athletic expertise) plays an important role in mediating the effect of the mental simulation of action on language comprehension.

In a second experiment, Holt and Beilock (2006) presented novice and expert football players with pictures of football players performing actions that either matched or did not match actions implied in preceding sentences. Critically, we manipulated the extent to which the action implied in the sentence was football specific (an action one would only perform were one a football player, e.g., a quarterback handing off to a receiver) versus not football specific (an action performed by a football player but that everyone should have performed in the past, e.g., a football player sitting down on a bench). Embedding both football-specific actions and non-football-specific (everyday) actions within the domain of football provides a stronger test of the prediction that knowledge and experience performing an action lead to covert action simulation when reading about that action. This is because even novices in a given domain should show evidence of this type of representation, provided they have experience performing the action in question. Under this view, both novices and experts should respond faster to a picture of a football player performing an everyday action that matches the action implied in a preceding sentence relative to a picture of an action that does not. In contrast, for football-specific actions, only those who have knowledge and experience performing the action should show the effect. This is exactly what was found. Thus, the ability to differentiate action orientations (suggesting one is representing sensorimotor information associated with the objects and individuals they are reading about) is not just a function of general domain knowledge but is dependent on specific experience one has performing the actions and interacting with the objects in question.

These findings are consistent with the idea that action possibilities are activated and simulated when individuals perceive specific objects or events, with this link dependent on the extent to which one has experience performing such actions. However, it should be noted that these results could be explained by a purely perceptual simulation of the sentences that involves no contribution from the motor system at all. We have turned to fMRI as a means to address this issue.

When listening to hockey-related action sentences, if hockey experts are mentally simulating the actions in question, they might show greater activation in motor-related regions of cortex relative to nonaction sentences. Novices would not be expected to show this pattern of activity. The specific pattern of neural activation obtained will help to elucidate precisely which components of the motor system underlie an experience-dependent influence of the mental simulation of action on language comprehension (or if the motor system is involved at all). Moreover, another interesting question that fMRI techniques may help to elucidate concerns whether those who have extensive visual experience watching actions (e.g., sports fans) but no actual playing experience show patterns of neural activation when comprehending hockey-action sentences more similar to novices, experts, or neither. Thus, the influence of visual and motoric expertise on language processing can be directly compared at the neural level—an important step in understanding how various forms of skill acquisition contribute to the read-about off-line representation of actions.

In a study aimed at addressing the issues outlined, we recruited hockey novices (who had neither hockey-playing nor hockey-watching experience), hockey experts (Division I intercollegiate hockey athletes), and hockey fans (who were carefully screened to have no hockey-playing experience but extensive hockey-watching experience). During fMRI scan acquisition, all subjects listened to sentences describing hockey actions (e.g., "The hockey player received the pass") and nonhockey actions (e.g., "The individual pushed the doorbell"). No overt behavioral task was performed in the scanner to prevent contaminating activation patterns related to comprehending the sentences with activation corresponding to stimulus-driven responses or overt preparation to perform the action described.

After exiting the scanner, individuals performed a version of the behavioral task used by Holt and Beilock (2006) described in this section. Specifically, participants were presented with the same hockey and nonhockey action sentences they had listened to during scanning followed by presentation of pictures of individuals performing actions that either did or did not match those implied in the sentence. We were interested in whether the match-mismatch effect found in Holt and Beilock (2006) for hockey stimuli varied as a function of hockey experience (i.e., fans, experts, novices) and how it related to neural activation when merely listening to hockey-action sentences.

All participants responded faster to pictures that matched the everyday actions implied in the sentences versus pictures that did not (i.e., the match-mismatch effect), replicating the work of Holt and Beilock (2006). This was not the case for the hockey actions. Only hockey players and hockey fans showed a match-mismatch effect for hockey-related sentences. Novices showed no difference in their response times for hockey action pictures that matched the action implied in the sentence versus those that did not.

To further elucidate the role of expertise in motor simulation and language comprehension, it is necessary to relate the neural activation observed while participants listened to hockey-action sentences with the aforementioned behavioral results. Interestingly, both ice-hockey experts and fans showed greater activation for hockey-action relative to nonhockey action sentences in a premotor region devoted to the planning and selection of actions (left lateral PMd). Novices did not show this pattern of activation, and activation for novices in this region while listening to hockey-action sentences was significantly less than both hockey players and hockey fans. Moreover, left PMd activity during hockey-action sentences positively correlated with the postscan behavioral task (i.e., the difference in response time to pictures that matched the hockey action implied in the sentence versus those that mismatched). Specifically, those individuals showing the greatest match-mismatch effect for hockey-related sentences showed the greatest amount of activation in the PMd region specifically for hockey-action sentences. Such results suggest that when individuals with either motor or visual expertise listen to domain-relevant action sentences, they recruit premotor regions involved in the planning and coordination of action execution. Although one might be surprised that hockey fans (with no playing experience) activated motor-planning areas when listening to hockey action sentences, such effects are consistent with work suggesting convergence in the systems used to perceive and perform actions (such as work on the human "mirror system"; for a review, see Garbarini & Adenzato, 2004). That is, the visual experience the hockey fans have may result in the recruitment of premotor areas involved in higher-level action planning when fans hear hockey actions described—at least more so than novices who have had no hockey-playing or -watching experience.

Together, these behavioral and neurophysiological findings suggest that we represent our surroundings, at least in part, via covert mental simulation of how we might execute an observed behavior or act on the objects we encounter, and importantly, that these simulations can differ as a function of one's action experience in a particular domain. Nonetheless, can we broaden this conception of bodily influence to include more than just the representation of action? That is, does the mental simulation of action serve functions beyond comprehension? The answer appears to be "yes." For example, by calling on and simulating one's own action-related experiences, one may better understand the actions, intentions, and goals of others—a potentially crucial component of social interaction (Decety & Grezès, 2006; Wilson & Knoblich, 2005). Moreover, simulation of such experiences can affect both the on-line interaction with and off-line representation (i.e., in the object's absence) of social objects (for a review, see Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005). Next, we consider work showing that automatic simulation of specific motor experiences can even influence one's preferences for stimuli in their environment.

PREFERENCE JUDGMENTS

If (a) individuals mentally simulate acting on the objects they perceive in their environment, (b) this mental simulation of action differs as a function of skill level, and (c) people prefer to act in ways that create less motor interference, then (d) individuals should report *liking* objects that are easier to act on—even though they have no intention to act. That is, the mental simulation of action may go beyond having an impact on representation and comprehension, influencing individuals' preferences for the stimuli they encounter. In an attempt to test these ideas, Beilock and Holt (2007) presented skilled and novice typists with two separate letter dyads on a screen and asked participants to indicate the dyad they preferred (Beilock & Holt, 2007). The dyads fell into one of two categories: dyads that would be typed with the same finger using standard typing methods (e.g., FV) or dyads that would be typed with different fingers (e.g., FJ). Each dyad pair always involved one dyad from each category, a paradigm first used by van den Bergh, Vrana, and Eelen (1990). Because typing is thought to involve the overlap of successive key strokes (Rumelhart & Norman, 1982), typing two letters with the same finger should result in more motor interference than typing two letters with different fingers, as the former case requires that the same digit essentially be in two places at once (or in very close succession).

As can be seen in Figure 2.3, skilled typists preferred dyads typed with different fingers (i.e., dyads *not* functionally incompatible) significantly more than chance. Novices did not show this preference. Importantly, participants were unaware of the link between our study and typing, and when asked, could not explicate how the letter dyads typed with the same versus different fingers differed. Why might skilled typists show the letter dyad preference that novices do not? If typing experience results in an association between specific letters and the motor programs used to type them and perceiving letters results in the activation of these motor plans (Prinz, 1997; Rieger, 2004), then such covert simulation of typing should provide information about the relative interference involved in acting on the letters presented. Moreover, if individuals prefer to act in ways that reduce interference, then they should prefer letter dyads that, when enacted, produce the least amount of motor interference.

To explicitly test these claims, while making their preference judgments on some trials in a first experiment, participants held a typing pattern in memory that involved the same fingers that would be used to type the presented dyads. If holding this pattern consumes the motor system in such a way that it can no longer inform typists' preference judgments, such preferences should disappear. As can be seen in Figure 2.3, this is exactly what was observed. A second experiment showed that this motor interference was specific to the digits actually involved in typing the dyads. When expert typists held a motor pattern in memory involving fingers *not* used to type the dyads, the preference remained (see Figure 2.3). Thus, covert mental simulation of acting on the information one is

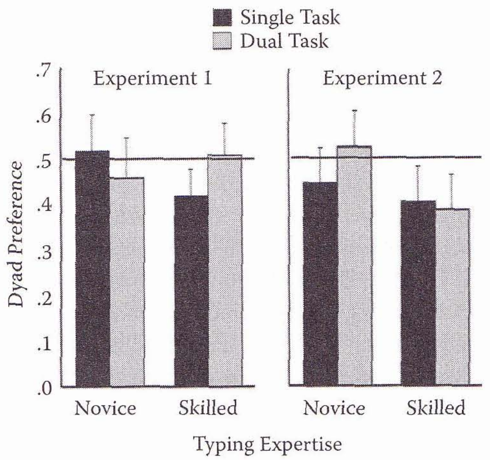


FIGURE 2.3 Letter dyad preferences in the single-task and dual-task blocks for novice and skilled typists in Experiments 1 and 2. The dark line at .5 represents chance. Error bars represent 95% confidence intervals. (Reprinted from "Embodied Preference Judgments: Can Likeability Be Driven by the Motor System?" by S. L. Beilock and L. E. Holt, 2007, *Psychological Science, 18,* 51–57.)

presented with not only has an impact on preference judgments but also is limited to information motorically resonant with the specific effectors involved in the simulated action.

IMPLICATIONS FOR THE ACQUISITION OF EXPERTISE

The behavioral and neurophysiological findings presented thus far suggest that we represent our surroundings, at least in part, via covert mental simulation of how we might execute an observed behavior or act on the objects we encounter. Moreover, by considering the influence of motor skill expertise on such simulations, we see the robust nature—and wide-ranging influence—mental simulation can have on cognitive tasks with no overt action component. These findings carry implications for understanding what makes an expert performer different from his or her novice counterpart, and they also shed light on how best to teach complex skills (with and without overt motor components) to others.

For example, motor imagery has been widely used as a rehabilitation technique for stroke and other patients who wish to regain finer motor control in certain tasks (for a review, see Dickstein & Deutsch, 2007). Motor imagery has also been used to train surgeons in complex surgical procedures (Hall, 2002; Rogers, 2006), to promote the learning and retention of complex athletic tasks (Driskell, Copper, & Moran, 1994; Feltz & Landers, 1983; Martin, Moritz, & Hall, 1999), and for the transfer of motor skills. For example, Gentili, Papaxanthis, and Pozzo (2006) demonstrated that imagery training using one arm can transfer to improved performance using the opposite arm. Mentally simulating an action, as reviewed in this chapter, is thought to activate the neural substrates involved in action production. It is perhaps not surprising, then, that simulation of certain actions benefits subsequent performance. Nonetheless, the full potential of this finding has yet to be exploited, not only as a rehabilitation or motor-learning technique but also as a potential means of acquiring more complex cognitive skills that do not involve overt action components, such as reading comprehension or spatial reasoning (see also Kosslyn & Moulton, Chapter 3, this volume).

Moreover, it is not just the explicit mental simulation of action that can improve performance. Action observation can result in improved performance as well. Vogt (1995) found that either observing or performing sequential arm movements resulted in similar improvement in the temporal consistency of executing such movements, suggesting that, in some cases, action observation facilitates subsequent motor performance as much as action production itself. In terms of higher-level cognitive skill learning, Glenberg and Robertson (1999) demonstrated that individuals more readily learned to operate a compass when they read about its operation *and* watched an actor physically enact the operation in comparison to individuals who only read about the actions. Although both groups gained similar levels of knowledge concerning compass operation, the group who watched the individual act on the object ultimately performed at the highest level on a subsequent novel compass navigation task. If watching an individual operate a compass results in the mental simulation of action in the perceiver that captures the action possibilities the compass affords, then subsequent performance should be facilitated in comparison to conditions in which such action possibilities are not made salient—exactly what was found.

Finally, the above-mentioned observation and imagery learning effects not only apply to skills with explicit action components (e.g., athletic tasks) but also can carry implications for the learning of skills that involve no overt action. Glenberg, Guttierrez, Levin, Japuntich, and Kaschak (2004) found that when first- and second-graders either manipulated or mentally simulated acting on objects described in the text they read, they showed markedly better comprehension and later memory for the text in comparison to children who simply reread the text without actively simulating its content. Thus, learning that involves the mental simulation or observation of action improves comprehension and retention of action-related text. And, as reviewed in this chapter, such learning is likely the result of activation of the neural substrates that are involved in performing the actions one reads about, activation that provides an elaborate and robust situational representation that aids in comprehension and retention.

CONCLUSIONS

At the beginning of this chapter, we posed the question of what makes an expert different from his or her novice counterpart. Although there is a large body of research that examines on-line performance as a means to understand skill-level differences, we have begun to look at the off-line mental simulation of action as a means to understand expertise. Our current work, as well as related work from other laboratories, reveals that skill expertise is not merely reflected during the actual unfolding of performance, but can also be seen off-line in terms of the ability to mentally simulate skill-relevant actions. We began by reviewing work suggesting a strong degree of functional equivalence between motor imagery and overt execution and then asked whether imagery content might differ as a function of one's skill level or whether motor imagery might have an impact on performance differently for expert and novice individuals. We then moved on to work demonstrating that one need not be explicitly attempting to act in order to call on the motor systems used during the actual execution of a given task. We demonstrated skill-level differences in covert action simulation during text and speech comprehension and showed how such simulation differences can have an impact on one's explicit preference judgments for the particular objects one encounters. Together, this work suggests that understanding how experts imagine executing and cognitively represent the actions they have mastered may prove just as important for the study of skill learning and performance as understanding how skilled actions themselves are produced.

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