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Beyond the scientific objectification of the human body: Differentiated analyses of human motion and object motion

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Abstract

Vision researchers typically objectify the human body in their studies of body perception by adopting the same theoretical approaches and experimental methodologies used in studies of object perception. While the human body can be understood as a physical object, it is also much more. Numerous behavioral and neurophysiological studies with adult and infant observers have demonstrated important differences in the visual perception of human motion and object motion. At least three factors; motor experience, visual experience, and emotional processes, differentiate the visual perception of animate, or at least observer-like, entities from inanimate entities.

I. Introduction: Is the human body simply an object?

The differentiation of animate, intentional entities from inanimate ones is fundamentally important for any organism that interacts with its environment. At a very basic level, the behavioral interactions that humans have with animate and inanimate beings differ significantly. For example, successful interactions with animate entities, relative to inanimate entities, involve added complexities such as the accurate detection and comprehension of intentions. While the class of animate entities is very large, human observers have the most experience, by far, interacting with one type of animate entity: people. The goal of this chapter is to review differences in the visual analysis of human motion and the motions of inanimate objects by both adult and infant observers. Visual analyses of non-human, animal motions will also be considered as recent evidence suggests that the perception of animal motion depends upon some of the same mechanisms that underlying the perception of human motion.

While developmental psychologists have long studied differences in the perception of animate and inanimate motions, many vision scientists have assumed that the same motion processes underlie the perception of both categories of motion. For example, let's consider the conclusions of three leading vision researchers of the 20th century. In his influential book "Vision," David Marr (1982) argued for a single, hierarchical visual mechanism that produces the same types of descriptions for both animate (e.g., humans and animals) and inanimate (e.g., tanks) stimuli. Similarly, Roger N. Shepard (1984) described visual motion perception as dependent upon the same processes no matter what the underlying input. As Shepard 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). The work of Gunnar Johannson provides another example of the scientific "objectification" of human bodies in action. Johansson's influential vector analysis model of visual motion perception (e.g., Johansson, 1964, 1976) was intended to apply to all categories of dynamic visual stimuli. Indeed, when Johansson first applied the point-light technique to the study of the perception of human movement (Johansson, 1973), he did so with the purpose of determining whether the mechanisms involved in the perception of rolling wheels were sufficient to account for the perception of moving animals. He concluded that they were. When he discovered that observers described their visual percepts of point-light displays of human movement as particularly vivid, Johansson (1973) attributed this enhanced vividness to differences in visual experience and most definitely not as a reflection of differentiated visual processes dedicated to the perception of human action.

Of course, the human body is a physical object. And, as will be outlined below, the visual perception of human motion and object motion share many functional and processing constraints. For example, the perception of a stationary mailbox for the purpose of navigating around it and perception of a seated woman for the purpose of navigating around her likely depend upon similar neural mechanisms. And, as will be outlined below, there are many situations in which human observers perceive human motion and object motion in the same ways (e.g., Shiffrar & Freyd, 1990; Funk, Shiffrar, & Brugger, 2005). Consistent with this, MEG data indicate that visual analyses of point-light displays of human motion and of object motion rely on the same brain regions during the first 200 msec of analysis (Virji-Babul et al., 2007). Thus, at several levels, the visual perception of people and objects rely on the same processes.

However, mounting evidence suggests the existence of fundamentally important differences between the perception of people and the perception of objects. From a functional point of view, we obviously interact differently with people than with objects. When I detect a friend executing a pendular waving motion with her arm, I might wave back or I might walk over to say hello. But, if I were to see that same pendular motion performed by the branch of a tree, I would neither wave to the tree nor initiate a conversation with it. As an inherently social stimulus, human motion affords different behavioral opportunities than object motion. Since we interact differently with people than with objects, it makes sense to wonder whether our visual system analyzes people and objects differently. Neurophysiological and psychophysical evidence, summarized below, overwhelmingly supports the hypothesis that visual analyses of human motion differ in some fundamental ways from visual analyses of object motion.

II. Differences in the visual perception of human and object motions: Adult observers

By definition, motion is a change in spatial location over time. Thus, one simple approach to the question of whether the visual system analyzes human motion and object motion differently is to investigate how these types of stimuli are analyzed over space and time. Because the input to the visual motion perception system comes from retinal receptors with relatively small receptive fields, the movements of real world stimuli must be inferred from a balanced integration of the luminance changes detected within many tiny regions of the retina. This creates a problem for the visual system that is analogous to John Godfrey Saxe's (1855) rendition of the classic Indian tale of six blind men feeling an elephant in order to identify it. One man feels only the elephant's tail. Another man feels a tusk. Yet another feels a knee, etc. Individually, no man can identify the elephant by generalizing from the tactile information gathered from one small region of the elephant's body. Instead, the identification of the elephant requires a complex, higher-level integration of the men's collective experiences. In the same way, no individual neuron in an observer's visual system can identify a real object's motion. Instead, motion measurements have to be combined across space and time.

IIa. Integrating Motion Across Space
So how does the visual system accurately assess the movements of real world entities from a multitude of tiny, local measurements? Simply averaging all of the motion measurements across an image would necessarily result in the perception of one big undifferentiated blob of motion. So how does the visual system resolve this problem? One class of global processing models posits that the visual system compares motion measurements across rigidly connected edges that have different orientations (e.g., Adelson & Movshon, 1982). Another class of local motion processing models selectively relies on the measurements taken from edge discontinuities, such as endpoints and corners, that indicate where one object ends and the next object begins (e.g., Hildreth, 1984). Over the years, it has been apparent that the human visual system uses both global and local motion processes (Shiffrar & Lorenceau, 1996). But, as we'll see below, the balanced interaction of local and global processes depends, in part, on whether the underlying stimulus being analyzed is human motion or object motion.

When observers view objects, such as squares, cars, and scissors, moving behind apertures (an experimental technique that simulates the measurement problem described above), their percepts indicate the use of local motion processes (Shiffrar & Pavel, 1991; Shiffrar & Lorenceau, 1996). Conversely, when observers view human motion through apertures, their percepts indicate the use of global motion processes (Shiffrar, Lichtey, & Heptulla-Chatterjee, 1997). Interestingly, use of these global analyses appears to depend on the physical plausibility of an observed action. When observers view a person walking with impossibly fast or impossibly slow gaits, their percepts indicate a switch back to a heavy reliance on local motion processes. Conversely, when observers view a person walking with typical, physically possible gaits, their percepts reflect a reliance on global motion processes (Shiffrar et al., 1997).
[figure X.1 here]

Point-light displays can also be used to examine how the visual system integrates motion measurements across space. Point-light displays are constructed by attaching small markers or point-lights to the major joints of moving actors or objects (see Figure X.1a). These stimuli are filmed so that only the point-lights are visible. When these highly degraded displays are set in motion, observers readily perceive human motion (e.g., Johansson 1973, 1976). Importantly, when a point-light defined walking person appears within a point-light mask, as shown in Figure X.1b, typical adult observers can reliably detect the person (e.g., Bertenthal & Pinto 1994). Point-light masks are typically constructed by duplicating one or more point-light walkers and then randomizing the starting locations of each of those duplicate points. As a result, the points in the mask have the same size, luminance, and velocities as the points defining the walker. Since the motions of the points defining the person and those defining the mask are identical, local analyses of the motions of individual points cannot be used to detect the walker. Because only the global configuration of the locations and motions of multiple points distinguishes the walker from the mask, detection of point-light walkers in a mask must rely on global or large-scale motion processes (Bertenthal & Pinto, 1994). When the same masking technique is used with non-human, inanimate motions (e.g., Hiris, Krebeck, Edmonds, & Stout, 2005; Kaiser et al., 2010), typical observers' demonstrate relatively marked decrements in their ability to detect these figures relative to their detection of point-light human motion. This pattern of results suggests that observers are better able to integrate human motion across image space than they are able to integrate object motion across space.

IIb. Integrating Motion Across Time
Temporal aspects of motion perception have traditionally been examined with apparent motion, or the illusory perception of movement from rapidly flashed static images. Evidence from this and other temporally based research paradigms indicates that the human visual system integrates human and object motions differently over time, at least under some conditions. In the case of apparent motion, for example, when different views of a moving person and different views of a moving object are displayed under conditions that give rise to apparent motion, the resulting percepts of the two classes of stimuli differ. When static images of a person in two different postures are flashed in rapid alternation (Figure X.2), adult observers generally report the perception of the shortest possible path of motion connecting those postures,

even if that path describes a physically impossible motion, such as one hand translating through another. The shortest possible paths of motion are also seen when two different views of an object are presented in rapid alternation. However, when pictures of the human body are presented at the slower temporal rates that are consistent with the temporal range of normal human action production, then observers tend to perceive paths of apparent motion that are consistent with the biomechanical constraints on the human body. Conversely, when objects are shown at these same slower rates, adult observers continue to report the perception of the shortest possible paths of apparent motion. This pattern of results suggests that human movement is analyzed by motion processes that operate over relatively large temporal windows and that take into account the biomechanical limitations of the human body (e.g., Shiffrar & Freyd, 1990; 1993).

[figure X.2 here]

The ability of adult observers to analyze human motion over extended temporal intervals has also been examined with point-light displays. In one such study, a point-light person walked in place while facing either left or right. The walker was then placed, at random locations, within a point-light mask that reduced the utility of local motion processes. Across trials, a blank display of varying durations separated each of the frames depicting the masked point-light walker. Across trials, observers tried to detect the walker and report whether it faced leftward or rightward (Thornton et al., 1998). Naïve observers were significantly above chance in their detection of the direction in which the point-light walker faced even when the blank temporal interval between each frame, or the inter-stimulus-interval, was as long as 120 milliseconds. In the domain of visual motion perception, 120 msec represents a very long gap that is well outside the range of local motion processes. This is not to say that temporally local analyses are not used during the perception of point-light displays of human motion. Indeed, under most conditions, both local and global motion analyses contribute to our perceptions of other people's actions. But the ability to perceive a coherent point-light walker in a point-light mask and across significant separations in both space and time is most impressive. This finding adds further support for the hypothesis that the visual perception of human movement is unusual in the extent to which it can tolerate massive amounts of noise (or gaps) in both the spatial and temporal dimensions.

IIc. Are people simply animals to the human visual system?

The studies described above compared the visual perception of moving people and moving objects. As a result, it is unclear whether the results of these studies are specific to the perception of human motion or whether they generalize to the perception of all animate and/or intentional motions. We know that observers can recognize non-human animals, including camels, horses, and penguins, from point light displays (e.g., Mather & West, 1993; Chouchourelou, Golden & Shiffrar, 2011). But are the same motion processing mechanisms employed during the perception of human movement and animal movement?

A superb, though little known, psychophysical study conducted by Leslie Cohen in her doctoral dissertation (2002) addressed the above question by comparing visual sensitivities to human, dog, and seal locomotions under otherwise identical conditions. Cohen found that observers were better able to detect the presence of coherent human motion than the presence of coherent seal motion or coherent dog motion in masked point-light displays. One could argue that this pattern of visual sensitivity simply reflects the differential amounts of real world visual experience that observers had had with these three types of motion. But Cohen's (2002) study provided an elegant control for visual experience. She ran three different groups of observers: seal trainers, dog trainers, and typical undergraduates. If levels of visual sensitivity simply reflected levels of visual experience, then seal trainers should show greater visual sensitivity to seal motion than to dog motion and dog trainers should show greater visual sensitivity to dog motion than to seal motion. Instead, Cohen (2002) found that all three classes of observers showed exactly the same pattern of visual sensitivity: the greatest visual sensitivity to human motion and the least visual sensitivity to seal motion. Based on these results, Cohen proposed that visual sensitivity to point-light displays of animal motion might reflect the degree of physical similarity between observed actions and the observer's own repertoire of performable actions. Certainly, it is much easier for humans to imitate the gaits of dogs than the undulating whole-body flops of seal locomotion on land.

The pattern of results summarized above raises a very interesting question. Let's start with the assumption, which, as indicated below, has received extensive support, that the visual perception of human motion relies on the observer's own bodily capabilities (e.g., Wilson & Knoblich, 2005). If visual sensitivity to animal motion reflects the degree of similarity between a seen animal's bodily structure and the bodily structure of observer, might this suggest that the visual perception of animal motion depends upon the same mechanisms employed during the visual perception of human motion? If the perception of animal motion and human motion tap the same mechanisms, then these two classes of motion should share core perceptual characteristics. Studies of visual sensitivity to point-light displays of human movement have demonstrated that the perception of human movement is orientation specific (e.g., Bertenthal & Pinto, 1994) and dependent upon global processes (e.g., Thornton et al., 1998). In a series of studies comparing visual sensitivity to point-light displays of human locomotion and horse locomotion, it was found that visual percepts of horse gaits are both orientation specific and spatio-temporally global (Pinto & Shiffrar, 2009). In other words, the visual perception of horse motion shares two fundamental characteristics with the visual perception of human movement. Furthermore, detection thresholds in these studies indicated that, overall, human observers are more sensitive to human movement than to horse movement (Pinto & Shiffrar, 2009). Follow up work further suggested that human observers are better able to recognize the movements of bipedal animals than the movements of apedal animals (Chouchourelou et al., 2011).

Taken together, the behavioral results described above suggest that the analyses underlying percepts of human motion and animal motions differ in a graded rather than dichotomous fashion. Furthermore, visual sensitivity to the movements of non-human animals appears to reflect the degree of similarity between an observed animal's body and the body of the observer. Such a conclusion suggests that, when it comes to visual motion perception, human motion may not be simply one exemplar within the perceptual category of animate motion. Instead, human motion may represent the prototypical exemplar at the very center of a graded category of animate motions. Indeed, the graded shape of that category's boundary may even be defined by the physical capabilities and/or the physical shape of the observer's own body. Consistent with this, when the limbs defining a point light walker are re-arranged so that they no longer match the structure of the human body, visual sensitivity to that human motion drops relative to visual sensitivity to the same moving limbs positioned in their typical

locations (Pinto & Shiffrar, 1999). Furthermore, when wooden beams are sized and arranged so that they simulate the gross structure of the human body, observers perceive those wooden beams as following paths of apparent motion that are consistent with the biomechanical constraints of the human body (Heptulla-Chatterjee et al., 1996). However, it is important to note that a human body is certainly not needed for the detection of animacy (e.g., Tremoulet & Feldman, 2000; Rutherford, Pennington & Rogers, 2006, see chapters X-Z in the current volume).

III. Neurophysiological differences between percepts of human and object motion

The psychophysical studies summarized above suggest that both overlapping and non-overlapping processes underlie visual percepts of human motion, animal motion, and object motion. Neurophysiological studies support that conclusion (see Blake & Shiffrar, 2007 for review) and suggest that patterns of activity in at least two neural areas differentiate analyses of human and object motions. In the first such study, David Perrett and his colleagues conducted single cell recordings in the macaque cortex and discovered that many neurons in the Superior Temporal Sulcus, or STS, are selectively responsive to human forms and motions (for review see Puce & Perrett, 2003). In the human, fMRI studies indicate that the posterior region of the STS, or STSp, reacts strongly to point-light depictions of upright and coherent, but not inverted or scrambled, human movement (Grossman & Blake, 2001; see also Chapter X in the current volume). Finally, research with transcranial magnetic stimulation and with lesion patients indicates that functionality within area STSp is required for the accurate perception of point-light displays of human movement (Grossman, Battelli & Pascual-Leone, 2005; Saygin, 2007). Importantly, given the above discussion, STSp responds more strongly to human motion than it does to animal-like motion (Pyles, Garcia, Hoffman, & Grossman, 2007) or to object motion (Beauchamp et al., 2003; see also Pelphrey chapter this volume). MEG activity indicates that analyses of point-light displays of human and object movement diverge approximately 200 msec after stimulus onset when processes in the right temporal lobe, encompassing the STSp, are triggered during the perception of human movement (Virji-Babul, Cheung, Weeks, Kerns, & Shiffrar, 2007; see also Grossman chapter in this volume).

While it may be tempting to describe the STSp as *the* region responsible for the analysis of human and human-like motion, there is at least one other region that is necessary for the accurate perception of point-light displays of human motion: the motor cortex. Lesion evidence indicates that a functional premotor cortex, like STSp, is a necessary pre-requisite for the differentiation of coherent and scrambled point-light actors and the identification of point-light actions (Saygin, 2007). EEG data further support the hypothesis that premotor cortex plays a critical role in the perception of coherent, but not scrambled, point-light displays of human motion (Ulloa & Pineda, 2007). Research with hemiplegic patients indicates that lesions to the motor system selectively degrade visual sensitivity to point-light actions corresponding to the observers' paralyzed limbs (Serino et al., 2009). Consistent with this, significantly greater motor system activity is found when observers view actions that they can perform than actions that they cannot perform (Stevens, Fonlupt, Shiffrar, & Decety, 2000). Finally, observers' motor skills correlate with their visual sensitivity to point-light displays of human movement (Price, Shiffrar, & Kerns, 2011)

IV. Development of the visual perception of human movement.

The evidence described above suggests that, at least in adult observers, visual analyses of the movements of humans and human-like animals differ from the visual analysis of object motion. At what developmental point does this differentiation appear?

The ability to perceive point-light displays of human motion arises early in life. The first support for this conclusion came from a classic preferential looking study (Fox & McDaniels, 1982). These researchers found that typical infants between the ages of four to six months could differentiate between point-light depictions of human motion and random motion and between upright and inverted point-light displays of human motion (Fox & McDaniels, 1982). Selective sensitivity to human motion is also evidenced in 8-month old infants by differences in amplitudes of event-related potentials (ERP) during observations of upright and scrambled point-light walkers (Hirai & Hiraki, 2005) and during observations of upright and inverted point-light walkers (Reid, Hoehl & Striano, 2006). These results are significant because they indicate that infants can differentiate at least one type of human action that they have never performed; that is, walking. On the other hand, when supported, very young infants exhibit a rhythmic alternation of their legs (Thelen, Fisher, & Ridley-Johnson, 1984) that might be a sufficient approximation of walking. Existence of this spontaneous movement pattern opens up the possibility that the perception of at least some actions, such as walking, may be subserved by innate mechanisms.

More recent work indicates that infants as young as two days old show a preference for unmasked point-light displays of upright biological (in this case, chicken) motion relative to either inverted or scrambled versions of these biological motion displays (Simion, Regolin & Bulf, 2008; see also Chapter X in this volume). Not surprisingly, the two day old human infants who participated in this experiment had no visual experience of chicken motion. Thus, this finding adds further support for the hypothesis that at least some aspects of visual sensitivity to human motion may be innate. Consistent with this, visually inexperienced chicks also exhibit a visual preference for coherent motions of other animals, especially other chickens (Vallortigara, Regolin, & Marconato, 2005). Such a preference would clearly be beneficial for accurate and rapid imprinting (Vallortigara et al., 2005).

While visual sensitivity to human or biological motions may reflect some innate mechanisms, it is also clear that visual sensitivity to human motion evolves during an observer's development. For example, three-month-old observers can detect perturbations in the phase relations between the points defining a coherent point-light human walker. But their detection abilities are equivalent for upright and inverted point-light walkers. However, just two months later, at the age of five months, observers demonstrate specialization in their visual sensitivity to upright human motion (Pinto, 2006). Infants also respond differently to human motion than to object motion. For example, seven month old infants will reproduce the action goals of a person but not the apparent action goals of an object (Mahajan & Woodward, 2009; see also

Woodward chapter this volume). Furthermore, the eye movements of one year old observers anticipate the actions of other people but not the actions of objects (Falck-Yttr, Gredeback & von Hofsten, 2006).

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 three months, infants demonstrate equivalent patterns of visual sensitivity to the motions of a point-light person, spider, and cat. By five 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 (Pinto, 2006). This pattern of "perceptual narrowing" 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 pSTS activity becomes increasingly tuned to human motion as typical children age (Carter & Pelphrey, 2006; see also, Pelphrey chapter this volume).

Interestingly, specialized tuning of the pSTS for the analysis of human actions is not obligatory. For example, in children with Autism Spectrum Disorder (ASD), pSTS activity does not become selective for human movement (Pelphrey & Carter, 2008; see also, Pelphrey chapter this volume). Consistent with this, observers with ASD do not show enhanced visual sensitivity to human motion relative to object motion (Kaiser, Delmolino, Tanaka, & Shiffrar, 2010). It remains to be determined whether this lack of tuning results from the social isolation associated with living with ASD, whether this lack of tuning gives rise to that social isolation, or both.

Perceptual sensitivity to simple, unmasked point-light displays of human movement starts to reach adult levels in observers as young as 5 years old (Pavlova et al., 2001; Blake, Turner, Smoski, Pozdol, & Stone, 2003). When point-light walkers are hidden within point-light masks, walker detection performance improves significantly between the ages of 6 to 9 years of age and again from 9 years to adulthood (Freire, Lewis, Maurer, & Blake, 2006). When visual sensitivity to point-light human motion and point-light object motion are compared in typical children, enhanced visual sensitivity to human motion relative to object motion, in both masked and unmasked displays, is clearly evident at 7 years of age and likely appears sooner (Kaiser et al., 2010).

An interesting wrinkle in our understanding of the development of visual sensitivity to the human body results when one compares the developmental timelines between preferences for coherent point-light displays of human/animal motion, summarized above, and preferences for coherent static depictions of the human body. Evidence from a standard preferential looking paradigm suggests that before the age of about 18 months, infants do not reliably differentiate between coherent and scrambled static drawings of the human body (Slaughter, Heron & Sim, 2002). The way in which static body stimuli are experimentally scrambled is likely important here. When scrambling is so extensive that limbs cannot be detected, ERP data suggest that young infants do differentiate between coherent and scrambled depictions of static body postures (Gliga & Dehaene-Lambertz, 2005). However, when bodies are scrambled at the level of limbs, such that, for example, a scrambled body consists of a model with legs coming out of her head and arms coming out of her torso, then infants as old as 15 months of age show no preference for coherent static human bodies. Given that human infants only a few days old preferentially attend to point-light displays of coherent chicken motion (Simion et al., 2008) as well as to coherent static human faces (Johnson, Dziurawiec, Ellis, & Morton, 1991), it is surprising that infants as old as 15 months still do not preferentially attend to coherent static depictions of the human form (Slaughter et al., 2002). This is rather unexpected when one considers the obvious fact that faces are always attached to bodies. In addition, and as summarized above, the results of several development studies with point-light displays of animal motion point to differentiated visual sensitivity to coherent and scrambled biological motion—stimuli that differ in their underlying form (Simion et al., 2008; Vallortigara et al., 2005). One potential explanation is that motion is the key facilitator of visual sensitivity to the human form (Christie & Slaughter, 2010). Another possibility is that, like faces (e.g., Johnson et al., 1991), preferences for static depictions of coherent human bodies are present very early in development and then decline. A third possibility is that the sophistication of global motion processes underlying human body percepts evolves more slowly than previously assumed.

V. But why do percepts of human motion and object motion differ?

The evidence summarized above supports the hypothesis that visual analyses of human movement and object movement differ in fundamental ways. The next obvious question is *why*. Put another way, what are the origins of our visual sensitivity to other people's actions? There are at least three basic factors that might differentiate, at least to human observers, human motion from object motion. First, human motion represents the only category of visual motion that human observers can both produce and perceive. I can execute patterns of movement that clearly approximate the actions of other people. But I cannot produce actions that duplicate the spatial-temporal characteristics of the motion trajectories of wind blown trees, melting ice cream, speeding cars, shifting sands, or crashing waves. If the visual system taps the motor system for information that facilitates the visual analysis of human action, then this perception-action linkage should differentiate visual analyses of and visual sensitivity to other people's actions relative to analyses of and sensitivity to other categories of visual motion perception.

Second, as inherently social creatures, typical observers have a lifetime of experience watching other people act and paying close attention to those actions (see chapter by Pelphrey for an important exception). Of course, we also have a lifetime of experience watching the wind blow shrubbery about and watching waves crash at the shoreline. But we pay relatively little attention to the specifics of those types of movement. Thus, it seems reasonable to propose that differences in visual experience might also differentiate visual percepts of human motion and object motion.

Finally, the ways in which people move their bodies directly convey extensive social and emotional information while the movements of objects do not. Thus, social and emotional analyses may also differentiate the perception of objects and people. In the sections below, findings are reviewed that support the impact of all three of these factors; motor experience, visual experience, and social-

emotional processes, in differentiating the perception of human motion from the perception of object motion. In other chapters in this volume, arguments are also posited for evolutionary pressures that might further differentiate perceptual analyses of human movement from other categories of movement.

Va. Motor Experience

In the last twenty years, the results of numerous studies have converged to suggest that the visual perception of human movement is related to the observer's own motor experience (see Prinz, 1997 and Wilson & Knoblich, 2005 for theoretical overviews). For example, the production of simple hand (and arm) movements by humans is described by the two-thirds power law that defines the relationship between the hand trajectory's instantaneous velocity and radius of curvature (Viviani, 2002). Human observers demonstrate accurate visual motion percepts when dynamic stimuli conform to this fundamental law of motor production but not when dynamic stimuli violate this law (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 the separation between the targets. Visual percepts of apparent motion between targets are consistent with this motor law (Grosjean et al., 2007). Furthermore, the perception of motor outcomes, such as throwing a dart, reflects each observer's own motor processes (Knoblich & Flach, 2001). Such evidence indicates that motor processes systematically constrain the visual perception of human movement. Indeed, it has been convincingly argues that the human visual system is optimized for the analysis of human generated movements (Viviani, 2002).

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 human actions. Some studies have shown that the actions performed by an observer interfere with that observer's perception of other people performing similar actions. For example, visual sensitivity to a point-light walker's gait speed is significantly lower while observers walk than when they stand or ride a bicycle during task performance (Jacobs & Shiffrar, 2005). 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 (Kilner, Paulignan, & Blakemore, 2003). Consistent with the importance of velocity profiles, this interference effect depends upon the similarity between the velocity profiles of simultaneously observed and produced arm movements (Kilner, Hamilton, & Blakemore, 2007). Motor learning, per se, has been shown to selectively enhance visual sensitivity to the actions of others. Observers can improve their perceptual sensitivity to point-light displays of unusual gaits by learning to execute those gaits while blindfolded (Casile & Giese, 2006). Finally, research with patient populations further supports the importance of motor constraints on the perception of human motion. For example, hemiplegic patients with motor system lesions exhibit degraded visual sensitivity to point-light actions that correspond to actions performed with their compromised limbs relative to visual sensitivity to point-light actions that correspond to their functional limbs (Serino et al., 2010). Case study evidence has documented an individual born without hands, and lacking internal representations of those absent hands, who consistently perceives paths of apparent hand rotation that are physically impossible (Funk et al., 2005). In other words, this individual perceives hands, which he has never hand, in the same way that handed observers perceive objects.

Important developmental research also supports the impact of the observer's motor capabilities on that observer's perception of other people's actions. 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 (Virji-Babul, Kerns, Zhou, Kapur, & Shiffrar, 2006). Learning a new motor skill also changes infant observer's percepts of that same motor skill in others (Sommerville & Woodward, 2005; Woodward, 2009; see Sommerville chapter this volume). Importantly, infants also show a preference in attending to actions that they themselves can currently perform. When given the opportunity to look at a point-light walker or a point-light crawler, infants who crawl prefer to look at the point-light crawler while infants who can walk prefer to look at the point-light walker (Sanefuji, Ohgami, & Hashiya, 2008; see Hauf chapter this volume). Since crawling infants see other people walking much more than they see other people crawling, this attention bias cannot be attributed to visual experience. Instead, this combination of results provides compelling support for a linkage between action production and action perception. In sum, motor experience shapes visual sensitivity to other people's actions.

Vb. Visual Experience

Yet, visual sensitivity to human motion is also dependent of visual experience. Computational modeling suggests that various aspects of visual sensitivity to human motion can be explained by visual experience alone (Giese & Poggio, 2003). As inherently social animals, humans typically spend more time watching other people act than they spend watching drifting clouds or swaying plants. The results of several psychophysical studies suggest that such biased patterns of experience have perceptual consequences. In one such study, observers viewed point-light displays of human walkers and rated the degree to which each figure looked human (Bulthoff, Bulthoff, & Sinha, 1998). As long as point-light walker displays retained their normal 2D projection, observers rated the walkers as human, even when the points-lights had three-dimensional structural anomalies. Such data suggest that visual experience is sufficient to override substantial depth distortions.

However, substantial levels of visual experience are needed to alter 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 (Jacobs, Pinto, & Shiffrar, 2004). Overall, observers most accurately identified walkers who performed their naturally occurring gaits. However, enhanced sensitivity to frequently observed actions 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. Visual experience also influences levels of neural activity in area STSp during the observation of masked point-light people in motion (Grossman, Blake & Kim, 2004).

The above results suggest that both visual experience and motor experience contribute to our visual sensitivity to human movement. Studies comparing the relative contributions of these two sources of information indicate that motor experience is the larger contributor. For example, when observers view point-light displays of themselves and others performing various actions, they are best able to

identify their own actions and least able to identify the actions of strangers (Loula et al., 2005). Enhanced sensitivity to self-generated actions can be attributed to contributions from the observer's own motor system (Knoblich & Flach, 2001). Visual experience cannot account for enhanced visual sensitivity to one's own actions (Prasad & Shiffrar, 2009).

Vc. Social and Emotional Processes

Anyone who has ever watched a silent Charlie Chaplin film knows that extensive social and emotional information is available from bodily movements alone. Research confirms this intuition. For example, naïve observers are above chance in their ability to detect a walking person's gender (e.g., Barclay, Cutting, & Kozlowski, 1978; Pollick et al., 2005) and identity (e.g., Jacobs et al., 2004; Loula et al., 2005; Jokisch et al., 2006) from point-light displays. Even more impressively, untrained observers can also detect, at least at above chance levels, another person's potential reproductive fitness (Brown et al., 2005), social dominance (Montepare & Zebrowitz-McArthur, 1988), and vulnerability to attack (Gunns et al., 2002) in point-light displays. Obviously, human movements express extensive social information that the human visual system can detect.

As a class, animate entities act with intention. Untrained observers can detect the intentions of point-light defined people in action. Observers can detect when a moving point-light actor intends to deceive the observer about his or her gender (Runeson & Frykholm, 1983). In another study, point-light displays were created of people who lifted an empty box normally and in a manner that erroneously suggested that the box was heavy. Again, observers accurately detected the deceitful lifts (Runeson & Frykholm, 1983). Visual sensitivity to the intention to deceive is experience dependent. For example, the accuracy with which a stationary observer can determine whether a point-light defined basketball player intends to pass an invisible basketball or intends to fake a pass depends upon the observer's motor and visual experience playing the game of basketball (Sebanz & Shiffrar, 2009).

Affective state can also be reliably detected in point-light displays of human movement (Atkinson et al., 2004; Pollick et al., 2001). Social context influences the perception of affective state in point-light actors. For example, when a point-light defined person expresses some emotional state during an interaction with another person, that emotional state is most accurately detected when point-light displays show both individuals rather than only the emotional individual (Clarke et al., 2005).

Neurophysiological evidence supports the hypothesis that social and emotional cues influence visual analyses of human motion. For example, the STSp responds more strongly during the perception of emotional than instrumental actions (Gallagher & Frith, 2004). Psychophysical evidence indicates that typical observers are most sensitive to the presence of a coherent point-light walker in a mask when that walker is in an angry emotional state than when that walker is in a neutral, happy, sad, or fearful emotional state (Chouchourelou et al., 2006). This behavioral finding is consistent with the existence of recurrent processing between the STSp and the amygdala, which appears to be primed for the detection of potential threats (Amaral, 2003). An angry person is clearly a threatening stimulus. Thus, these results suggest that emotional processes automatically contribute to and indeed help to define visual sensitivity to the actions of other people. Since people express emotional states and behave socially, while physical objects do not, it appears likely that emotional processes help to differentiate analyses of human and object motions.

VI. Conclusions

The results summarized above suggest that human observers of all ages typically process, experience, and react to the movements of other people differently than to the movements of objects. This differentiation starts early in observers' lives and both enlarges and becomes more refined as observers gain experience observing and interacting with the physical and social worlds. Psychophysical studies with adults and infants suggest that motor experience plays a particularly influential role in shaping our perceptions of other people's actions. Observers also demonstrate high levels of visual sensitivity to the movements of animals that are shaped like and can move like the observer. This, along with studies of patient populations, suggests that the visual differentiation of animate and inanimate motions may depend upon the physical similarity between seen bodies and the observer's own body. In other words, animate entities may simply be entities that move like the observer.

References

Adelson, E. H. & Movshon, J. A. 1982. Phenomenal coherence of moving visual patterns. *Nature, 300*: 523-525.

Amaral, D. G. 2003. The amygdala, social behavior, and danger detection. *Annual New York Academy of Science, 1000*: 337-347.

Atkinson, A.P., Dittrich, W.H., Gemmell, A.J., & Young, A.W. 2004. Emotion perception from dynamic and static body expressions in point-light and full-light displays. *Perception, 33*: 717-746.

Barclay, C., Cutting, J., & Kozlowski, L. 1978. Temporal and spatial factors in gait perception that influence gender recognition. *Perception & Psychophysics,* 23: 145-152.

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.

Bertenthal, B.I., & Pinto, J. 1994. Global processing of biological motions. *Psychological Science*, 5: 221-225.

Blake, R., & Shiffrar, M. 2007. Perception of human motion. *Annual Review of Psychology, 58*: 47-73.

Blake, R., Turner, L., Smoski, M., Pozdol, S., & Stone, W. 2003. Visual recognition of biological motion is impaired in children with Autism. *Psychological Science*, 14: 151-157.

Brown, W.M., Cronk, L., Grochow, K., Jacobson, A., Liu, C.K., et al. 2005. Dance reveals symmetry especially in young men. *Nature,* 438: 148-150.

Bulthoff, I., Bulthoff, H., & Sinha, P. 1998. Top-down influences on stereoscopic depth-perception. *Nature Neuroscience, 1*: 254 – 257.

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.

Chouchourelou, A., Matsuka, T., Harber, K., & Shiffrar, M. 2006. The visual analysis of emotional actions. *Social Neuroscience, 1*: 63-74.

Chouchourelou, A., Golden, A. & Shiffrar, M. 2011. What Does "Biological Motion" really mean? Differentiating visual percepts of human, animal, and non-biological motions. In Kerri Johnson & Maggie Shiffrar Eds. Visual perception of the human body. Oxford University Press.

Christie, T., & Slaughter, V. 2010. Movement contributes to infants' recognition of the human form. *Cognition, 114*: 329-337.

Clarke, T.J., Bradshaw, M.F., Field, D.T., Hampson, S.E., & Rose, D. 2005. The perception of emotion from body movement in point-light displays of interpersonal dialogue. *Perception,* 34: 1171-1180.

Cohen, L. R. 2002. The role of experience in the perception of biological motion. *Dissertation Abstracts International: Section B: the Sciences & Engineering, 63,* 3049.

Cutting, J. E. 1982. Blowing in the wind: Perceiving structure in trees and bushes. *Cognition, 12*: 25-44.

Falck-Yttr, T., Gredeback, G., & von Hofsten, C. 2006. Infants predict other people's action goals. Nature Neuroscience, 9: 878-879.

Fox, R., & McDaniel, C. 1982. The perception of biological motion by human infants. *Science*, 218: 486-487.

Freire, A., Lewis , T.L., Maurer, D., & Blake, R. 2006. The development of sensitivity to biological motion in noise, *Perception, 35*: 647-657.

Funk, M., Shiffrar, M. & Brugger, P. 2005. Hand movement observation by individuals born without hands: Phantom limb experience constrains visual limb perception. *Experimental Brain Research, 164*: 341-346.

Gallagher, H.L., & Frith, C.D. 2004. Dissociable neural pathways for the perception and recognition of expressive and instrumental gestures. *Neuropsychologia*, 42: 1725-1736.

Giese, M.A., & Poggio, T. 2003. Neural mechanisms for the recognition of biological movements. *Nature Reviews Neuroscience,* 4: 179-192.

Gliga, T., & Dehaene-Lambertz, G. 2005. Structural encoding of body and face in human infants and adults. *Journal of Neuroscience*, 17: 1328-1340.

Grosjean, M., Shiffrar, M., Knoblich, G. 2007. Fitts' Law Holds for Action Perception, *Psychological Science, 18*: 95-99.

Grossman, E.D., & Blake, R. 2001. Brain activity evoked by inverted and imagined biological motion. *Vision Research, 41*: 1475-1482.

Grossman, E.D., Blake, R., & Kim, C-Y. 2004. Learning to see biological motion: Brain activity parallels behavior. *Journal of Cognitive Neuroscience, 16*: 1669-1679.

Grossman, E.D., Battelli, L., & Pascual-Leone, A. 2005. Repetitive TMS over STSp disrupts perception of biological motion. *Vision Research,* 45: 2847-2853.

Gunns, R.E., Johnston, L., & Hudson, S. 2002. Victim selection and kinematics: A point-light investigation of vulnerability to attack. *Journal of Nonverbal Behavior, 26*: 129-158.

Heptulla-Chatterjee, S., Freyd, J., & Shiffrar, M. 1996. Configural processing in the perception of apparent biological motion. *Journal of Experimental Psychology: Human Perception and Performance, 22*: 916-929.

Hildreth, E. 1984. *The measurement of visual motion*. Cambridge, MA: MIT Press.

Hirai, M., & Hiraki, K. 2005. An event-related potentials study of biological motion perception in human infants. *Cognitive Brain Research,* 22: 301-304.

Hiris, E., Krebeck, A., Edmonds, J. & Stout, A. 2005. What learning to see arbitrary motion tells us about biological motion perception. *Journal of Experimental Psychology: Human Perception & Performance, 31*: 1096-1106.

Jacobs, A., Pinto, J., & Shiffrar, M. 2004. Experience, context, and the visual perception of human movement, *Journal of Experimental Psychology: Human Perception & Performance, 30*: 822-835.

Jacobs, A. & Shiffrar, M. 2005. Walking perception by walking observers. *Journal of Experimental Psychology: Human Perception & Performance, 31*: 157-169.

Johansson, G. 1964. Perception of motion and changing form. *Scandinavian Journal of Psychology, 5*: 181-208.

Johansson, G. 1973. Visual perception of biological motion and a model for its analysis. *Perception & Psychophysics, 14*: 201-211.

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.

Johnson, M., Dziurawiec, S., Ellis, H., & Morton, J. 1991. Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition, 40*: 1–19.

Jokisch, D., Daum, I., & Troje, N. 2006. Self-recognition versus recognition of others by biological motion: Viewpoint-dependent effects. *Perception, 35:,* 911-920.

Kaiser, M., Delmolino, L., Tanaka, J. & Shiffrar, M. 2010. Comparison of visual sensitivity to human and object motion in Autism Spectrum Disorder. *Autism Research*, *34*: 191-195.

Kilner, J., Paulignan, Y., & Blakemore, S-J. 2003. An interference effect of observed biological motion on action. *Current Biology, 13*: 522-525.

Kilner, J., Hamilton, A. F., & Blakemore, S-J. 2007. Interference effect of observed human motion on action is due to velocity profile of biological motion. *Social Neuroscience, 2*: 158-166.

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.

Mahajan, N. & Woodward, A. 2009. Seven month old infants selectively reproduce the goals of animate but not inanimate agents. *Infancy, 14*: 667-679.

Mather, G. & West, S. 1993. Recognition of animal locomotion from dynamic point-light displays. *Perception, 22*: 759-766.

Marr, D. 1982. *Vision: A computational investigation into the human representation and processing of visual information*. San Francisco: W. H. Freeman.

Montepare, J.M., & Zebrowitz-McArthur, L.A. 1988. Impressions of people created by age-related qualities of their gaits. *Journal of Personality and Social Psychology, 55*: 547-556.

Pavlova, M., Krägeloh-Mann, I., Sokolov, A., & Birbaumer, N. 2001. Recognition of point-light biological motion displays by young children. *Perception*, 30: 925-933.

Pelphrey, K.A. & Carter, E.J. 2008. Brain mechanisms for social perception: Lessons from autism and typical development. *Annals of the New York Academy of Sciences, 1145*, 283-299.

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. 1999. Subconfigurations of the human form in the perception of biological motion displays. *Acta Psychologica, 102,* 293 - 318.

Pinto, J., & Shiffrar, M. 2009. The visual perception of human and animal motion in point-light displays, *Social Neuroscience, 4,* 332-346.

Pollick, F.E., Kay, J.W., Heim, K., & Stringer, R. 2005. Gender recognition from point-light walkers. *Journal of Experimental Psychology: Human Perception & Performance, 31,* 1247-1265.

Pollick, F.E., Paterson, H.M., Bruderlin, A., & Sanford, A.J. 2001. Perceiving affect from arm movement. *Cognition, 82, 51-61.*

Price, K. J., Shiffrar, M., & Kerns, K. 2011. Movement perception and movement production in Asperger's Syndrome. *Research in Autism Spectrum Disorder, in press.*

Prinz W. 1997. Perception and action planning. *European Journal of Cognitive Psychology, 9,* 129-154.

Prasad, S. & Shiffrar, M. 2009. Viewpoint and the recognition of people from their movements. *Journal of Experimental Psychology: Human Perception & Performance, 35,* 39-49.

Puce, A., & Perrett, D. 2003. Electrophysiology and brain imaging of biological motion. *Philosophical Transactions of the Royal Society B Biological Sciences 358*, 435-445.

Pyles, J.A., Garcia, J.O., Hoffman, D.D., & Grossman, E.D. 2007. *Vision Research, 47,* 2786-2797.

Reid, V. M., Hoehl, S., & Striano, T. 2006. The perception of biological motion by infants: An event related potential study. *Neuroscience Letters*, *395*, 211–214.

Runeson, S., & Frykholm, G. 1983. Kinematic specification of dynamics as an informational bias for person-and-action perception: Expectation, gender recognition, and deceptive intent. *Journal of Experimental Psychology: General, 112:* 585-615.

Rutherford, M.D., Pennington, B.F. & Rogers, S.J. 2006. The perception of animacy in young children with autism. *Journal of Autism and Developmental Disorders, 36*: 983-992.

Sanefuji, W., Ohgami, H. & Hashiya, K. 2008. Detection of the relevant type of locomotion in infancy: Crawlers versus walkers. Infant *Behavior & Development, 31*: 624-628.

Saxe, J. G. 1855. *Poems by John Godfrey Saxe*. Boston: Ticknor and Fields.

Saygin, A. P. 2007. Superior temporal and premotor brain areas necessary for biological motion perception. *Brain, 130*: 2452-2461.

Sebanz, N. & Shiffrar, M. 2009. Detecting deception in a bluffing body: The role of expertise. *Psychonomic Bulletin & Review, 16*: 170-175.

Serino, A., Casavecchia, C., DeFilippo, L., Coccia, M., Shiffrar, M., & Ladavas, E. 2010. Lesions to the motor system affect action understanding. *Journal of Cognitive Neuroscience, 223*: 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., 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. & Pavel, M. 1991. Percepts of rigid motion within and across apertures. *Journal of Experimental Psychology: Human Perception and Performance, 17*: 749-761

Simion, F., Regolin, L., & Bulf, H. 2008. A predisposition for biological motion in the newborn baby. *Proceedings of the National Academy of Sciences USA*, *105*: 809-813.

Slaughter, V., Heron, M., & Sim, S. 2002. Development of preferences for the human body shape in infancy. *Cognition*, *85*: B71-B81.

Sommerville, J.A. & Woodward, A.L. 2005. Pulling out the intentional structure of action: the relation between action processing and action production in infancy. *Cognition, 95*: 1-30.

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.

Thelen, E., Fisher, D. M., & Ridley-Johnson, R. 1984. The relationship between physical growth and a newborn reflex. *Infant Behavior and Development, 7*: 479-493.

Thornton, I., Pinto, J., & Shiffrar, M. 1998. The visual perception of human locomotion. *Cognitive Neuropsychology, 15*: 535-552.

Tremoulet, P., & Feldman, J. 2000. Perception of animacy from the motion of a single object. *Perception, 29*: 943–951.

Ulloa, E.R., & Pineda, J.A. 2007. Recognition of point-light biological motion: Mu rhythms and mirror neuron activity. *Behavioural Brain Research, 183*: 188-194.

Vallortigara, G., Regolin, L., & Marconato, F. 2005. Visually inexperienced chicks exhibit spontaneous preference for biological motion patterns. *PloS Biology, 3*, e208.

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.

Virji-Babul, N., Kerns, K., Zhou, E., Kapur, A., & Shiffrar, M. 2006. Perceptual-motor deficits in children with Down syndrome: Implications for intervention. *Down Syndrome Research and Practice, 10*: 74-82.

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.

Wilson, M. & Knoblich, G. 2005. The case for motor involvement in perceiving conspecifics. *Psychological Bulletin, 131*: 460-473.

Woodward, A. 2009. Infants' grasp of other's intentions. *Current Directions in Psychological Science, 18*: 53-57.

Figure Captions

Figure 1
(a) A series of static outlines depicting the changing shape of a walking person's body with points positioned on the major joints and head. (b) A point light walker is constructed by removing everything from each image except the points. When static, these displays are difficult to interpret. However, once set in motion, observers readily detect the presence of a walking person.

Figure 2
An apparent motion display of an arm on either side of a person's head. At long inter-stimulus intervals, the arm appears to move around the head. With brief inter-stimulus intervals, the arm appears to move through the head following the shortest possible path of apparent motion.
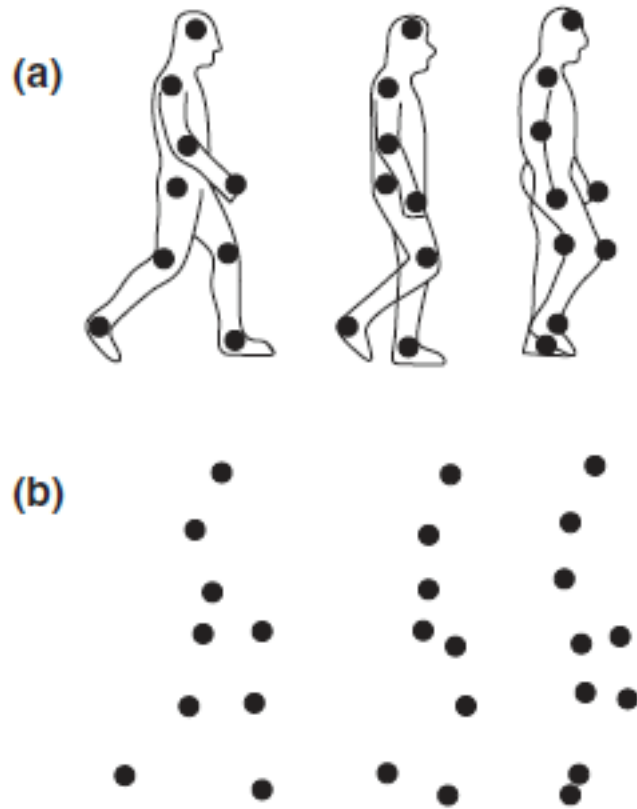
Figure 1

(a)

(b)

Figure 2