



# People watching: visual, motor, and social processes in the perception of human movement

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Successful social behavior requires the accurate perception and interpretation of other peoples' actions. In the last decade, significant progress has been made in understanding how the human visual system analyzes bodily motion. Neurophysiological studies have identified two neural areas, the superior temporal sulcus (STS) and the premotor cortex, which play key roles in the visual perception of human movement. Patterns of neural activity in these areas are reflective of psychophysical measures of visual sensitivity to human movement. Both vary as a function of stimulus orientation and global stimulus structure. Human observers and STS responsiveness share some developmental similarities as both exhibit sensitivities that become increasingly tuned for upright, human movement. Furthermore, the observer's own visual and motor experience with an action as well as the social and emotional content of that action influence behavioral measures of visual sensitivity and patterns of neural activity in the STS and premotor cortex. Finally, dysfunction of motor processes, such as hemiplegia, and dysfunction of social processes, such as Autism, systematically impact visual sensitivity to human movement. In sum, a convergence of visual, motor, and social processes underlies our ability to perceive and interpret the actions of other people. © 2010 John Wiley & Sons, Ltd. *WIREs Cogn Sci* 2011 2 68–78 DOI: 10.1002/wcs.88

## INTRODUCTION

We spend enormous sums of money to watch other people move. For example, in the United States in 2009 alone, Major League Baseball and the National Football League had combined revenues of over 12 billion dollars.<sup>1</sup> Of course, baseball and football fans could have saved the vast majority of this money, not to mention hours and hours of time, by simply reading the scores and statistics after each game. Instead, they paid impressive sums to watch games unfold on television broadcasts, or even better, to attend games in person. Why? Because human beings are fascinated by the ways in which other people move. Watching outstanding athletes perform is simply captivating. Observing a talented dancer can be mesmerizing. In terms of interpersonal attraction, the lyrics of numerous songs attest to the fact that there is something in the way she (or he) moves.

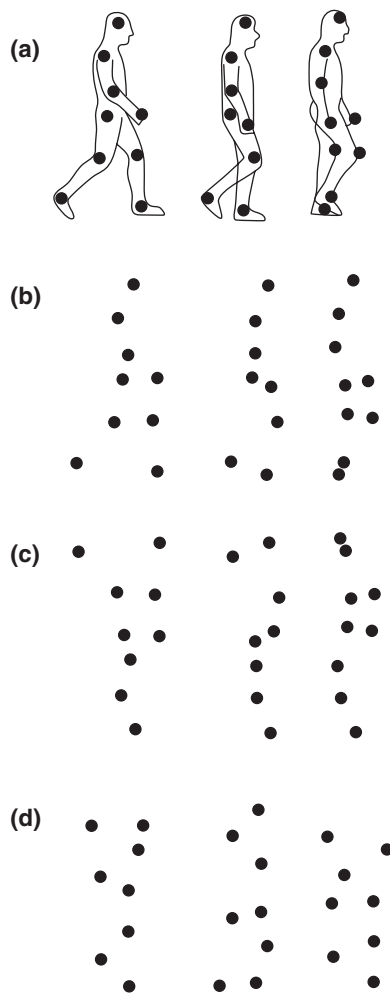
How do we perceive and interpret the movements of other people and why is their movement so engaging? Modern research addressing these questions started in the 1970s when Gunnar Johansson constructed movies of point-light-defined people in action. Johansson attached small lights to an actor's major joints and head and then filmed that actor's actions so that only the lights were visible (Figure 1(a) and (b)). When naïve observers viewed these point-light movies, they accurately detected the underlying actions in as little as a fifth of a second.<sup>2</sup> Although Johansson's goal was to construct a model of visual motion perception that applied equally well to all categories of visual motion,<sup>3</sup> he nonetheless noted that percepts of human motion were significantly more vivid than percepts of other types of motion.<sup>2</sup>

Many researchers in the vision sciences have approached the question of how observers analyze the movements of other people in the same way that they studied the visual analyses of object movement. 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

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**FIGURE 1** | (a) A series of static outlines depicts the changing shape of a walking person's body with point-lights attached to the major joints and head. (b) A point-light walker is constructed by removing everything from each image except the point-lights. When static, these displays are difficult to interpret. Once set in motion, typical observers readily detect the presence of a walking person. (c) When point-light movies are inverted, visual sensitivity drops significantly. (d) The locations of the points defining a point-light walker can be randomized within the same area. These scrambled walkers, which can be used to construct point-light masks, contain the same local motion information as coherent walkers but lack the global structure of the human body.

of human actions. This difference can be readily understood if one starts with the premise that the goal of perception is to help people function within their environments. Perception clearly facilitates our ability to navigate environments and manipulate objects. The detection of trees for collision avoidance may be fairly similar to the detection of stationary people so that you can avoid colliding with them. But unlike trees, humans are locomotive and inherently social creatures who interact with other people in complex and subtle

ways. The human visual system appears to be well tuned for the detection of both physical and social characteristics of the human body in motion.<sup>4</sup>

## TYPICAL DEVELOPMENT

Early preferential looking studies demonstrated that typical infants between the ages of four and six months can differentiate between point-light depictions of human motion and random motion and between upright and inverted point-light displays of human motion.<sup>5</sup> More recent work indicates that even 2-day-old infants show a preference for upright human motion, suggesting that the capacity to orient toward other people's actions may be innate.<sup>6</sup> Nonetheless, visual sensitivity to point-light displays of human motion evolves during an observer's development. For example, 3-month-old observers can detect perturbations in the phase relations between the points defining a coherent point-light walker. But their detection abilities are equivalent for upright and inverted point-light walkers (Figure 1(b) and (c)). However, just 2 months later, at the age of 5 months, observers demonstrate specialization in their visual sensitivity to upright human motion.<sup>7</sup>

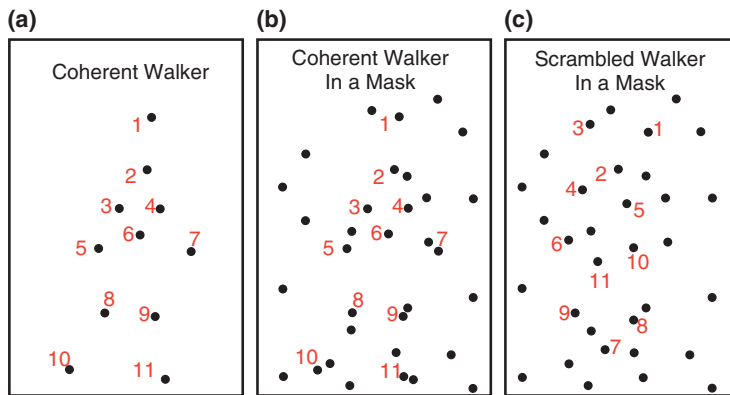
Additional evidence in support of the hypothesis that the human visual system becomes increasingly tuned for analyses of human motion comes from tasks comparing infants' visual sensitivity to point-light displays of human and animal motions. At the age of 3 months, infants demonstrate equivalent patterns of visual sensitivity to a point-light person, spider, and cat. By 5 months of age, patterns of visual sensitivity shift significantly and infants demonstrate greater sensitivity to point-light displays of human motion than to point-light displays of animal motion.<sup>7</sup>

Perceptual sensitivity to simple, unmasked point-light displays of human movement starts to reach adult levels in observers as young as 5 years old.<sup>8</sup> When point-light walkers are hidden within point-light masks (Figure 2(b)), walker detection improves significantly from 6 to 9 years of age and again from 9 years of age to adulthood.<sup>9</sup>

## PERCEPTUAL SENSITIVITIES IN ADULT OBSERVERS

### Orientation Dependence

A significant characteristic of the visual perception of human motion that has been repeatedly documented is its orientation dependence. Observers demonstrate greater visual sensitivity to upright human motion than to inverted human motion.<sup>10</sup> For example,



**FIGURE 2** | (a) Motion coherence detection tasks are frequently used to measure visual sensitivity to point-light displays of human motion. In these tasks, half of the trials depict (b) a coherent point-light walker hidden within a mask. In the other half of the trials, the starting locations of the points defining the walker are scrambled and the resulting scrambled or incoherent walker (c) is placed within a mask. Because the mask is constructed from the point-light walker that appears within it, the individual points defining the mask and walker (whether coherent or scrambled) have identical motions.

an observer's ability to identify coherent walkers<sup>11</sup> and other complex actions drops when point-light displays are inverted (Figure 1(c)). Visual experience is insufficient to account for this orientation effect. In a study of this issue, dog trainers and seal trainers were asked to detect the presence of coherent dog, seal, and human motion in masked point-light displays.<sup>12</sup> To the extent that visual experience drives orientation dependence, dog trainers should exhibit more orientation-dependent sensitivity to dog motion than to seal motion while seal trainers should show more orientation-dependent sensitivity to seal motion than to dog motion. In contrast to this prediction, both dog trainers and seal trainers demonstrated the most sensitivity and orientation dependence to point-light human motion, significantly less to point-light dog motion, and the least sensitivity and orientation dependence during the perception of point-light seal motion.<sup>12</sup>

## Visual Experience

However, visual sensitivity to human motion is not independent of visual experience. Indeed, in his original studies, Johansson<sup>2</sup> conjectured that the especially vivid percepts that observers readily experience when viewing point-light displays of human movement reflect observers' extensive prior experience looking at human movement outside of the laboratory. Consistent with this, computational modeling suggests that various aspects of visual sensitivity to human motion can be explained by visual experience alone.<sup>13</sup> As inherently social animals, humans necessarily spend more time watching other people act than they spend watching drifting clouds or wind blown leaves. The results of several psychophysical studies suggest that this tendency to direct our gaze toward other people has perceptual consequences. In one such study, observers viewed point-light walkers and rated the degree to which each figure looked human.<sup>14</sup> As long as point-light

walkers retained normal two-dimensional projections, observers rated the walkers as human, even when the displays had three-dimensional anomalies in depth. Such data suggest that visual experience is sufficient to override significant depth distortions.

Substantial levels of visual experience are needed to modify our visual percepts of human movement. For example, observers in one study viewed point-light displays of friends and strangers walking with commonly occurring gaits and unusual gaits.<sup>15</sup> Walkers were more accurately identified when they performed their naturally occurring gaits. However, enhanced sensitivity to frequently observed gaits required over a dozen hours, per week, of face-to-face, real-world interaction between the observer and the person depicted as a point-light walker.

## Global Analyses

Another fundamentally important characteristic of the visual perception of human movement is global processing. When a point-light-defined person walks within a point-light mask (Figure 2), observers can reliably detect the person.<sup>10</sup> Point-light masks are typically constructed by duplicating a point-light walker and then randomizing the starting locations of the duplicate points. Because the points in the mask have the same size, luminance, and velocities as the points defining the walker, local or point-by-point analysis cannot be used to detect the walker. Instead, only the global spatiotemporal configuration of the points distinguishes the walker from the mask. Thus, the ability to detect masked point-light walkers, as well as other findings,<sup>16</sup> indicates that the detection of point-light walkers involves the integration of motion cues over space and time.

The ability of adult observers to analyze human motion over extended temporal intervals has been examined by expanding the amount of time in between the frames depicting a point-light walker.<sup>17</sup> Naïve observers are significantly above chance in their

detection of the direction in which a point-light person faces while walking in place even when the inter-frame interval is as long as 120 ms.<sup>17</sup> This is not to say that temporally local analyses are not used during the perception of point-light displays. Indeed, under most conditions, our visual percepts of other peoples' actions depend upon both local and global motion analyses.

Studies of apparent motion with displays containing substantial bodily form cues (Figure 3) confirm that the visual perception of human motion occurs over long temporal extents. For example, when presented with two rapidly alternating pictures of a moving person, observers generally perceive the shortest path of motion connecting the two body postures, even if that path requires the perception of a physically impossible action, such as a hand passing through a person's head. However, when pictures of two body postures are presented at slower rates of alternation that are consistent with the temporal characteristics of normal human actions, observers tend to perceive paths of apparent motion that are consistent with physically possible paths of human movement.<sup>18</sup> Conversely, when control objects are shown at the same slow rates, the shortest, physically impossible path of apparent motion is perceived. Taken together, these results indicate that human movement is analyzed by processes that operate over relatively large spatiotemporal windows and that take into account the biomechanics of the human body.<sup>19</sup>

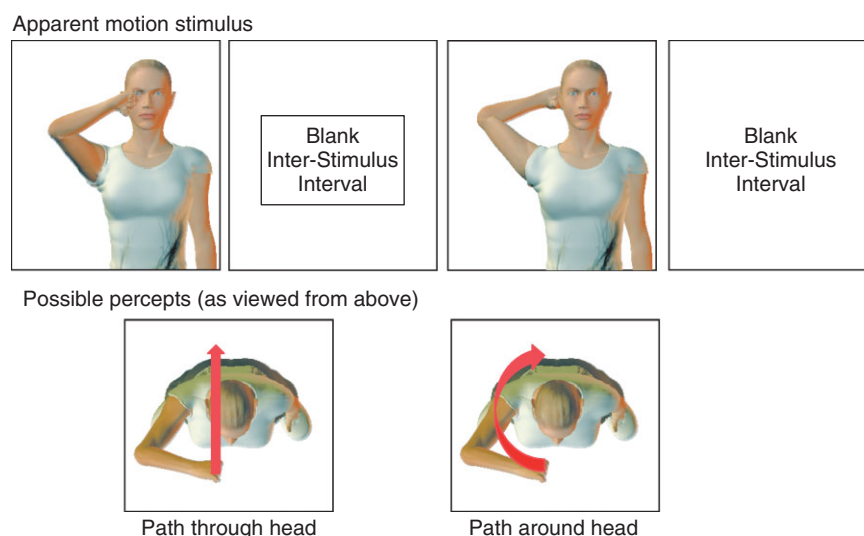
Finally, global processing is not a characteristic of the perception of all categories of complex visual motion. The detection of complex, nonhuman motion differs from the detection of human motion in a mask. For example, when the ability to detect a point-light person and a point-light horse walking within a mask is compared, observers demonstrate greater visual sensitivity to the presence of coherent human motion.<sup>20</sup>

## Attention

The visual perception of point-light displays of human movement also depends upon attention. Focused attention is required for the detection of a point-light walker within a point-light mask.<sup>21</sup> Nonetheless, unattended point-light walkers influence the perception of attended walkers.<sup>22</sup> Thus, both bottom-up and top-down processes are employed during the perception of point-light displays of human motion.<sup>4</sup>

## Motor Experience

Another fundamental aspect of the visual perception of human movement is its dependence on the observer's own motor experience. For example, the production of simple hand and arm movements within a plane is described by the two-thirds power law that defines the relationship between the hand trajectory's instantaneous velocity and radius of curvature.<sup>23</sup> Visual motion percepts are systematically distorted



**FIGURE 3** | Two frames from an apparent motion display depict a woman's arm in front of and behind her head. When these two images are presented in repeated alternation, the arm appears to move straight through the woman's head along the shortest path of apparent motion even though that path is physically impossible. As the rate of alternation slows, the arm appears to move naturally around the woman's head along a longer, but physically possible, path of apparent motion.



whenever dynamic stimuli violate this fundamental principle of movement production.<sup>23</sup> 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 human motion between targets conform to this motor law.<sup>24</sup> Furthermore, the perception of motor outcomes reflects each observer's own motor processes. For example, when observers try to predict where a thrown dart will land, their predictions are most accurate when they observe dart throws that they themselves had previously performed.<sup>25</sup> Such evidence indicates that motor processes systematically constrain the visual perception of human movement. Indeed, it has been convincingly argued that the human visual system is optimized for the analysis of movements generated by humans.<sup>23</sup>

Additional support for the hypothesis that motor processes impact the visual perception of human movement comes from interference effects during the simultaneous production and perception of the same human actions. In one such study, walking observers, relative to stationary observers or observers riding a bicycle, showed deficits in their visual sensitivity to the walking speeds of an observed person.<sup>26</sup> Furthermore, the perceived weight of an invisible box being lifted by a point-light-defined person depends on the weight of the box being lifted by the observer.<sup>27</sup> Thus, action production interferes with action perception. Conversely, action perception also interferes with action production. 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.<sup>28</sup> Consistent with the importance of velocity profiles,<sup>23</sup> this interference effect depends upon the similarity between the velocity profiles of simultaneously observed and produced arm movements.<sup>29</sup> Finally, motor learning significantly influences action perception. Observers can improve their visual sensitivity to point-light displays of unusual actions by learning to execute those actions while blindfolded.<sup>30</sup>

Taken together, the results of these studies are consistent with the hypothesis that action perception and action production are tightly coupled. But, how does this coupling actually work? Current evidence and theoretical models suggest that action-perception coupling reflects the sharing of body representations by the motor and visual system.<sup>31,32</sup> When the visual and motor systems must compete for access to the same body representation, interference occurs.<sup>31</sup> However, interactions between the visual and motor systems can also have facilitatory effects. For example, when observers try to discriminate between pairs

of body postures, their visual sensitivity to postural differences improves when they move limbs corresponding to the observed limbs that they are visually analyzing.<sup>33</sup> Interestingly, the amount of available processing time determines whether perception-action coupling is facilitatory or inhibitory. When processing time is brief, inhibition results. When processing time is extended, facilitation occurs.<sup>33</sup> It has been suggested that<sup>33</sup> this shift from inhibitory to facilitatory interactions between the visual and motor systems may reflect the gradual decay of sensorimotor representations within working memory.<sup>34</sup>

When observers move, they often do so with the goal of coordinating their actions with those of another person. Consider, for example, handshakes and kisses. The potential for action coordination also shapes visual sensitivity to human movement. When action coordination is possible, visual analyses of the observer's own gait speed relative to the gait speed of a nearby point-light walker depend upon the observer's own gait speed, motor exertion, and level of physical fitness.<sup>26</sup> Conversely, when action coordination is impossible, perceptual comparisons between self and other movement are independent of these motoric constraints. Thus, interactive observers can perform visual analyses of human movement that are distinct from the visual analyses performed by noninteractive observers.

The above results all converge in suggesting that both visual and motor experiences contribute to our visual sensitivity to human movement. Normally, visual and motor experiences are inherently confounded. Observers tend to perform the same actions that they see others perform. Monty Python's famous skit, the Ministry of Silly Walks, provides an amusing counterexample. Under such conditions that decouple motor and visual experience, motor experience appears to contribute more to our percepts than visual experience. For example, when observers view point-light displays of themselves, friends and strangers individually performing various actions, they are best able to identify their own actions even though they have the most visual experience with their friends' actions.<sup>35</sup> Enhanced sensitivity to self-generated actions can be attributed to contributions from the observer's own motor system.<sup>25,35</sup> Studies of person and action recognition across egocentric and allocentric viewpoints suggest that visual experience, *per se*, cannot account for enhanced visual sensitivity to one's own actions.<sup>36</sup>

## Social Processes

Traditional models of the visual system describe it as a general-purpose processor that analyzes all

categories of moving objects similarly.<sup>37</sup> In contrast to this homogeneous approach, more recent social brain theories suggest that the visual system is tuned for the detection and analysis of socially relevant information.<sup>38,39</sup> The movements of the human body convey cues that are important for successful social interaction. Imagine, e.g., the trouble that would arise if an observer were unable to rapidly differentiate between the arm movements of a punch and a handshake. Two general predictions can be made from social brain theories. First, if the human visual system is tuned for the detection of socially relevant information, then observers should be able to detect substantial social information from the movements of other people. Second, to the extent that brain structure reflects social constraints,<sup>38</sup> social cues should influence perceptual analyses. Evidence in support of both of these predictions is outlined below.

### *Detection of Social Information*

Observers can detect an impressive array of social information in point-light displays of human movement. For example, naïve observers are above chance in their ability to detect the gender and the identity of point-light-defined walkers in motion but not when static.<sup>35,40</sup> Observers are also able to detect sexual orientation from body movements alone.<sup>41</sup> Other studies have demonstrated that untrained observers can detect another person's intention to deceive,<sup>42</sup> potential reproductive fitness, psychological openness, age, social dominance, and vulnerability in point-light displays (see Ref 4 for review). In sum, when people move, their movements express extensive social information that the human visual system is capable of detecting.

Affective state can also be reliably detected in point-light displays of human movement. Observers can readily identify the emotions felt by point-light-defined individuals who move their entire body<sup>43</sup> or just an arm.<sup>44</sup> Affective states are most recognizable when a point-light person appears in a social interaction with another point-light person.<sup>45</sup> Thus, social and emotional cues appear to be integrated during the visual perception of human movement.

### *Influences of Social-Emotional Content*

In studies of the visual perception of the human body in apparent motion, visual context changes the onset of perceived motion. For example, when apparent motion stimuli depict a person performing a simple action, observers report more compelling motion percepts and earlier motion onsets (as opposed to the perception of static flashing) when those actions are presented within social contexts than

within object contexts or in isolation.<sup>46</sup> In other words, the perception of human movements directed toward another person is enhanced relative to human movements directed toward an object. These results are consistent with the hypothesis that social processes change fundamental aspects of the visual perception of human movement. Given that human movement is an inherently social stimulus, it certainly makes sense that social context would contribute to its analysis.

Affective cues also modulate visual sensitivity to human movement. When point-light walkers expressing different emotional states are placed within point-light masks that equate the velocity information between each walker and the mask in which it appears, observers demonstrate greater visual sensitivity to the presence of angry point-light walkers than they do to the presence of happy, sad, fearful, or neutral emotional state point-light walkers.<sup>43</sup> An angry person is potentially a threatening stimulus. As outlined in the *Neurophysiological* section, heightened visual sensitivity to potentially threatening human actions is consistent with direct neural connections between threat detection mechanisms and visual mechanisms involved in the perception of human movement.

## NEUROPHYSIOLOGICAL MECHANISMS

In recent years, substantial progress has been made in defining the neural mechanisms underlying visual analyses of human motion. Research with stroke patients has demonstrated that at least two areas, the superior temporal sulcus (STS) and the premotor cortex, are required for the accurate detection of coherent point-light displays of human motion.<sup>47</sup> The STS is understood as a largely visual area that integrates form and motion information within the visual domain and integrates visual information with other sensory information. The premotor cortex is a part of the 'mirror neuron' system that is thought to link action production with action perception.<sup>48</sup> Experimental evidence connecting these areas with the visual perception of human motion is described in the following section.

### *Visual*

From single cell recordings in the macaque cortex, David Perrett and his colleagues first discovered that STS neurons are selectively responsive to the human body in motion (see <sup>49</sup> for review). More recent brain imaging data indicate that the posterior region of the STS, or STSp, reacts strongly to point-light depictions of coherent, but not scrambled, human movement

(Figure 1) in a manner that is modulated by visual experience.<sup>50</sup> STSp responsiveness is greater during the perception of upright displays of point-light people in motion than during the perception of the same displays when inverted.<sup>51</sup> STSp activity appears to be hemisphere dependent as the right STSp frequently responds more strongly than the left.<sup>52</sup> Finally, research with transcranial magnetic stimulation indicates that functionality within area STSp is required for the accurate perception of point-light displays of human movement in typical observers.<sup>53</sup>

## Motor

Visual perception of point-light displays of human movement also selectively triggers activity in the human premotor cortex.<sup>54</sup> Electroencephalography (EEG) data indicate further that the premotor cortex, part of the mirror system, plays a critical role in the perception of coherent, but not scrambled, point-light displays of human motion.<sup>55</sup> Motor system activity during action perception is modulated by whether an observed action is humanly possible to perform<sup>56</sup> and by the observers' past motor experience with the observed action.<sup>57</sup>

## Social

STSp activity is clearly involved in the analysis of visual cues to socially relevant information.<sup>58</sup> Indeed, overlapping neural circuitry is involved in the visual perception of emotions, social cues, and human action. For example, the STSp responds more strongly during the perception of emotional actions than during the perception of instrumental actions.<sup>59</sup> The responsiveness of STSp to social and emotional information likely reflects the considerable feedback that STSp receives from the amygdala, a subregion of the limbic system involved in the assessment of social-emotional cues.<sup>38,60</sup> Consistent with this prediction, STS activity is strongly modulated by the degree of potential threat in visual stimuli.<sup>61</sup> Indeed, this area may contribute to the determination of the social significance of observed actions.

## IS THE PERCEPTION OF HUMAN MOTION 'SPECIAL'?

The evidence summarized above indicates that the perception of human motion depends upon a convergence of visual, motor, and social processes. This convergence, in turn, implies that the perception of human movement differs, at least in some ways, from the perception of other types of complex

movement. As inherently social creatures, humans typically spend more time looking at and attending to other humans than any other category of moving objects or creatures. Furthermore, the human motor system obviously codes extensive information about human movement and little if any information about the movements of rolling rocks or wind blown trees. Finally, human social interactions are largely with and about other humans. Thus, each of these systems, visual, motor, and social, can be understood as tuned for the analysis of human information. To the extent that this holds true, the perception of human motion should differ in fundamental ways from the perception of other types of complex motion.

As an aside, it is important to note a potentially confusing issue of nomenclature. The term 'biological motion' has been traditionally used to describe point-light displays of human motion.<sup>2</sup> This term implies that the visual system analyzes all biological motions similarly, whether human, animal, or plant. Yet, as discussed in the following section, increasing evidence suggests that different types of 'biological' motions are processed in dissimilar ways. Thus, while the term 'biological motion' has historical significance, the term 'human motion' is a more precise and as such, is being increasingly adopted.

Neurophysiological and psychophysical evidence indicates that the visual perception of human and object motions differ in several respects. For example, the mirror system responds during the perception of actions but not objects.<sup>48</sup> STSp activity is greater during the perception of human motion than during the perception of object motion.<sup>52</sup> Magnetoencephalography (MEG) activity indicates that analyses of point-light displays of human movement and object movement diverge approximately 200 ms after stimulus onset.<sup>62</sup> MEG activity further demonstrates dissociable cortical processing between coherent and scrambled point-light displays of human movement.<sup>63</sup> The results of psychophysical studies converge with these neurophysiological results in suggesting that typical observers exhibit qualitatively different patterns of visual sensitivity to global human motion and to object motion.<sup>19</sup>

Other studies have compared the perception of human and nonhuman, animal motions. Naïve observers can readily identify and classify animals depicted in dynamic point light displays.<sup>64</sup> Nonetheless, adult observers demonstrate greater visual sensitivity to human motion than to animal motion in point-light displays.<sup>20</sup> By the age of 5 months, infants respond to phase differences in upright human gaits but not in upright animal gaits.<sup>7</sup> Indeed, the developmental trajectory of sensitivities to human

and animal motions suggests that the infant visual system becomes specialized or tuned for the detection of canonical human motion.<sup>7</sup> Consistent with this, STSp activity becomes increasingly tuned to human motion as typical children age.<sup>39</sup> In adults, STSp activity is greater during the perception of human motion than during the perception of animal-like creature motion.<sup>65</sup> Furthermore, the mirror system is engaged during the visual perception of human motion but not animal motion.<sup>66</sup> Taken together, these results suggest that increased neural activity in the STSp and mirror system may differentiate visual sensitivity to human and animal motions.

## INDIVIDUAL DIFFERENCES IN VISUAL SENSITIVITY TO HUMAN MOTION

If visual sensitivity to human motion depends upon motor and social processes, then disruptions to those processes should lead to decrements in visual sensitivity to point-light displays of human action. Studies of patients with motor disorders support the impact of motor processes on action perception. For example, children with motor impairments resulting from Down syndrome show decrements in their visual sensitivity to point-light displays of human motion relative to age-matched control observers.<sup>67</sup> Hemiplegic patients with motor system lesions exhibit degraded visual sensitivity to point-light actions that correspond to their compromised limbs but not to point-light actions that correspond to their functional limbs.<sup>68</sup> Finally, when observers born without hands view apparent motion displays of hands, their percepts of apparent hand rotations depend upon whether they have a mental representation or 'body schema' of their own physically absent hands. Observers lacking a mental representation of their congenitally absent hand perceive physically impossible paths of apparent hand rotation. Those with hand schema perceive physically possible paths of apparent hand rotation.<sup>69</sup> Evidently, internal representations of one's own limbs influence the visual perception of other people's actions performed with corresponding limbs.

The impact of social dysfunction on visual sensitivity to human movement has been assessed in observers with Autism Spectrum Disorder (ASD). ASD is characterized by a triad of symptoms including dysfunctional social behavior, communication impairments, and repetitive or stereotyped behaviors.<sup>70</sup> Although ASD presents differently in different people, social dysfunction is at its core. Recent evidence indicates that observers with ASD experience selective deficits in their visual sensitivity to point-light displays of human movement. For example, children with

ASD perform more poorly than matched control observers in the detection of coherent human motion but not in the detection of coherent static form.<sup>8</sup> Furthermore, young adults on the Autism Spectrum show no difference in their visual sensitivity to human motion and object motion while, consistent with the social brain theories, typically developed observers show greater visual sensitivity to human movement than to object movement.<sup>71</sup>

Brain imaging data support compromised visual processing of point-light displays of human motion by observers with ASD. The STSp exhibits structural and processing deficits in observers with ASD (see Ref 71 for review). Furthermore, the STSp in children with ASD, relative to typical control children, shows less response selectivity to human motion.<sup>39</sup> The mirror neuron system<sup>48</sup> also appears to be compromised in observers with ASD,<sup>72</sup> although that point is more controversial.

The presence of autistic traits is not a dichotomous phenomenon. Instead, the magnitude of autistic traits varies normally within the typically developing population.<sup>73</sup> When visual sensitivity to human and object motions is assessed in typical observers as a function of the magnitude of their autistic tendencies, a consistent pattern of results emerges. Specifically, as the magnitude of a typical observer's autistic tendencies increases, their visual sensitivity to human motion decreases while their visual sensitivity to object motion is unchanged.<sup>74</sup> Assuming that human movement is a socially relevant stimulus, these results are consistent with social brain theories<sup>38,39</sup> in suggesting that the typical human visual system is tuned for the detection of socially relevant information.

## CONCLUSION

In conclusion, our ability to perceive and interpret the actions of other people depends upon a convergence of information from visual, motor, and social processes. As inherently social beings, we appear to come into this world ready and able to detect the actions of the people around us.<sup>6</sup> After a few years of typical experience, the visual systems of children become tuned for the detection of human motion relative to the detection of objects and animals in motion.<sup>7,39</sup> While reflecting real-world phenomena such as a lifetime of experience watching other people move and the need for successful social interactions, observers' percepts of human movement can also be understood as embodied in that people use their own motor experience to perceive the actions of others.<sup>4,19,31,32</sup>

Additional studies of the visual perception of human action are needed to tackle numerous issues



with important applied and theoretical implications. For example, aging populations raise the question of how visual sensitivity to human movement evolves when observers age beyond the age of typical research participants—university students. As wars trigger increases in the number of amputees, more research is needed to understand the impacts of limb loss and prosthetic use on visual sensitivity to other people's movements. Because cell phone use increasingly distracts drivers, the need rises for studies of pedestrian detection under conditions of divided attention.

In a final point, the interconnected triad of motor, visual, and social factors that define our percepts of the human body in motion highlights a potential cost of studying the visual perception of abstract

stimuli such as random-dot kinematograms and plaid patterns. While these stimuli have long dominated studies of visual motion perception, our visual systems did not evolve for their detection. While abstract stimuli can be precisely defined and controlled, it is unclear how one might come to understand the complex interactions between real-world behaviors and sensorimotor processes with stimuli that do not correspond to behaviorally relevant entities found outside the laboratory.<sup>75</sup>

## NOTES

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