Embodied Cognition and Sport

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Successful athletic performance requires precision in many respects. A batter stands behind home plate awaiting the arrival of a ball that is less than three inches in diameter and moving close to 100 mph. His goal is to hit it with a bat that is also less than three inches in diameter. This impressive feat requires extraordinary temporal and spatial coordination. The sweet spot of the bat must be at the same place, at the same time, as the ball. A basketball player must keep a ball bouncing as she speeds from one end of the court to another, evading defensive players. She may never break pace as she lifts from the ground, throwing the ball fifteen feet toward a hoop that is eighteen inches in diameter.

Familiarity with professional-level play might lead one to lose sight of the exactness of the skills involved. For a good and amusing remedy to this, watch a few minutes of the Robocup. This annual soccer tournament matches teams consisting of the most technologically advanced robots on Earth. The robots shuffle around the field, slowly. They occasionally bump into each other, causing one or both to fall down. While a human soccer player moves smoothly toward a ball, never breaking stride as he controls it with his foot until lofting a pass to a player downfield, the robot's encounter with the ball is anything but fluid. It stops in front of the ball, inspecting it as though it's some unknown object that's just fallen from outer space. It bounces from foot to foot before carefully orienting itself *just so*. The kick, when it finally comes, sends the ball rolling a few feet, typically in a random direction. If it hasn't fallen on its butt, the robot freezes, it's work done.

Although athletes differ from non-athletes in the finesse they bring to particular situations, we must all of us move our limbs and torso and head so that we walk smoothly, reach accurately, bend and twist appropriately, and keep our eyes fixed on objects as they move past us. Thus, one task facing a psychologist involves explaining how the body does such things within the sometimes very demanding spatial and temporal constraints that a given task imposes. Part of the goal of this chapter is to sketch the commitments of an *embodied* approach to such an explanation. We shall see that an embodied account of motor skills draws concepts that depart radically from more traditional cognitivist theories of motor activity. Similarly, because an embodied approach to cognition introduces new ways to understand the human capacity for social interaction, it also promises to shed new light on how athletes coordinate their actions with each other.

1. Themes of Embodiment

"Embodied Cognition" is best understood as a label for a diverse research program that spans work across the cognitive spectrum, including memory (Glenberg 1997), perception (O'Regan and Noë 2001), language (Kaschak, *et al.* 2005), and emotion (Barrett 2012) (see Shapiro 2014a for a representative collection). Additionally, it takes as its subject matter not just human beings, but simple organisms such as crickets (Webb 1996), simulated agents (Beer 2003), and robots (Brooks 1991). Given its breadth, the job of offering a succinct characterization of embodied cognition faces obvious difficulties.

Yet another challenge besets efforts to articulate the distinctive character of embodied cognition. Traditional cognitive psychology, not to mention many of its scientific predecessors, recognized the body's significance in thought processes. Indeed, Descartes, famous for his distinction between mind and body, nevertheless denied that the relationship between mind and body is simply like that of sailor in a ship. Rather, he insisted, "I am most tightly joined and, so to speak, commingled with it, so much so that I and the body constitute one single thing." (1641/1993:

53). Granting that investigations of cognition have, for centuries, acknowledged close ties between mind and body, a natural question arises: What new or novel connections between mind and body has embodied cognition discovered?

One of us (Shapiro 2008, 2011, 2012) has sought to respond to both worries above – how to limn the boundaries of embodied cognition given its wide scope and how to isolate those features of embodied cognition that mark it is a new approach to psychology – by describing various "themes" that pop up repeatedly in the various areas that embodied cognition researchers investigate. One such theme is Conceptualization. Research that supports conceptualization reveals that the properties of a body constrain and thus influence how an organism conceives of its world. This idea builds on the Gibsonian notion of an affordance (Gibson 1979). Gibson argued that organisms perceive their environments in terms of how they may interact with the objects they encounter. Thus, a branch that a bird perceives as something to perch on might be perceived by a monkey as something to swing from. A prominent area of embodied cognition – enactivism – takes this Gibsonian suggestion further, arguing that the perceived world is a consequence of the actions the body takes toward it. (O'Regan & Nöe 2001, Nöe 2004). Thus, insofar as different kinds of organisms have different kinds of bodies, and different kinds of bodies interact with the world in different ways, differently embodied organisms perceive, and thus conceive, of the same world in different ways. We shall take up the Conceptualization theme in the final section of this chapter, where we discuss work that reveals athletes to possess special perceptual abilities as a result of their training.

A second theme of embodiment Shapiro describes is Constitution. Claims concerning constitution are especially common in an area of embodied cognition devoted to showing how cognition might extend beyond the brain. Much of this research focuses less on the actual body's contribution to cognition than it does on the use of external "props", such as calculators or diaries, to enhance cognition. For instance, Clark and Chalmers (1998) imagine a scenario involving a man, Otto, who relies extensively on his diary in order to compensate for the loss of his "natural" memory. On their view, the entries in the diary constitute actual memories, no less authentic than those that once would have been stored in Otto's hippocampus. More generally, those who pursue the idea of Constitution seek to show how parts of the world might be recruited to become parts (constituents) of a cognitive system. The challenge these researchers face is to defend the claim that parts of the world qualify as actual *constituents* of cognition rather than mere causal influences on cognitive processes that remain completely "brain bound" (see Adams and Aizawa 2008 and Rupert 2009 for criticisms). Failure to make the case for constitution over causation opens these researchers to the second worry we expressed above: they have not identified anything novel about embodied cognition because psychologists have long known that the world causally contributes in numerous ways to cognitive processes.

The third theme, Replacement, shall be the focus in the section below. The basic idea behind Replacement is that features of embodiment work to facilitate cognition in previously unrecognized ways. Replacement departs from traditional cognitive psychology in eschewing its strong commitment to a computational theory of mind, according to which cognition is an entirely computational process that involves the operation of algorithms over representational states, and in seeking to replace computationalism with something else (e.g dynamical systems theory). In its most radical form, Replacement advances the idea that thought processes involve no representational states at all, and thus have no need for computational processes (Shapiro 2013). Surely this claim goes too far, offering no positive account of how to construe cognitive capacities such as memory or planning in a non-representational format (see Shapiro 2014b for discussion). More mildly, and promisingly, advocates of Replacement see the body as "stepping in" to do work that once would have been attributed to computational processes. It is to this milder strain of replacement we now turn.

2. From Programs to Bodies

As the behaviorism that dominated psychology in the middle part of the twentieth century gave way to computational theories of cognition, psychologists interested in bodily movement endorsed the idea that such movements were under the control of a *motor program* (Keele 1968; Schmidt 1976). Schmidt, a significant figure in the development of the motor program concept, summarizes the view:

> The program is generally thought to contain a centrally stored, prestructured set of muscle commands that are capable of carrying out movement without feedback information about the achievement of the environmental goal. Viewed this way, the program must determine which muscles contract, in what order, with what force, and for how long…(1976: 242).

Although the motor program concept evolved over the course of continued investigation, the basic idea (still with us today, as in Neilson and Neilson 2005) maintains a strong commitment to a computational theory of cognition. The motor program is, in a fairly literal sense, a computer program. It contains instructions written in a language of thought that the nervous system must first read and then execute. "Before we reach out for an object," Ghez explains, "our nervous system must first select a motor program that specifies (1) the sequence of muscles needed to bring the hand to the desired point in space and (2) how much each muscle must contract" (1985, p. 494). Presumably, Ghez would claim, the nervous system of the batter we mentioned above would have selected a series of commands that caused the muscles in the batter's arms to flex and extend in just the right way to produce a base hit.

The motor program approach to explaining muscle control is in keeping with the more general computational theory of cognition that retains prominence in most psychology departments today. Memory, for instance, might be analyzed in terms of stored representations that are recalled for current inspection; processes of language production tap into representations of grammatical rules that dictate the form of linguistic structures; vision involves the application of algorithms to information derived from the retinal image. Although proponents of embodied cognition have sought to challenge computationalism as it plays out across the broad domain of psychology, of special interest in the present context is the embodied response to motor programs. If muscle control is not under the direction of a program that the nervous system executes, from where does the control come?

Crucial to answering this question is, from an embodied perspective, rejection of the idea that control must come from a controller. Various research programs within embodied cognition seek to show that muscle control emerges from tight interactions between the body, the nervous system, and the environment. Notions central to the computational theory of cognition – program, representation, executor – are discarded, to be replaced with notions better suited to describe the continuous interactions between brain, body, and world. Often, these new notions draw from the conceptual resources of dynamical systems theory.

Well-studied in this context is the development of stepping behavior in infants. A behavior such as walking requires delicate coordination between two legs. It is easy to take for granted that the legs of walking bipeds must move 180 degrees out of phase relative to each other (Thelen & Ulrich 1991: 60). But, of course, there are many more ways for stepping to go wrong than to go right. The legs might move in parallel, as they would if hopping. One leg might move at a slower frequency than another, or with a larger amplitude. Moreover, each leg contains over a dozen muscles. There are joints at the hip, the knee, and the ankle. Designing a motor program that maintains control of all of these factors, coordinating them with the precision necessary to produce a fluid gait, would be no easy task.

Progress in understanding how the nervous system accomplishes this difficult feat begins with the realization that a leg can be treated as a spring with a certain tension and weighted by a specific mass. Just as a spring will equilibrate to the same length given any initial stretching or compression, so too the musculature of the leg insures that it will tend toward a particular orientation regardless of its displacement. Thelen and Ulrich (1991) tested this idea with seven-month-old infants, who, when held above a treadmill so that the soles of their feet could touch the moving belt, engaged in stepping behavior. They conjecture that "the mechanical pulling of the leg backward stretches the leg muscles and allows them to store energy, much like stretching a spring beyond its equilibrium point. When the leg is stretched to its anatomical limit, it uses this stored energy to spring forward" (1991: 43).

Of course, the development and production of stepping behavior in human beings cannot, as it might be in the "passive walkers" that roboticists have created (Collins, *et al.* 2005), be attributed solely to the interaction of the spring-loaded legs with the environment. The effect of the moving treadmill belt on the legs does not account for why the legs adopt a pattern of stepping in which they adopt the necessary 180 degree out-of-phase motion. The nervous system must be involved in such calibration. But the contribution the nervous system makes to stepping behavior should not be taken to diminish the extent of the departure from a motor program explanation of motion that work like Thelen and colleagues' presents.

In the first place, conceiving of the legs as weighted springs that, in effect, oscillate like pendula, opens the way for recruiting a new explanatory framework for understanding limb movements. In particular, the language of dynamical systems, with its reference to state spaces, attractors, and control variables – concepts useful for characterizing the behavior of systems like pendula that change over time – lends insight into behavior that would otherwise have been forced into a computational framework of dubious appropriateness. Thelen and Ulrich, for instance, identified the alternating pattern of stepping behavior on the treadmill into which 7 month old infants settled as an attractor point. Because the behavior of a dynamical system heads toward an attractor point from various initial conditions, Thelen and Ulrich predicted that infants' stepping would "resolve" into the alternating step pattern despite perturbations to the system. After inducing several perturbations – one in which the treadmill speed was increased, another in which a split treadmill caused the infants' legs to move at different speeds – Thelen and Ulrich confirmed their prediction. The alternating step attractor "pulled" the initially disrupted stepping behavior back into stability (1991). This example displays how dynamical systems theory can be applied to a domain once thought to be most fruitfully investigated from a computational perspective.

The example also highlights a prominent theme within embodied cognition literature. We mentioned above that the nervous system remains an important contributor to stepping behavior. Maintenance of the anti-phase motions of the legs seems to require that information about the state of one leg regulate the state of the other (Thelen & Ulrich 1991: 61). But, even if a computational description of how such information is processed turns out, in the end, to offer the best understanding of this particular feature of stepping behavior, one must not lose sight of how recognition of the body's physical properties constrains and minimizes candidate motor program explanations. This idea illustrates the Replacement theme we introduced in the previous section.

Replacement, in this case, involves the elimination of computational processes in favor of simple mechanics. We noted already that the leg contains over a dozen muscles and three joints. A motor program that succeeded in controlling the behavior of these components and synchronizing them with the same number of components in the other leg would, doubtless, require sophisticated and elaborate neural computations. How much simpler the task becomes when conceiving of the legs as simple springs! Because springs behave as they do in virtue of their tension and mass, there is no need for motor program to guide their behavior – no more need than there is for a motor program to guide the behavior of a slinky as it descends a staircase. And, to the extent that computation is necessary for tasks such as calibration of the two legs, the conception of the legs as single spring-like units reduces the complexity of the algorithms needed to control their behavior. As Thelen, Kelso, and Fogel note, "The dynamic conceptualization allows, in short, for much less information to be abstractly represented, and much more information in the sense of a wide variety of trajectories to come 'for free.'"(1987: 45).

We see, then, one way in which an embodied approach to cognition might contribute to an understanding of athletic performance. Examination of the mechanical properties of the body suggests ways in which certain tasks, once thought to require computational solutions, might be better explained with a non-computational alternative. Such an explanation replaces computational talk with descriptions of the dynamical behavior of the body. The batter who connects with the ball speeding toward his chest does something fantastically complicated, no doubt; but, it turns out, the task is less computationally demanding as one might first have supposed. The batter's arms are, after all, physical objects whose motion is subject to the same sort of dynamical analysis that emphasizes the mechanical – in contrast to computational – forces at work in an infant's stepping behavior. On this conception, the role of the motor program shifts from omniscient planner, responsible for controlling the contraction and extension of individual muscles, to opportunistic cobbler, taking advantage of the dynamical properties that muscles, bones, and joints bring for free.

If an embodied perspective on bodily movement reveals how the brain's computational burden might be reduced by taking advantage of the body's natural dynamics, so too does a focus on embodiment show perceptual processes to be far less computationally expensive than traditional cognitive science would suppose. Wonderfully illustrative of this embodiment-inspired shift from computational explanations of perception is research that investigates how an outfielder manages to catch a fly ball. That outfielders – amateurs as well as professionals – seem to have little difficulty tracking a ball from the instant of its impact with a bat to the second before it hits the ground, which may involve a distance of over 100m, appears to be quite a marvel. Somehow, the outfielder manages to position himself exactly where he needs to be to intercept the ball. Moreover, given the initial distance between the outfielder and the ball, cues that might be useful for depth perception, such as parallax and disparity, are ineffective.

One way to explain how the outfielder maneuvers his body to just where it needs to be treats the task as a difficult computational problem. The idea is that the outfielder makes a prediction about the trajectory the ball will take after impact with the bat. The inputs to the computation include such things as the force with which the ball was hit, its direction as it leaves the bat, and its speed. But also included in the computation must be factors like wind direction, air resistance, and the ball's spin. This so-called "Trajectory Prediction" explanation of the outfielder's performance assumes that all of these inputs feed into various cognitive systems that then grind through the appropriate computations, returning as output the location where the ball will drop, which is then used to guide the movement of the outfielder.

Of course, this computation-heavy explanation of how an outfielder intercepts a fly ball is possible in principle. But research suggests that outfielders are in fact not very good at predicting the trajectory a ball will take (Shaffer & McBeath 2005). Psychologists who study the outfielder problem have largely abandoned computational solutions in favor of those that assign a prominent role to the outfielder's ability to track continuously a single variable. The outfielder moves his body in such a way as to keep this variable constant, or invariant.

One such explanation, Linear Optical Trajectory (LOT), requires that the outfielder position himself so that the fly ball, which in fact has a parabolic trajectory, will appear to ascend in a straight line from home plate (see Figure 1). Once having situated himself in a position where the ball's trajectory appears to be a straight line, the outfielder will in the exact location he needs to be to catch the ball. As Andy Clark describes the LOT method, "[i]nstead of using sensing to get enough information inside, past the visual bottleneck, so as to allow the reasoning system to 'throw away the world' and solve the problem wholly internally, it uses the sensor as an open conduit allowing environmental magnitudes to exert a constant influence on behavior" (Clark 2007: 266, his emphasis).

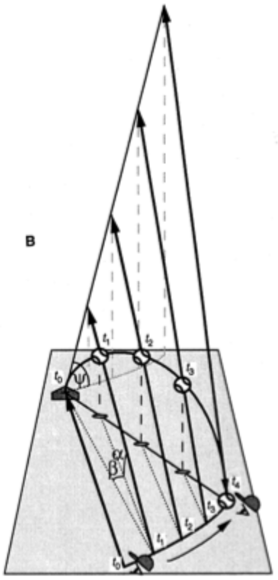

Figure 1: The ball's trajectory is parabolic, but the outfielder's motion can make it appear linear and ascending (McBeath, Shaffer, and Kaiser 1995).

Competing with LOT is an alternative explanation that, while sharing LOT's emphasis on the outfielder's need to track a single variable, chooses a different variable. According to Optical Acceleration Cancellation (OAC), the outfielder must position himself so that the upwards acceleration of the ball is fixed at a constant rate. Deviation from a constant rate provides the outfielder with cues that allow him to adjust his location relative to the ball. If the ball's acceleration appears to slow as it climbs upward, the outfielder must move forward to catch it. On the other hand, if the ball's acceleration appears to increase, the outfielder must move backwards to catch it (see Figure 2).

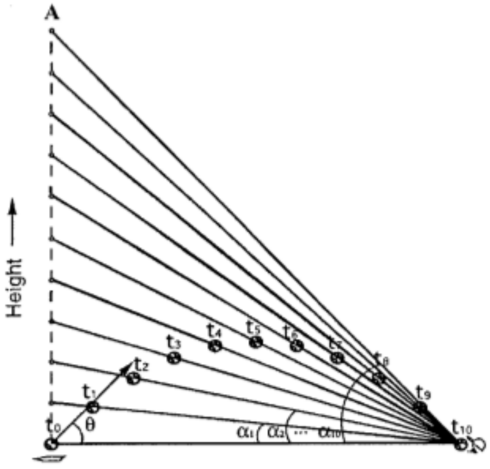

Figure 5: The outfielder will intercept the ball when making its upwards acceleration appear constant, i.e. to be rising equal distances in equal time intervals (Shaffer & McBeath 2002).

Recent evidence suggests that OAC is more likely the strategy that outfielders actually use (Fink, Foo, and Warren 2009), but in the present context, less important than which of LOT or OAC is the correct explanation of the outfielder's performance is the sense in which these explanations offer an embodied alternative to computationally-heavy ones. An explanation like Trajectory Prediction, we saw, conceives of the outfielder's problem as demanding a solution consisting of computations over representations of a large number of variables. The output of the computations will be a prediction of the ball's trajectory, and the outfielder's job is then to move his body to the precise location at the end of the trajectory.

In contrast, both LOT and OAC seek to replace a computational explanation of the fielder's behavior with one that integrates the outfielder's motion into the solution. Through his motion, the outfielder establishes and then maintains continuous contact with a single variable (linear motion or constant acceleration). There is simply no need to represent such things as the ball's initial direction and speed. Factors like wind and air-resistance are rendered irrelevant insofar as they become subsumed within linear motion or constant acceleration. All that matters to the embodied strategies is that the outfielder keeps his body in a position where the ball appears to be moving straight up or with a constant acceleration.

We have seen two examples now where an embodied perspective on sports performance – and performance more generally – marks a departure from more traditional comptutational accounts. In the case of calculating limb movements, the idea of a motor program that computes how muscles must flex and extend in order to move the limb is replaced by dynamical systems approaches that conceive of muscles and limbs as spring-masses or oscillators. As such, limbs will exhibit "for free" certain kinds of behavior, and the job of the nervous system shifts from one of designing and selecting precise motor programs to a vastly simpler one of governing the actions of simple machines with latent patterns of motion that need only to be released and coordinated. In the second case, we see how a body in motion can establish and maintain contact with a single variable, rendering unnecessary the sophisticated computations that a stationary observer would otherwise require in order to accomplish a task such as catching a fly ball. Embodied cognition, as we understand it, thus invites sports psychologists to hunt for explanations of athletic performance that minimize the computational demands on a nervous system that seems better conceived of as a source of control for a body already primed for movement and perception.

3. The Social Aspect of Sports

Above we distinguished three themes of embodied cognition: Conceptualization, Constitution, and Replacement. The discussion of motor programs illustrates the fruitfulness of *replacing* traditional computational explanations with explanations that focus on bodily mechanics.

Here we focus on the social aspect of sports, which provides nice examples of Conceptualization and builds further connections between embodied cognition and sports psychology.

Many sports involve interpreting and anticipating the behavior of other athletes. In basketball, for example, an athlete not only must execute actions in light of her immediate goals and overall game strategy, she also must coordinate her actions with her teammates' complementary actions and opponents' disruptive, incompatible actions. Coordinating her actions with teammates and opponents' actions requires interpreting their behavior and anticipating what they will do next. For instance, she must recognize when an opponent is driving to the basket (as opposed to faking a drive to open enough space to shoot), she must anticipate the positions in which her teammates will be when the opponent is driving to the basket, and decide whether to pursue the driving opponent or let a better positioned teammate step in to defend against the drive. This dynamic interaction happens very quickly, and superior athletes are more highly skilled at coordinating their behavior with teammates and opponents' behavior.

Coordination between executing one's own actions and anticipating others' actions is not unique to team sports. Even in so-called individual sports, such as running, boxing, and karate, the athlete's actions are influenced by what she takes other athletes to be doing. Take running, for example. In a track race, a runner approaches the competition with a general race plan. In most cases, executing the race plan will depend on others athletes' performances. Suppose the race plan is to finish in the top two spots (in order to advance to the next round of competition, for example). The athlete must determine whether the runners around her are struggling more than she is and whether runners that pass her can sustain that pace. She must moderate her own effort so that she has enough energy left to finish strongly at the end of the race all the while making sure she is well positioned in terms of place and effort in relation to the other athletes. As this example shows, individual sports involve coordination between one's own actions and competitors' actions, as well.

Given that many sports involve this social element, the following question arises: How do we coordinate our actions with others' actions in sports? Neuroscientists have discovered that action execution and action observation recruit some of the same neurological systems. More specifically, research on mirror neurons has shown that parts of the sensorimotor system that are responsible for producing planned actions are also partly responsible for interpreting and anticipating others' actions, which suggests that performing a particular action and perceiving that action are closely related skills, realized by the same neural mechanism (Fogassi et al., 2005; Gallese, 2009; Gallese, Keysers, & Rizzolatti, 2004). We describe the action mirror neuron system in more detail below.[1]

The action mirror neuron system consists of the premotor cortex and parts of the posterior parietal cortex, specifically, the rostral part of the inferior parietal lobule and the lower part of the precentral gyrus plus the posterior part of the inferior frontal gyrus. These areas are involved in sensory guidance of movement and the production of planned movements. Scientists have discovered two kinds of mirror neurons in these areas: strictly congruent and broadly congruent mirror neurons (Rizzolatti & Craighero, 2004). Strictly congruent mirror neurons fire for the execution or observation of particular narrowly construed behaviors. For example, a group of strictly congruent mirror neurons will fire only when a subject observes or executes a pincer grasp to pick up an object. These same neurons will not fire when the subject executes or observes a full-hand grasp. Other groups of strictly congruent mirror neurons fire only for full-hand grasps. Broadly congruent mirror neurons, in contrast, fire for the same action less narrowly construed. For example, a particular group of broadly congruent mirror neurons will fire when the subject observes or executes both pincer grasps or full-hand grasps. The same group of neurons will fire when the subject uses its hand to pick up a piece of food to eat or when it observes another subject use a tool to pick up the food to eat. Broadly congruent mirror neurons are both visuo-motor, as the previous

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[1] For more comprehensive overviews of the mirror neuron system, see Rizzolatti and Craighero (2004), Pineda (2009), and Rizzolatti and Sinigaglia (2010).

examples show, and audio-motor. If a subject *hears*, e.g., someone eating food, mirror neurons that correspond to mouth-related actions will fire.

A subset of broadly congruent mirror neurons, so-called logically related mirror neurons, is particularly important for action perception (Csibra, 2007; Iacoboni, 2005; Rizzolatti & Sinigaglia, 2010). These neurons have all the features of broadly congruent mirror neurons and one interesting additional feature: they fire for the end-state of an action sequence even when the end-state is unobserved. For example, logically related mirror neurons fire for the act of grasping an object or, upon observing another's grasping motion, they fire for the motor act of eating. In the first-person case, the neurons fire while executing a certain action, A, but in the third-person case they fire in expectation of B, the probable next behavior in the sequence. Thus, these mirror neurons *predict* or *anticipate* the target's next behavior.

Although there is no consensus on the precise role of mirror neurons in action understanding, the evidence suggests that mirror neurons are at least *part* of the neural substrate of action interpretation and anticipation (Rizzolatti & Sinigaglia, 2010). The activation of strictly congruent mirror neurons provides information about the precise details of the observed action (e.g., that it is a whole-handed grasp), and broadly congruent mirror neurons provide more general information about the observed action (e.g., that it is an eating-related grasp). Logically related mirror neurons function as predictive mechanism for familiar behaviors (e.g., they fire in expectation of eating), thus providing information about the probable next behavior in a sequence. Each kind of mirror neuron provides different information about the observed action, and this information facilitates action interpretation and anticipation of others' actions.[2]

Of course, the patterns of neural activation for action execution and observation do not completely overlap. For example, the observer's brain exhibits various inhibitory responses that

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[2] See Spaulding (2013) for an extended defense of these claims.

prevent the observer from actually performing the action, the actor's brain receives and processes proprioceptive information that the observer's brain does not, and the neural activity in the actor's mirror neuron system is stronger than in the observer's mirror neuron system. Although motor mirror neuron activity may be strong enough to produce covert, unconscious movements, in normal cases the observer does not act exactly as the observed target acts. Nevertheless, the discovery that action observation and execution recruit the very same neurons is an intriguing finding, and it has significant implications for sports psychology.

Putting all of this together, the neuroscientific research on mirror neurons suggests that action observation and execution share a common neural basis, *viz.* the mirror neuron system. Thus, we have at least a partial answer to our question about how action coordination occurs: the same system underlies both production and observation of action. Mirror neurons are deployed one way (in conjunction with other neural systems) when executing an action, and they are deployed another way (in conjunction with other neural systems) when observing others execute that action.

To illustrate how mirror neurons work, we used relatively simple actions, but the same lessons apply to the more complex actions involved in sports. Driving toward the basket and observing an opponent drive toward the basket activate the same neural system. One interesting implication of this tight coupling between motor and perceptual processes is that the more skilled one becomes at performing a particular action the better one will be at interpreting and anticipating the outcome of that action. For example, these findings imply that expert golfers should be better at putting, but they also should be better at perceptually discriminating and predicting the trajectory of others' putts. This implication is empirically substantiated in the literature on sports psychology.

As it turns out, the ability to perceive athletic behaviors differs according to one's experience in producing those behaviors (Shiffrar & Heinen, 2015). Expert athletes are better than novice athletes and mere spectators at interpreting and predicting the outcome of athletic behaviors that are similar to the ones they perform. For example, a professional basketball player can judge more accurately whether or not a player is faking a drive to the basket and whether or not a shot will go in the basket than a novice or spectator can. Female ballet dancers can perceptually discriminate the choreography of female ballet dancers better than male ballet dancers, even though male ballet dancers frequently observe female ballet choreography. In both of these examples, the motor expertise seems to bring about perceptual expertise. And this is just what one would expect given that the same neural system underlies action production and perception.

Focusing on how one's body influences one's perception illustrates a central theme of embodied cognition we introduced above, namely Conceptualization. The idea begins with recognition that through extended practice, athletes' bodies become more adept at executing particular skills. In turn, the brains of these athletes, and in particular their mirror neurons, become tuned to recognizing actions of a particular kind. This tuning enables athletes to perceive movements, or patterns of movement, that remain invisible to novices. Insofar as these perceptual feats reflect abilities to categorize certain motions as, e.g., driving to the basket, or, in ballet, a *saute*, they illustrate the idea of Conceptualization. The athletes see or conceive of the world (or of the motions of individuals in the world) differently than do non-athletes. Were we to focus just on explicating computational motor programs underwriting athletic performance, we would miss this insight.

Importantly, this coupling between athletic performance and perception has implications for sports psychology, as well. The effects of this tight coupling between motor and perceptual processes explain why novice athletes and spectators substantially overestimate their own athletic abilities, a phenomenon known as the Dunning-Kruger effect. The Dunning-Kruger effect is a cognitive bias in which the more knowledgeable and competent one is, the more accurately one assesses one's knowledge and competence. Individuals who are not knowledgeable or competent with respect to some issue egregiously overestimate their own knowledge and competence and fail to recognize others' equal or superior knowledge and competence (Kruger & Dunning, 1999). For example, people who have poor social skills tend to overestimate their ability to figure out what other people are thinking or feeling, whereas those who are more socially skilled give a more accurate assessment of their ability to "read" other people (Ames & Kammrath, 2004; Realo et al., 2003). In general, the deficiency of the less competent is invisible to them because recognizing their deficiency requires the very competency they lack.

In sports, this effect can be observed in the difference between an elite athlete's assessment of his athletic skills and the self-assessment of novices or spectators. The preceding discussion can help us explain how this bias arises. Performing athletic maneuvers in a particular sport increases your ability to perceptually discriminate athletic maneuvers in that sport. Thus, practicing putting makes one better able to assess the difficulty of a particular putt, visually analyze and predict the outcome of the putt, and more accurately assess one's ability to make this putt. Novice golfers and spectators are less adept at visually analyzing the difficulty of the putt and less able to accurately assess their ability to make the putt. Thus, for novice golfers and spectators, a particularly difficult putt literally looks easier.

The discussion so far explains the correlation between motor and perceptual abilities and the cognitive bias that results from this. The previous findings focus on elite athletes, novices, and spectators' *passive* observations of athletic behaviors. In most sporting events, however, athletes must interpret and anticipate others' behavior while at the same time executing their own athletic behaviors. The coupling between motor and perceptual processes also helps us to understand what happens when athletes interacting in an athletic competition have to balance motorically producing their own behavior and perceiving others' behavior.

In this interactive context, because motor and perceptual processes are realized in part by the same neurological system, action perception and production compete for the same neurological resources. In other words, focusing on producing athletic behavior may impair one's ability to perceive athletic behaviors, and focusing on perceiving athletic behaviors may impair one's ability to produce athletic behaviors. The skills that are disrupted will depend on the skill level of the athlete.

As a novice basketball player, one must focus one's attention and effort on dribbling the basketball properly, i.e., pushing the basketball to the ground at the right angle, force, and cadence. As one practices more, the simple skill of dribbling becomes easier and one does not need to focus on it to do it well. At the intermediate level, one masters dribbling in more challenging contexts, e.g., running and dribbling, dribbling with a defender trying to get the ball, etc. For expert basketball players, dribbling becomes automatized and requires no conscious attention. Indeed, focusing on dribbling may in fact disrupt their performance. The automation of basic skills like dribbling frees up the expert's attention for more complex athletic moves and strategic plays (Christensen, Sutton, & McIlwain, 2016).

Given the nature of skill mastery, what is impaired when one is perceiving and executing athletic behaviors depends on one's skill level. For novices, observing others dribble may disrupt one's own attempt at dribbling, and focusing on dribbling may make it difficult to observe others dribbling. Indeed, for this reason it is amusing to watch a group of children learn how to dribble basketballs. For intermediate level athletes, dribbling itself requires no conscious attention. Driving to the hoop, however, is more challenging, and doing this while perceiving a defender may disrupt one's ability to execute the drive. For expert basketball players, the previous skills are relatively easy and more or less automated. This frees up the expert's attention to focus on strategy, e.g., running plays to orchestrate a height mismatch between an offensive and defensive player. Executing a more complex athletic move may interfere with the expert athlete's ability to interpret and anticipate opponents' moves, thereby disrupting her ability to run effective strategic plays.

A further consequence of how production and perception are coordinated is that interacting athletes sometimes are so focused on executing their own actions that they do not perceive opponents' overt disruptive actions. As sports fans can attest, it is baffling to see elite athletes miss glaring opportunities. In these instances, interacting athletes' perception of other athletes' behavior may be impaired even in comparison to spectators. Though perplexing to sports fans, this impairment is a straightforward consequence of how perception and motor production are coordinated in the sensorimotor system. Given that action execution and perception involve the same neurological resources, when one of these tasks is much more demanding, it diminishes the ability to achieve the other task.

4. Conclusion

The body contributes to cognition in surprising ways – ways that more standard computationally-oriented approaches to cognition often fail to appreciate. In this chapter we have focused on how the mechanics of the body can *replace* the need for computational solutions to various motor and perceptual tasks. We have also examined the neural basis for social cognition, which can result in perceptual and conceptual refinements that reflect an individual's specific history of interaction with objects, including other individuals, in her environment. Sports psychologists have been quick to notice the significance of these ideas in their efforts to understand athletic performance. Indeed, some sports psychologists have been instrumental in expanding and developing research programs within embodied cognition (see especially Beilock 2008). We believe that continued erosion in the disciplinary boundaries between embodied cognition and sports psychology will bring tremendous benefits to both fields.

References

Adams, F. & Aizawa, K. (2008). *The Bounds of Cognition*. Malden: Blackwell Publishing.

Ames, D. R., & Kammrath, L. K. (2004). Mind-reading and metacognition: Narcissism, not actual competence, predicts self-estimated ability. *Journal of Nonverbal Behavior, 28*(3), 187-209.

Barrett, L. (2012). Emotions are real. *Emotion*, 12, 413-429.

Beer. R. (2003). The dynamics of active categorical perception in an evolved model agent. *Adaptive Behavior*, 11, 209-243.

Beilock, S. (2008). Beyond the playing field: Sport psychology meets embodied cognition. *International Review of Sport and Exercise Psychology*, 1(1), 19-30.

Brooks, R. (1991). Intelligence without representation. *Artificial Intelligence*, 47, 139-159.

Christensen, W., Sutton, J., & McIlwain, D. J. (2016). Cognition in skilled action: Meshed control and the varieties of skill experience. *Mind & Language,* 31(1), 37-66.

Clark, A. (2007). "Re-inventing ourselves: The plasticity of embodiment, sensing, and mind. *Journal of Medicine and Philosophy,* 32, 263-282.

Clark, A. and Chalmers, D. (1998). The extended mind, *Analysis*, 58, 7-19.

Collins, S., Ruina, A., Tedrake, R., and Wisse, M. (2005). Efficient bipedal robots based on passive-dynamic walkers. *Science,* 307, 1082-1085.

Csibra, G. (2007). Action mirroring and action interpretation: An alternative account. In P. Haggard, Y. Rosetti, & M. Kawato (Eds.), *Sensorimotor Foundations of Higher Cognition: Attention and Performance*: Oxford University Press.

Descartes, R. (1641/1993). *Meditations on First Philosophy*. D. Cress (Trans., 3rd. ed.). Indianapolis: Hackett Publishing Co.

Fink, P., Foo, P., and Warren, W. (2009). Catching fly balls in virtual reality: A critical test of the outfielder problem. *Journal of Vision,* 9, 1-8.

Fogassi, L., Ferrari, P. F., Gesierich, B., Rozzi, S., Chersi, F., & Rizzolatti, G. (2005). Parietal lobe: From action organization to intention understanding. *Science, 308*(5722), 662-667.

Gallese, V. (2009). Motor abstraction: A neuroscientific account of how action goals and intentions are mapped and understood. *Psychological Research, 73*(4), 486-498.

Gallese, V., Keysers, C., & Rizzolatti, G. (2004). A unifying view of the basis of social cognition. *Trends in Cognitive Sciences, 8*(9), 396-403.

Ghez, C. (1985). Voluntary movement. In E. Kandel, and J. Schwartz (Eds), *Principles of Neural Science*, 2nd ed. (493-501). New York: Elsevier Science Publishing Co Inc.

Gibson, J.J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton-Mifflin.

Glenberg, A. (1997). What memory is for. *Behavioral and Brain Sciences*, 20, 1-55.

Iacoboni, M. (2005). Understanding others: Imitation, language, empathy. In S. Hurley & N. Chater (Eds.), *Perspectives on Imitation: Mechanisms of imitation and imitation in animals* (Vol. 1, pp. 77-99). Cambridge, MA: MIT Press.

Kaschak, M., Madden, C., Therriault, D., Yaxley, R., Aveyard, M. and Blanchard, A. (2005). Perception of motion effects on language processing. *Cognition*, 94, B79-B89.

Keele, S. (168). Movement control in skilled motor performance. *Psychological Bulletin*, 70, 387- 403.

Kruger, J., & Dunning, D. (1999). Unskilled and unaware of it: how difficulties in recognizing one's own incompetence lead to inflated self-assessments. *Journal of personality and social psychology, 77*(6), 1121.

McBeath, M., Shaffer, D., and Kaiser, M. (1995). "How baseball outfielders determine where to run to catch fly balls. *Science,* 268, 569–573.

Neilson, P. & Neilson, M. (2005). An overview of adaptive model theory: solving the problems of redundancy, resources, and nonlinear interactions in human movement control. *Journal of Neural Engineering*, 1, S279-S312.

Noë, A. (2004). *Action in Perception*. Cambridge: MIT Press.

O'Regan, K. & Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, 24, 939-1031.

Pineda, J. A. (2009). *Mirror Neuron Systems: The Role of Mirroring Processes in Social Cognition*. New York: Humana.

Realo, A., Allik, J., Nõlvak, A., Valk, R., Ruus, T., Schmidt, M., & Eilola, T. (2003). Mind-reading ability: Beliefs and performance. *Journal of Research in Personality, 37*(5), 420-445.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience, 27*(1), 169-192.

Rizzolatti, G., & Sinigaglia, C. (2010). The functional role of the parieto-frontal mirror circuit: interpretations and misinterpretations. *Nature Reviews Neuroscience, 11*(4), 264-274.

Rupert, R. (2009). *Cognitive Systems and the Extended Mind.* New York: Oxford University Press.

Shaffer, D. & McBeath, M. (2005). Naïve beliefs in baseball: Systematic distortion in perceived time of apex for fly balls. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* 31, 1492-1501.

Shapiro, L. (2008). The embodied cognition research programme. *Philosophy Compass*, 2, 338-346.

Shapiro, L. (2011). *Embodied Cognition*. New York: Routledge.

Shapiro, L. (2012). Embodied cognition," in E. Margolis, R. Samuels, and S. Stich (Eds.), *The Oxford Handbook of Philosophy of Cognitive Science* (pp. 118-147). New York: Oxford University Press.

Shapiro, L. (2013). Dynamics and cognition, *Minds & Machines,* 23, 353-375.

Shapiro, L. (ed.) (2014a). *The Routledge Handbook of Embodied Cognition*. New York: Routledge.

Shapiro, L. (2014b). Review of Hutto, D. and Myin, E. *Radical Enactivism: Basic Minds without Content* (Cambridge: MIT Press, 2012), *Mind,* 123, 213-220.

Schmidt, R. (1976). Control processes in motor skills. *Exercise & Sport Sciences Reviews*, 4(1), 229-262.

Shiffrar, M., & Heinen, T. (2015). Die Fähigkeiten von Athleten verändern deren Wahrnehmung von Handlungen. *Zeitschrift für Sportpsychologie.*

Spaulding, S. (2013). Mirror neurons and social cognition. *Mind & Language, 28*(2).

Thelen, E., Kelso, J. and Fogel, A. (1987). Self-organizing systems and infant motor development. *Developmental Review*, 7, 39–65.

Thelen, E. and Ulrich, B. (1991). Hidden skills: A dynamic systems analysis of treadmill stepping during the first year. *Monographs of the Society for Research in Child Development,* 56: 1-97.

Webb, B. (1996). A cricket robot. *Scientific American*, 275, 62-67.