

Athletic ability changes action perception:
Embodiment in the visual perception
of human movement.

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Abstract

How does the human visual system detect and interpret human actions? Traditional models of the visual system suggest that the same set of visual processes is used by all observers to analyze all classes of visual images. This theoretical framework predicts that observers, whether paralyzed or athletic, analyze and perceive objects and actions similarly. Embodied theories of perception assert that visual processes are constrained by an observer's motor abilities. According to this approach, what one sees is determined by what one can physically do. Furthermore, human movement represents a special category of visual motion stimuli because it is the only type of motion that humans can both produce and perceive. This article reviews recent behavioral and neurophysiological research on the visual perception of human movement and focuses on the role of the motor system in this process. Action perception by athletes is emphasized because their special motor and visual abilities provide a particularly important challenge to traditional theories of vision.

Athletes challenge traditional theories of visual perception.

Traditionally, the visual system has been understood as a general-purpose processor that analyzes all classes of visual images in the same way (Marr, 1982). According to this perspective, all observers employ the same visual processes to analyze all categories of visual stimuli, whether object or human. For example, Roger N. Shepard (1984), a ground-breaking researcher of the visual motion perception, argued that observers analyze visual movement in the same way for all images. As he eloquently stated, "There evidently is little or no effect of the particular object presented. The motion we involuntarily experience when a picture of an object is presented first in one place and then in another, whether the picture is of a leaf or of a cat, is neither a fluttering drift nor a pounce, it is, in both cases, the same simplest rigid displacement (p 426)." This "general-purpose processor" model is not unrelated to the idea that the visual system is a module (Fodor & Pylyshyn, 1981) that is "encapsulated" unto itself. Thus, visual perception is immune to non-visual factors (Fodor, 1983).

Just as John Donne (1572-1631) challenged the idea that people can be understood as independent entities with his famous meditation, "No man is an island, entire of itself...", researchers are increasingly challenging the hypothesis that vision can be understood as an isolated system. Interestingly, athletes provide some of the best evidence in support of the idea that visual perception depends upon more than the patterns of light detected by the photoreceptors in our eyes.

Numerous studies have documented that elite athletes have superior perceptual abilities (e.g., Abernethy, 1990; Kioumourtzoglou et al., 1998; Williams & Davids, 1998). At least some of that perceptual expertise likely reflects perceptual learning. That is, if you see the same motion or pattern repeatedly, your visual sensitivity to that motion or pattern increases (E.J. Gibson, 1969; Fahle & Poggio, 2002). But there is increasing reason to believe that perceptual learning, in and of itself, is insufficient to explain the superior levels of visual sensitivity enjoyed by many top athletes. Instead, as the following sections make clear, motor expertise also enhances visual sensitivity. As experts in the movements of their own bodies, athletes present a significant challenge to traditionally modular theories of visual perception. The goal of this article is to provide an overview of this challenge in several steps. First, we'll discuss the concept and some of the support for embodied theories of perception; that is, theories arguing that an observer's motor abilities impacts that observer's visual sensitivities. Then we'll discuss the impact of motor processes on the differentiation of the visual perception of human motion from the visual perception of object motion. Following this, we'll discuss visual sensitivity to human movement by athletic observers. The results of brain imaging and behavioral studies indicate that athletes experience enhanced visual sensitivity to the actions of other people and, consistent with embodied theories of perception, this enhancement can be attributed to motor experience and expertise.

What is embodied perception?

In the 1970s and beyond, many scientists conducting research on visual perception held as their explicit goal the development of computers that could “see”. Because mathematical rigor is required for the construction of computational models of psychological phenomena, many scientists assumed that visual perception could be fully understood through the development of abstract programs that would allow desktop computers to successfully identify objects. This approach thus assumes that the way to determine how humans see is to build a computer that can see. Obviously, computational modeling is a powerful tool for the development and testing of behavioral and neural principles. But desktop and laptop computers differ from human beings in some fundamental ways. One of the biggest differences is that human beings have visual systems that are encased in heads that are attached to bodies. Theories of embodied perception argue that the visual system cannot be understood as a processor of abstract symbols, but rather as physical, context-dependent system that controls and is controlled by a body that interacts in real time with, and must survive within, a physical environment. The core premise in theories of embodied perception is that bodily states and possibilities for actions define visual perception.

The embodied perception approach has generated exciting new findings in many different domains of perceptual research including, but certainly not limited to, language perception, distance perception, time perception, and motion perception (for review see recent books by Klatzky, MacWhinney & Behrmann, 2008; Wachsmuth, Lenzen & Knoblich, 2008). Because the focus on this article is on the visual perception of human movement, the research of only two major “embodied perception” researchers is summarized here. Meg Wilson, a professor of Psychology at the University of California at Santa Cruz, has constructed an elegant theoretical platform for embodied perception (e.g., Wilson, 2008; Wilson, 2002; Wilson & Knoblich, 2005). She has also found, for example, that psychological phenomena traditionally understood as symbolic, such as language and working memory capacity, are actually defined by the sensorimotor limitations of the human body (e.g., Wilson & Fox, 2007). Dennis Proffitt, from the University of Virginia, has demonstrated in an extensive series of psychophysical studies that the visual perception of fundamental physical features, such as distance, height, and slant, depends upon the observer’s ability to move. For example, Proffitt and his colleagues have shown that hills appear steeper when observers stand at the top of the hill than when they stand at the bottom of the hill (Proffitt et al., 1995). Given the biomechanics of the human body, it is easier for people to walk up steep hills than to walk down them. Consistent with this, Proffitt (2006) has proposed that the visual perception of a hill’s slope reflects the physical effort that observers would need to exert to transverse that slope. It follows that the perceived slope of a hill reflects an observer’s physiological potential. Consistent with this, hills appear to be steeper when observers are fatigued from a long run (Proffitt et al., 1995). Observers who are elderly or physically unfit also judge hills to be steeper than observers who are young

or athletic (Bhalla & Proffitt, 1999). Such data converge in supporting embodied theories of visual perception that link visual perception to the observer’s motor capabilities.

The embodied visual perception of bodies in motion

The studies described above indicate that motor processes impact perceptual processes, in general. Other research has focused on the visual perception of one subcategory of visual motion stimuli; namely, the movements of the human body. Human action represents a special category of perceptual stimuli for many reasons. Because human beings are inherently social, they tend to live in peopled environments. As a result, human movement is often the most frequently seen type of movement in our social environments. Furthermore, from a very early age, typical observers spontaneously direct their visual attention toward other moving people (Klin, Lin, Gorrindo, Ramsay, & Jones, 2009). Given that infants and children rely on the actions of adults for their survival, it can be argued that human action is the most psychologically meaningful, and the most potentially life altering category of dynamic events in typical human environments. Over the past two decades, increasing evidence suggests that there is an especially tight coupling between the visual perception of human motion and the observer’s motor abilities.

Modern research addressing the question of how observers perceive human motion started in the 1970s when Gunnar Johansson constructed movies of point-light defined people in action. Adapting a technique originally developed by Etienne Jules Marey (1895), Johansson attached small lights to an actor’s major joints and head and then filmed that actor’s actions so that only the lights were visible (Figure 1). When naïve observers viewed these point-light movies, they could accurately detect the underlying actions in as little as a fifth of a second (Johansson, 1973). While Johansson’s goal was to construct a model of visual motion perception that applied equally well to all categories of visual motion (Johansson, 1976), he nonetheless noted that percepts of human motion were significantly more vivid than percepts of other types of motion (Johansson, 1973).

Since Johansson’s pioneering work in the 1970s, many vision scientists have studied how observers analyze the movements of other people with the same methodologies and theoretical frameworks used in past studies of the visual perception of moving objects (for review see Shiffrar, Kaiser & Chouhroulou, 2010). At first blush, the human body is, of course, a physical object. Yet, as Johansson first hinted, there seems to be something a little different about our perception of human actions. This difference can be readily understood if takes an embodied approach to the visual perception of movement. If we assume that the visual perception of other people’s actions depends upon input from the observer’s own motor system, just as distance and slant perception depend upon the observer’s motor capabilities, then some unique implications result for the visual perception of human movement. Human observers have a motor system that can imitate and reproduce the movements of other people. Conversely, the human motor system cannot accurately reproduce the movements of non-human motions

such as crashing ocean waves, tornados and wind blown trees. A person's ability to copy the movements of another entity obviously depends, in large part, on the degree of structural similarity between that person and that entity (be it another person, a rock, or a dog). Some researchers have argued that the ability to imitate what we see fundamentally changes our percepts (Wilson, 2001). More specifically, visual percepts change as a function of the degree to which an observer's motor system can represent and reproduce an observed stimulus, and in so doing, provide disambiguating information to the visual system about that stimulus (e.g., Loula et al., 2005). Thus, embodied theories of perception predict that input from an observer's own motor system might differentiate the visual analysis and perception of stimuli that the observer can physically imitate (e.g., other people walking) from stimuli that the observer's motor system cannot accurately imitate (e.g., bird flight and rolling rocks). This perceptual differentiation may be gradual rather than dichotomous (Cohen, 2002).

Neurophysiological findings

Numerous behavioral and neuro-physiological studies have produced results that are consistent with embodied theories of the visual perception of human movement. For example, brain imaging research indicates that neural activity in the motor system, specifically, in the premotor cortex, increases when observers view point-light displays of human actions (Saygin, Wilson, Hagler, Bates, & Sereno, 2004). When the premotor cortex is lesioned, observers lose much of their visual sensitivity to human movement (Saygin, 2007).

The existence of "mirror neurons" also supports coupled processing of the visual and motor systems during the perception of human and primate movement. First identified in the premotor cortex of monkeys, mirror neurons respond when an animal performs an action and also when the animal observes another individual performing that same action (Rizzolatti, Fogassi, & Gallese, 2001). In the monkey, these intriguing neurons respond only when an activity involves primate motion and do not respond to similar motions made by a mechanical device (Rizzolatti et al., 2001). A correlate of this mirror system has been investigated in human observers and it too responds to actions that a human observer can perform but not to actions that a human observer cannot perform (Buccino et al., 2004).

Another second brain area that appears to be involved in the perceptual analysis of other people's actions is the posterior region of the superior temporal sulcus or STSp (e.g., Grossman et al., 2000; Puce & Perrett, 2003). While the STSp does not appear to be endowed with motor properties, this region is interconnected with the mirror system, albeit indirectly (Rizzolatti & Craighero, 2004). Like the mirror system, the STSp is more responsive during the visual perception of human movement than during the visual perception of object movement (e.g., Beauchamp, Lee, Haxby, & Martin, 2003). Patterns of neural activity during the perception of human motion and during the perception of object motion diverge approximately 200 msec after stimulus onset (Virji-Babul, Cheung, Weeks, Kerns, & Shiffrar, 2007).

Divergent neural activity during the perception of human motion and object motion may reflect a more fundamental

difference in the analyses of actions that observers can and cannot reproduce. One study testing this hypothesis examined brain activity while observers viewed possible human motion, impossible human motions, and impossible object motions (Stevens, Fonlupt, Shiffrar & Decety, 2000). These three categories of visual movement were generated through the use of apparent motion. The visual perception of apparent motion occurs when observers view different static images presented briefly in sequential order. Under the appropriate temporal conditions, observers perceive one moving image rather than two stationary images. Typically, percepts of apparent motion appear to follow the shortest physical path that connects the two stationary images. Consistent with this, when observers view two different images of a moving person, they generally perceive the shortest path connecting the two body postures, even if that path requires the perception of a physically impossible motion (see Figure 2). This is consistent with the "shortest-path constraint" in apparent motion and is found with both humans and objects in apparent motion (Shiffrar & Freyd, 1990). However, when pictures of the human body are presented at slower temporal rates, rates that are consistent with the temporal range of normal human actions, something very different is perceived. Under these conditions, observers tend to perceive paths of apparent motion that are consistent with the biomechanical limitations on the production of human action (Shiffrar & Freyd 1990; 1993). Conversely, when objects are shown at the same slow temporal rates, the shortest, physically impossible path of apparent motion is perceived. This pattern of results suggests that human actions are analyzed by processes that take into account the biomechanical constraints on the production of human movement and that operate over relatively large temporal windows (Shiffrar & Pinto, 2002).

When PET scans are used to assess neural activity during the perception of people and objects in apparent motion, the results are consistent with embodied theories of visual perception. When pairs of pictures of the human body in different postures were presented slowly, participants perceived biomechanically possible paths of apparent human motion and PET scans showed significant bilateral activity in the primary motor cortex and cerebellum. However, when these same picture pairs were presented more rapidly, participants then perceived impossible paths of human movement, and selective motor system activity was no longer found (Stevens et al., 2000). Conversely, when the pictures of objects were presented at either fast or slow display rates, no motor system activation was indicated. Thus, motor system activity is found during the perception of performable human actions but not during the perception human actions that are impossible to perform.

Within the category of performable human actions, motor system activity is also modulated by the degree of past motor experience that an observer has with an observed action. One brain imaging study measured brain activity in three types of observers, expert ballet dancers, expert capoeira dancers (a Brazilian folk dance involving the martial arts), and control individuals with no dance training while they watched movies of other people performing ballet and capoeira moves. The fMRI data indicated increased motor system activation when ballet and capoeira dancers watched movies of the dance style that they

themselves perform (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005). Because motor experience is usually confounded with visual experience (e.g., ballet dancers watch lots of ballet), a subsequent study disengaged the roles of visual and motor experience by taking advantage of the fact that male and female ballet dancers perform both gender-specific and gender-neutral ballet moves. This study found that greater motor system activity when observers viewed ballet moves specific to their own motor repertoire (Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006). That is, greater motor system activation was found when female ballet dancers viewed female specific ballet moves than when they viewed male specific ballet moves, even though they had extensive visual experience with both categories of ballet moves. The reverse pattern was found for male ballet dancers. These results indicate, at the very least, that motor system activity correlates when the magnitude of the observer's motor experience with an observed action.

Perceptual findings

While brain imaging data tell us that the motor system is active during the perception of human movement, behavioral data are needed to determine whether motor system activity actually changes observers' visual sensitivity to human movements relative to other categories of visual motion. Fundamental differences in the visual analyses of human and object motion have been documented with psychophysical studies of the "aperture problem." Because all visual systems measure motion through spatially limited receptors, motion information falling outside of each receptive field cannot be measured. This naturally produces inherently ambiguous motion measurements. Integrating individually ambiguous motion signals across different spatial locations provides one solution to this aperture problem (Hildreth, 1984). However, this solution comes with its own set of problems because the motion integration that is needed to integrate one object's motion, but must often be inhibited across different objects (Shiffrar & Lorenceau, 1996). As a result, the visual system must strike a delicate balance between motion integration and motion segmentation. Interestingly, the same balance point does not appear to be adopted for human motion and object motion. When observers view a walking person through a set of windows or apertures, their percepts of coherent motion suggest that they have integrated motion information across the disconnected regions of space. However, when observers view complex objects, such as cars or scissors, through apertures, they perceive incoherent motion that indicates a lack of integration across space (Shiffrar, Lichtey, & Heptulla-Chatterjee, 1997). Consistent with embodied theories of perception, spatially extended motion integration only occurs during the perception of physically possible human motions (Shiffrar et al., 1997).

Another important aspect of the visual perception of human movement is its dependence on the laws of motor production. For example, the production of simple hand and arm movements within a plane is described by the two-thirds power law which defines the relationship between the hand trajectory's instantaneous velocity and radius of curvature (e.g., Viviani & Stucchi, 1992). Visual motion percepts are systematically distorted whenever dynamic stimuli violate this fundamental

principle of motor production (Viviani, 2002). Another law of motor production, known as Fitt's law, defines how quickly a person can move between two targets as a function of target width and separation. Visual percepts of apparent motion between targets are consistent with this motor law (Grosjean, Shiffrar, & Knoblich, 2007). Such evidence indicates that motor processes systematically constrain the visual perception of human movement. Indeed, Viviani (2002) convincingly argues that the human visual system is optimized for the analysis of human generated movements.

Comparing the perception of people and animals

While the visual perception of human and non-human motions differ, this difference can be difficult to understand, with a high degree of certainty, from comparisons of humans and object motions because people and objects differ in so many ways. To bridge that difference, several studies have compared the visual perception of human motion with the visual perception of animal motion. While naïve observers are capable of identifying and classifying animals depicted in dynamic point light displays (e.g., Mather & West, 1993; Pavlova & Sokolov, 2001), increasing evidence indicates differentiated analyses of human and animal motion. For example, when infants view point-light displays of human and animal motion, their ability to differentiate phase perturbed from canonically timed limb movements changes over the course of their development (Pinto, 2006). At the age of 3 months, infants are sensitive to phase differences in the limb movements of point-light human and animal motion. Just 2 months later, infants only respond to phase differences in upright human motion. This pattern of results suggests that the infant visual system becomes specialized or tuned for the detection of canonical human motion (Pinto, 2006). Specialized perceptual tuning is supported by fMRI data indicating that STSp activity becomes increasingly tuned to human motion as typical children age (Carter & Pelphrey, 2006). This perceptual and neural tuning for the perception of human movement is maintained into adulthood as adult observers demonstrate greater visual sensitivity to human movement than to movements of quadruped animals including horses (Pinto & Shiffrar, 2009) and dogs (Cohen, 2002).

Brain imaging data convergence is supporting the hypothesis that percepts of human and non-human animal motions differ in fundamental ways. Electroencephalography or EEG measures indicate that the visual perception of human movement engages the observer's motor system while the perception of animal motion does not (Martineau & Cochin, 2003). Furthermore, fMRI data indicate that STSp activity is greater during the perception of human motion than during the perception of animal-like creature motion (Pyles, Garcia, Hoffman, & Grossman, 2007). Taken together, these results support embodied theories of perception by suggesting that observers use their own motor systems to assist in their visual interpretations of other people's actions.

Seeing myself in others?

The above results suggest that the more similar an observed action is to the observer's range of performable actions, the greater the activity in the observer's motor system

and the greater the observer's visual sensitivity to that action. If we push this hypothesis to its logical conclusion, we are left with the prediction that observers should show the greatest visual sensitivity to their own actions. Because each person can best imitate his or her own actions, it follows that each observer's own perceptual system should optimally tuned for the detection of that his or her own actions. A series of psychophysical data support this prediction. In one such study, participants were filmed while they threw darts at a dartboard. Many days later, they viewed brief movies of the initial portions of their own dart throws and other people's dart throws. When asked to predict where each dart would land on the dartboard, participants' predictions were most accurate when they viewed their own dart throws (Knoblich & Flach, 2001).

In a related study, participants were filmed while performing a variety of actions, such as jumping in place and boxing. The films were converted into point-light movies. Two months or more later, these same participants viewed pairs of point-light actors performing two different actions and reported whether each pair depicted the same person or two different people. Identity discrimination performance was best when participants viewed point-light displays of their own actions (Loula et al. 2005). Subsequent studies ruled out the possibility that enhanced visual sensitivity to self-generated actions results from visual experience (Prasad & Shiffrar 2009). Consistent with importance of motor experience on action perception, observers can improve their visual sensitivity to unusual actions by repeatedly executing those actions while blindfolded; that is, in the absence of any visual experience with those actions (Casile & Giese, 2006). Thus, the above results suggest that, as a result of motor system input, each individual's visual system is indeed optimized for the perception of his or her own actions. Brain imaging studies are needed to determine whether neural activity in an observer's motor system is greatest during the visual perception of that observer's own actions.

What do athletes see differently?

Consistent with embodied theories of perception, the studies summarized above suggest that observers use their own motor systems to facilitate their visual perceptions of their own and other people's actions. Athletes, especially elite athletes, have much more finely tuned motor systems than non-athletes. This suggests that visual sensitivities to human actions should vary as a function of an observer's own athletic ability. The studies reviewed below describe some of the ways in which athletes differ from non-athletes in their visual sensitivity to human motion.

Athletes frequently analyze the movements of their teammates and competitors for the purpose of action coordination. This process requires moving observers to compare their own bodily actions and postures with those of other people. Psychophysical research indicates that observer action changes visual perceptions of other people's postures and actions. In a set of studies, observers viewed pairs of different human body postures while moving their own bodies (e.g., Reed & Farah, 1995; Reed & McGoldrick, 2007). On half of the trials, postures pairs were identical. In the other trials, the two postures differed by the positions of the legs or arms. Observers viewed

each pair, while simultaneously moving their arms or legs, and reported whether or not each posture pair was identical. The results showed that posture discrimination was impacted by the observer's own movements in a limb specific manner. In other words, visual sensitivity to postural changes was altered when observers perceptually judged and physically moved corresponding limbs. The direction of that impact was time dependent. Visual performance in the body posture discrimination task improved with temporal increases in overall display duration while visual performance decrements were found when stimulus duration decreased (Reed & McGoldrick, 2007).

Other research has demonstrated that an observer's actions also change his or her perceptions of other people's actions. One such study compared visual sensitivity to walking speed in observers who simultaneously walked on a treadmill, stood on a treadmill or pedaled a stationary bicycle (Jacobs & Shiffrar, 2005). While gait speed discrimination performance was similarly good for standing and cycling observers, walking observers showed systematic decrements in their visual sensitivity to other people's walking speeds. Such results suggest that the simultaneous production and perception of the same action type decreases visual sensitivity to that category of actions. Consistent with this, when observers try to judge the weight of a box from the movements of the person lifting that box, their percepts of the lifter's actions depend upon how much weight they themselves simultaneously lift (Hamilton, Wolpert & Frith, 2004). A box being lifted by another person appears to weigh less when the observer is simultaneously lifting a heavy box. Conversely, the weight of the observed box appears greater while the observer is lifting a light box (Hamilton et al., 2004).

Selective interference of action production on action perception is thought to reflect competing demands for access to shared visual-motor representations (e.g., Prinz, 1997) that code for both the execution and perception of the same action. While the studies above indicate that action production impacts action perception, the reverse is also true; that is, action perception also impacts action execution. For example, the variability of an individual's sinusoidal arm movements increases during the observation of another person's sinusoidal arm movements in a tangential direction (Kilner, Paulignan, & Blakemore, 2003). Conversely, action execution is not disrupted when observers view similar displays of robotic movement (Kilner et al., 2003). Consistent with the importance of velocity profiles (e.g., Viviani, 2002), this interference effect depends upon the similarity between the velocity profiles of simultaneously observed and produced arm movements (Kilner, Hamilton, & Blakemore, 2007).

Visual sensitivity to another person's actions also depends upon the observer's motor capabilities. Walking observers who exert more effort by walking up an inclined treadmill perceive other people's gaits speeds differently than walking observers who exert less effort by walking on a flat treadmill (Jacobs & Shiffrar, 2005). Similarly, when observers are asked to judge another person's walking speed while walking on a treadmill, physically fit observers perceive other walkers as relatively slowly while "couch potato" or out of shape observers perceive other people's gaits as relatively fast (Jacobs & Shiffrar, 2005).

This linkage between action perception and action production appears to be modulated by functionality; namely, whether the observer can coordinate his or her actions with the actions of an observed other. When action coordination is possible because, for example, an observer walks in the same direction as a walking partner, the observer's visual sensitivity to relative gait speed reflects his or her motor capabilities. However, when action coordination is impossible because, for example, an observer is walking away from another person, the observer's visual sensitivity to relative gait speed is independent of the observer's motor capabilities (Jacobs & Shiffrar, 2005). Thus, under a wide range of conditions, moving observers perform visual analyses of human movement that are distinct from the visual analyses performed by stationary, non-interactive observers.

These results have practical implications for athletes and coaches involved in team sports. Consider soccer, for example, in which some members of a team sit on the bench while other members of the team run about the field. Both groups, as well as the spectators, are trying to accurately assess the movements of all of the players on the fields. However, the players on the field are attempting to simultaneously execute and perceive the same actions (generally running) while the players on the bench are seeing (running) and doing (sitting or standing) two different things. This difference in motor activity suggests that players perceive the actions in a soccer match differently when they are on the field and when they are on the bench. This also might explain while players and coaches sometimes seem to perceive human actions within matches differently.

Deception detection in sports

A fundamentally important skill in many sports is the ability to detect the intentions of one's opponents. To continue with the soccer example, when goalies attempt to block a penalty kick, they sometimes do so by predicting the direction in which a ball is going to travel from the kicker's actions. Several studies from sports psychology indicate that athletes are better than novices at predicting the outcome of observed actions (e.g., Abernethy, 1989; Muller, Abernethy, & Farrow, 2006). A study of rugby players has shown that expert rugby players are better than novice rugby players at detecting deceptive moves, such as when an attacking player fakes a move to the right and then cuts to the left (Jackson, Warren, & Abernethy, 2006). This study provided the first experimental evidence that visual and/or motor expertise in a particular domain improves one's ability to read intentions from other people's moving bodies. Changes in running direction are large scale, salient events. The importance of large scale body movements is suggested by rigorous research on the prediction of a tennis ball's trajectory from the movements of the person hitting that ball. This research suggests that expert and novice tennis players rely on global analyses of whole body movements to make their predictions even when sufficient local information is available (Huys, Canal-Bruland, Hagemann, Beek, Smeeton & Williams, 2009). Athlete's predictive abilities during the visual perception of relatively subtle basketball moves have also been examined (Sebanz & Shiffrar, 2009). In this study, expert and novice basketball players viewed full body videos, point-light movies,

and static pictures of a basketball player faking and making passes. Each video or movie stopped just before the ball left (pass) or appeared that it would leave (fake) the player's hands. In a static condition, observers saw only the final frame that depicted players' postures just before an actual or faked pass. Expert basketball player performed this deception detection task significantly better than novices, but only in the dynamic conditions, indicating that experts rely on movement cues to detect deception in subtle actions.

A psychophysical study of expert and novice handball players raises important questions about the degree to which deception detection by athletic observers reflects their visual expertise and/or their motor expertise (Canal-Bruland & Schmidt, 2009). At present, neither motor nor visual experience can fully account for behavioural measures of athletes' visual sensitivity to deceptive actions (Canal-Bruland, van der Kamp & van Kesteren, 2010). However, recent brain imaging data do suggest that, when predicting stroke direction in badminton, expert badminton players show enhanced levels of neural activity in the areas associated with action execution (Wright, Bishop, Jackson & Abernethy, 2010). To the extent that deception detection relies on the prediction of the outcomes of bodily actions, these results support the hypothesis that motor processes enhances athletes' visual sensitivity to deceptive actions.

In an elegant series of studies using psychophysical measures and transcranial magnetic stimulation (TMS), the neural correlates of action anticipation were measured in a group of professional basketball players, professional basketball coaches, and professional sports journalists (Aglioti, Cesari, Romani & Urgesi, 2008). This selection of participants was motivated by the fact that basketball players have extensive visual and motor experience with basketball moves while coaches and journalists have only extensive visual experience with basketball movements. In the psychophysical component of this research, all three groups of participants viewed brief movies of a basketball player shooting free throws. In half of the movies, the ball landed in the basket. However, observers never saw the end result of the shots but instead tried to predict whether the ball would land in the basket from the player's movements and, under some conditions, from the ball's trajectory. Elite basketball players were able to predict the outcome of free throws sooner and more accurately than participants with largely or exclusively visual expertise with free throws (journalists and coaches). This result supports the hypothesis that motor expertise selectively enhances visual sensitivity to related actions (Aglioti et al., 2008). TMS was used to measure corticospinal excitability in these three groups of participants while they watched basketball free throws and soccer kicks. Both professional basketball players and journalists showed motor system activation specific to the observation of basketball free throws, suggesting that both visual and motor experience play important roles in action prediction. Yet, the basketball players showed finer grained motor system activation than basketball observers, suggesting that motor experience, per se, is key in the accurate anticipation of action outcomes.

Action perception by the injured athlete

If an observer's movement capabilities truly change that observer's visual sensitivity to other people's actions, then injured observers should experience systematic changes in their visual sensitivity to actions that they are currently unable to perform. For the athlete, this raises the question of whether physical injury changes one's perception of sporting actions. While this question has yet to be studied directly with athletes, recent evidence indicates that injury can cause significant decrements in visual sensitivity to actions that an observer could once perform, and still frequently see, but can no longer perform (Serino, Casavecchia, De Filippo, Coccia, Shiffrar, & Ladavas, 2010). In this study, visual sensitivity to point-light displays of simple human movements was measured in ten healthy control observers and in ten hemiplegic observers who were unable to move one of their arms. Point-light stimuli were constructed from videos of the hemiplegic participants while they performed various movements (e.g., crossing themselves, blowing a kiss, smoking a cigarette, etc.) with their functional arm. The experimental manipulation simply involved showing the original and mirror reversed version of each movie to control and hemiplegic participants and asking them to identify each action. When movies were mirror reversed, the performed actions appeared to have been performed by the hemiplegic observers' paralyzed arm. Injured observers showed greater visual sensitivity to point-light actions that they could perform with their unaffected arm than to point-light actions that appeared to have been performed with their paralyzed arm. Healthy control observers showed equal visual sensitivity to the original and mirror-reversed actions. These results suggest that physical injury impacts an observer's visual sensitivity to movements that he or she can no longer perform. This conclusion supports the role of motor processes in action perception and thus provides additional evidence in support of embodied theories of perception.

Of course, not all elite athletes have fully functioning bodies, in the traditional sense. Every year, for example, tri-athletes who are single, double, and soon even triple amputees successfully complete one of the challenging athletic events in the world, the Ironman triathlon on the big island of Hawaii. If the visual perception of human movement depends upon the observer's ability to perform that movement, then how do observers who are amputees perceive human actions performed with their missing limbs? A study of the visual perception of arm rotations by observers born without arms suggests that the motor processes contribute to the visual perception of human movement as a function of the correspondence between observed motion patterns and the observer's own internal body representation (Funk et al., 2005). When no correspondence can be found between an observer's own body representation and the perceived bodily actions of other people, those actions appear to be analyzed as objects; that is, without the benefit of motor processes. However, when observers have neural representations for limbs that they have never actually had, then their visual percepts of limb movements do not significantly differ from those of typically limbed observers (Funk et al., 2005).

Conclusions

Theories of embodied perception assert that visual processes are tightly constrained by the physical body within which the visual system is housed. Human bodies are capable of executing some actions, but not others. The results of the studies summarized above suggest that percepts of the physical and social environments depend upon the ways in which observers' bodies can move, have moved, are moving, and are represented in the neural mechanisms underlying body schemata. Elite athletes can move their bodies in ways that recreational athletes and non-athletes cannot. That motor expertise has been found to change activity in the neural mechanisms underlying action perception and to change visual sensitivity to perceived actions. Thus, athletes don't simply have superb bodies, they also have superb visual systems that are extraordinarily well tuned to the actions around them. Such findings present critical challenges to traditionally disembodied theories of vision because traditional theories necessarily predict that the human visual system should function in the same way whether it were attached to the body of an elite athlete, a desktop computer, or a gardening rake. Instead, the perceptual abilities of athletes indicate that the human visual system processes information in a manner that reflects the body to which it is attached.

References

- Abernethy, B. (1989). Expert-novice differences in perception: How expert does the expert have to be? *Canadian Journal of Sport Sciences*, 14, 27-30.
- Abernethy, B. (1990). Expertise, visual search and information pick-up in squash. *Perception*, 19, 63-77.
- Aglioti, S.M., Cesari, P., Romani, M., & Urgesi, C. (2008). Action anticipation and motor resonance in elite basketball players. *Nature Neuroscience*, 11, 1109-1116.
- Beauchamp, M.S., Lee, K.E., Haxby, J.V., & Martin, A. (2003). fMRI responses to video and point-light displays of moving humans and manipulable objects. *Journal of Cognitive Neuroscience*, 15, 991-1001.
- Bhalla, M., & Proffitt, D.R. (1999). Visual-motor recalibration in geographical slant perception. *Journal of Experimental Psychology: Human Perception and Performance*, 25, 1076-1096.
- Buccino, G., Lui, F., Canessa, N., Patteri, I., Lagravinese, G., Benuzzi, F., Porro, C.A., and Rizzolatti, G. (2004) Neural circuits involved in the recognition of actions performed by nonconspecifics: An fMRI study. *Journal of Cognitive Neuroscience*, 16, 114-126.
- Calvo-Merino, B., Glaser, D.E., Grèzes, J., Passingham, R.E., & Haggard, P. (2005). Action observation and acquired motor skills: an fMRI study with expert dancers. *Cerebral Cortex*, 15, 1243-1249.
- Calvo-Merino, B., Grèzes, J., Glaser, D. E., Passingham, R. E., & Haggard, P. (2006). Seeing or doing? Influence of visual and motor familiarity in action observation. *Current Biology*, 16, 1905 - 1910.
- Canal-Bruland, R., & Schmidt, M. (2009). Response bias in judging deceptive movements. *Acta Psychologica*, 130, 235-240.
- Canal-Bruland, R., van der Kamp, J., & van Kesteren, J. (2010). An examination of motor and perceptual contributions to the recognition of deception from other's actions. *Human Movement Science*, 29, 94-102.

- Carter, E.J. & Pelphrey, K.A. (2006). School-aged children exhibit domain-specific responses to biological motion. *Social Neuroscience*, 1, 396-411.
- Casile, A., & Giese, M.A. (2006). Non-visual motor learning influences the recognition of biological motion. *Current Biology*, 16, 69-74.
- Cohen, L. R. (2002). *The role of experience in the perception of biological motion*. Unpublished dissertation. Temple University, Philadelphia, PA.
- Fahle, M. & Poggio, T. (2002). *Perceptual learning*. Cambridge, MA: MIT Press.
- Fodor, J.A. (1983). *The modularity of mind*. Cambridge, Mass: MIT Press.
- Fodor, J.A., & Pylyshyn, Z. (1981). How direct is visual perception? *Cognition*, 9, 139-196.
- Funk, M., Brugger, P., & Shiffrar, M. (2005). Hand movement observation by individuals born without hands: Phantom limb experience constrains visual limb perception. *Experimental Brain Research*, 164, 341-346.
- Gibson, E.J. (1969). *Principles of perceptual learning and development*. East Norwalk, CT, USA: Appleton-Century-Crofts.
- Grosjean, M., Shiffrar, M., & Knoblich, G. (2007). Fitts' Law Holds for Action Perception. *Psychological Science*, 18, 95-99.
- Grossman, E., Donnelly, M., Price, R., Pickens, D., Morgan, V., et al. (2000). Brain areas involved in perception of biological motion. *Journal of Cognitive Neuroscience*, 12, 711-720.
- Hamilton, A., Wolpert, D., & Frith, U. (2004). Your own action influences how you perceive another person's action. *Current Biology*, 14, 493-498.
- Hildreth, E. (1984). *The measurement of visual motion*. Cambridge, MA: MIT Press.
- Huys, R., Canal-Bruland, R., Hagemann, N., Beek, P.J., Smeeton, N.J., & Williams, A.M. (2009). Global information pickup underpins anticipation of tennis shot direction. *Journal of Motor Behavior*, 41, 158-170.
- Jackson, R.C., Warren, S., & Abernethy, B. (2006). Anticipation skill and susceptibility to deceptive movement. *Acta Psychologica*, 123, 355-371.
- Jacobs, A. & Shiffrar, M. (2005). Walking perception by walking observers. *Journal of Experimental Psychology: Human Perception & Performance*, 31, 157-169.
- Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception & Psychophysics*, 14, 195-204.
- Johansson, G. (1976). Spatio-temporal differentiation and integration in visual motion perception: An experimental and theoretical analysis of calculus-like functions in visual data processing. *Psychological Research*, 38, 379-393.
- Kilner, J.M., Hamilton, A.F.C., & Blakemore, S.J. (2007). Interference effect of observed human movement on action is due to velocity profile of biological motion. *Social Neuroscience*, 2, 158-166.
- Kilner, J.M., Paulignan, Y., & Blakemore, S.J. (2003). An interference effect of observed biological movement on action. *Current Biology*, 13, 522-525.
- Kioumourtoglou, E., Kourtessis, T., Michalopoulou, M. & Derri, V. (1998). Differences in several perceptual abilities between experts and novices in basketball, volleyball and water polo. *Perceptual and Motor Skills*, 86, 899-912.
- Klatzky, R.L., MacWhinney, B., & Behrmann, M. (2008). *Embodiment, ego-space and action: Carnegie Mellon Symposia on Cognition Series*. Hove Sussex: Psychology Press.
- Klin, A., Lin, D. J., Gorrindo, P., Ramsay, G., & Jones, W. (2009). Two-year-olds with autism orient to non-social contingencies rather than biological motion. *Nature*, 459, 257-261.
- Knoblich, G., & Flach, R. (2001). Predicting the effects of actions: interactions of perception and action. *Psychological Science*, 12, 467-472.
- Loula, F., Prasad, S., Harber, K., & Shiffrar, M. (2005). Recognizing people from their movement. *Journal of Experimental Psychology: Human Perception & Performance*, 31, 210-220.
- Marey, E. J. (1895/1972). *Movement*. New York: Arno Press & New York Times.
- Marr, D. (1982). *Vision: A computational investigation into the human representation and processing of visual information*. San Francisco: W. H. Freeman.
- Martineau, J., & Cochin, S. (2003). Visual perception in children: human, animal and virtual movement activates different cortical areas. *International Journal of Psychophysiology*, 51, 37-44.
- Mather, G., & West, S. (1993). Recognition of animal locomotion from dynamic point-light displays. *Perception*, 22, 759-766.
- Muller, S., Abernethy, B., & Farrow, D. (2006). How do world-class cricket batsmen anticipate a bowler's intention? *The Quarterly Journal of Experimental Psychology*, 59, 2162-2186.
- Pavlova, M.A., & Sokolov, A. (2001). Recognition of point-light biological motion displays by young children. *Perception*, 30, 925-933.
- Pinto, J. (2006). Developing body representations: A review of infants' responses to biological-motion displays. In G. Knoblich, M. Grosjean, I. Thornton, and M. Shiffrar (Eds.), *Perception of the human body from the inside out*. Oxford University Press, 305-322.
- Pinto, J., & Shiffrar, M. (2009). The visual perception of human and animal motion in point-light displays. *Social Neuroscience*, 4(4), 332-346.
- Prasad, S. & Shiffrar, M. (2009). Viewpoint and the recognition of people from their movements. *Journal of Experimental Psychology: Human Perception & Performance*, 35, 39-49.
- Prinz W. (1997). Perception and action planning. *European Journal of Cognitive Psychology*, 9, 129-154.
- Proffitt, D.R. (2006). Embodied perception and the economy of action. *Perspectives on Psychological Science*, 1, 110-122.
- Proffitt, D.R., Bhalla, M., Gossweiler, R., & Midgett, J. (1995). Perceiving geographical slant. *Psychonomic Bulletin & Review*, 2, 409-428.
- Puce, A. & Perrett, D. (2003). Electrophysiology and brain imaging of biological motion. *Philosophical Transactions of the Royal Society London. B Biological Sciences*, 358:435-445.
- Pyles, J.A., Garcia, J.O., Hoffman, D.D., & Grossman, E.D. (2007). Visual perception and neural correlates of novel "biological motion." *Vision Research*, 47, 2786-2797.
- Reed, C.L., & Farah, M.J. (1995). The psychological reality of the body schema: a test with normal participants. *Journal of Experimental Psychology: Human Perception & Performance*, 21, 334-343.
- Reed, C.L. & McGoldrick, J.E. (2007). Action during body perception: Processing time affects self-other correspondences. *Social Neuroscience*, 2, 134 -149.
- Rizzolatti, G. & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience*, 27, 169-192.
- Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience*, 2, 661-670.
- Saygin, A. P. (2007). Superior temporal and premotor brain areas necessary for biological motion perception. *Brain*, 130, 2452-2461.

- Saygin, A.P., Wilson, S.M., Hagler, D.J., Bates, E. & Sereno, M.I. (2004). Point-light biological motion perception activates human premotor cortex. *The Journal of Neuroscience*, 24, 6181-6188.
- Sebanz, N. & Shiffrar, M. (2009). Detecting deception in a bluffing body: The role of expertise. *Psychonomic Bulletin & Review*, 16, 170-175.
- Serino, A., De Filippo, L., Casavecchia, C., Coccia, M., Shiffrar, M. & Ladavas, E. (2010). Lesions to the motor system affect action understanding. *Journal of Cognitive Neuroscience*, 22, 413-426.
- Shepard, R. N. (1984). Ecological constraints on internal representation: Resonant kinematics of perceiving, imagining, thinking, and dreaming. *Psychological Review*, 91, 417-447.
- Shiffrar, M. & Freyd, J. (1990). Apparent motion of the human body. *Psychological Science*, 1, 257-264.
- Shiffrar, M. & Freyd, J. (1993). Timing and apparent motion path choice with human body photographs. *Psychological Science*, 4, 379-384.
- Shiffrar, M., Kaiser, M. & Chouchourelou, A. (2010). Seeing human movement as inherently social. In "The Science of Social Vision" by R. B. Adams, N. Ambady, K. Nakayama & S. Shimojo (Eds). New York: Oxford University Press.
- Shiffrar, M., Lichtey, L., & Heptulla Chatterjee, S. (1997). The perception of biological motion across apertures. *Perception & Psychophysics*, 59, 51-59.
- Shiffrar, M. & Lorenceau, J. (1996). Increased motion linking across edges with decreased luminance contrast, edge width and duration. *Vision Research*, 36, 2061-2067.
- Shiffrar, M. & Pinto, J. (2002). The visual analysis of bodily motion. *Common mechanisms in perception and action: Attention and Performance*, Vol. XIX. Oxford University Press, 381-399.
- Stevens, J.A., Fonlupt, P., Shiffrar, M., & Decety, J. (2000). New aspects of motion perception: Selective neural encoding of apparent human movements. *NeuroReport*, 11, 109 - 115.
- Virji-Babul, N., Cheung, T., Weeks, D., Kerns, K., & Shiffrar, M. (2007). Neural activity involved in the perception of human and meaningful object motion. *NeuroReport*, 18, 1125-1128.
- Viviani, P. (2002). Motor competence in the perception of dynamic events: a tutorial. In *Common Mechanisms in Perception and Action: Attention and performance*, Vol. XIX, ed. W Prinz, B Hommel, pp. 406-42. Oxford: Oxford University Press.
- Viviani, P., & Stucchi, N. (1992). Biological movements look uniform: evidence of motor-perceptual interactions. *Journal of Experimental Psychology: Human Perception & Performance*, 18, 603-23.
- Wachsmuth, I., Lenzen, M., & Knoblich, G. (2008). Embodied communication in humans and machines. New York: Oxford University Press.
- Williams, A.M. & Davids, K. (1998). Visual search strategy, selective attention and expertise in soccer. *Research Quarterly for Exercise and Sport*, 69, 111-128.
- Wilson, M. (2001). Perceiving imitable stimuli: Consequences of isomorphism between input and output. *Psychological Bulletin*, 127, 543-553.
- Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin and Review*, 9, 625-636.
- Wilson, M. (2008). How did we get from there to here? An evolutionary perspective on embodied cognition. In P. Calvo & T. Gomila (Eds.), *Directions for an Embodied Cognitive Science: Towards an Integrated Approach*. Elsevier.
- Wilson, M. & Fox, G. (2007). Working memory for language is not special: Evidence for an articulatory loop for novel stimuli. *Psychonomic Bulletin and Review*, 14, 470-473.
- Wilson, M. & Knoblich, G. (2005). The case for motor involvement in perceiving conspecifics. *Psychological Bulletin*, 131, 460-473.
- Wright, M.J., Bishop, D.T., Jackson, R.C., & Abernethy, B. (2010). Functional MRI reveals expert-novice differences during sport-related anticipation. *NeuroReport*, 21, 94-98.

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