Recognizing People From Their Movement

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Human observers demonstrate impressive visual sensitivity to human movement. What defines this sensitivity? If motor experience influences the visual analysis of action, then observers should be most sensitive to their own movements. If view-dependent visual experience determines visual sensitivity to human movement, then observers should be most sensitive to the movements of their friends. To test these predictions, participants viewed sagittal displays of point-light depictions of themselves, their friends, and strangers performing various actions. In actor identification and discrimination tasks, sensitivity to one's own motion was highest. Visual sensitivity to friends', but not strangers', actions was above chance. Performance was action dependent. Control studies yielded chance performance with inverted and static displays, suggesting that form and low-motion cues did not define performance. These results suggest that both motor and visual experience define visual sensitivity to human action.

As inherently social beings, humans depend on other people for everything from emotional support to pedestrian safety. A fundamental prerequisite for successful social interaction is the ability to perceive and interpret the actions of others. Decades of psychophysical research have demonstrated that the human visual system is finely tuned to the social cues available in human movement. For example, when whole body human movements are reduced to the movements of a few point-lights (Johansson, 1973), observers can still identify a point-light actor's emotional state, deceptive intent, motor effort, vulnerability, and gender (Brownlow, Dixon, Egbert, & Radcliffe, 1997; Dittrich, Troscianko, Lea, & Morgan, 1996; Runeson & Frykholm, 1981, 1983). Observers are even able to determine individuals' sexual orientation from brief and degraded displays of their actions (Ambady, Hallahan, & Conner, 1999).

What defines such impressive visual sensitivity to human movement? Two general classes of theories have been proposed. One set of theories emphasizes the fact that human movement is the only category of motion that humans both produce and perceive. As a result, an observer's motor system constrains his or her visual analysis of other people's actions (e.g., Prinz, 1997; Shiffrar & Pinto, 2002; Viviani & Stucchi, 1992). The second class of theories focuses on the fact that humans have a lifetime of experience watching other people move. Such extensive visual experience is thought to selectively enhance visual sensitivity to the human movement (Bülthoff, Bülthoff, & Sinha, 1998; Giese & Poggio,

2003; Johansson, 1973). The goal of the current studies was to compare the contributions of both visual experience and motor experience to visual sensitivity to a fundamental social attribute, that is, a person's identity.

Nearly everyone has had the experience of identifying other people from their actions. Identity perception includes the ability to recognize friends, strangers, and even oneself (Ashmore & Jussim, 1997). Developmental psychologists understand identity perception as a critical building block in the development of a child's sense of self (e.g., Lewis, 1999). This perceptual process is thought to rely on a "like-me mechanism" through which infants come to understand that other people are psychological agents who can perform actions similar to one's own (Meltzoff & Moore, 1995). This connection between self and other may lay the foundation for social interaction and more developmentally sophisticated processes such as empathy (Decety & Chaminade, 2003; Salovey, Mayer, & Caruso, 2002). Thus, identity perception is thought to play a significant role in social and emotional development.

In the first experimentally rigorous study of identity perception from motion, Cutting and Kozlowski (1977) filmed 6 friends individually walking back and forth with point-lights attached to their major joints. Two months later, these same friends were asked to view the resulting point-light movies and to identify the person depicted in each movie. Performance was above chance, and participants recognized themselves as well as their friends. In a modified replication, participants were better able to recognize themselves than their friends (Beardsworth & Buckner, 1981). Although participants in both studies could perform the identification task, their performance was not exceptional (32%–58% correct). Thus, previous research demonstrates only modest visual sensitivity to a point-light person's identity and an unclear advantage for self-recognition.

The finding that observers may be better able to recognize themselves than their friends is intriguing and has important implications for theories of biological motion perception. Except when watching themselves in a mirror, humans have relatively little experience viewing their own bodies from a sagittal perspec-

tive. How can observers exhibit superior sensitivity to a stimulus with which they have relatively little visual experience?

Common coding theory suggests that perceptual and motor systems share representations for the same actions (Prinz, 1997). As a result, watching another individual perform an action triggers activation of the observer's motor representation of that action. Recent evidence from neuroscience supports this common coding approach. For example, mirror neurons in the premotor cortex of the macaque monkey respond to both the production of an action, such as grasping a peanut, and the perception of another individual performing that same action (Rizzolatti, Fogassi, & Gallese, 2001). Brain imaging data suggest that a corresponding perception-action matching system exists in Broca's area of the human brain (Iacoboni et al., 1999). Additional human data also support the notion of common coding between action and perception. For example, common motor areas are active during the observation and the planning of movement (Blakemore & Decety, 2001; Decety & Grezes, 1999). It is important to note that motor system activation occurs during the observation of biomechanically possible, but not impossible, human actions (Stevens, Fonlupt, Shiffrar, & Decety, 2000). Thus, the ability to physically reproduce an observed action is critical (Wilson, 2001). Obviously, each person can best reproduce his or her own actions. It follows that the perception–action matching system should be optimally tuned for the observation of each individual's own actions. If so, then one would expect to find that observers demonstrate the greatest visual sensitivity to their own actions.

Recent evidence supports this prediction. When watching movies of one's self and others lifting boxes of various weights, temporal differences in premotor cortex activity differentiate one's own actions from another's actions (Grezes, Frith, & Passingham, 2004). Similarly, when participants view videos of themselves and strangers throwing darts at a target, they better predict the results of their own dart throws than the dart throws of strangers (Knoblich & Flach, 2001). Superior prediction of one's own actions supports the hypothesis that participants use their own motor experience to perceive human action. In a related study, participants drew familiar and unfamiliar characters on a tablet in the absence of visual feedback (Knoblich & Prinz, 2001). In a subsequent recognition task, participants viewed two kinematic displays reproducing these drawings and indicated which of these they had produced. These researchers concluded that motor processes influenced perception because participants accurately recognized their own previously unseen drawings. Interestingly, performance with familiar and unfamiliar characters did not differ, suggesting that previous experience producing particular characters may not play a significant role in character recognition.

Other aspects of biological motion perception cannot be easily explained by perceptual-motor coupling. For example, when participants are asked to assess the depth relations across the points making up a three-dimensional point-light walker, performance depends critically on whether observers view the walker from common or unusual viewpoints (Bülthoff et al., 1998). Furthermore, the ability to discriminate between two point-light-defined people depends on whether they adopt common or rare gait styles (Jacobs, Pinto, & Shiffrar, 2004). Thus, other behavioral evidence suggests that visual sensitivity to human action depends on the extent to which observers have previous experience watching particular actions from particular perspectives. Consistent with this finding, imaging data indicate that neural activity in a visual area known to process biological motion, the posterior region of the superior temporal sulcus (pSTS; e.g., Bonda, Frey, & Petrides, 1996; Oram & Perrett, 1994), is modulated by visual experience, because the more participants view a point-light-defined action, the greater their pSTS response (Grossman & Blake, 2001). Furthermore, computational modeling studies have shown that numerous aspects of biological motion perception can be explained by visual experience alone (e.g., Giese & Poggio, 2003). Lastly, the fact that observers in previously conducted identity perception studies can accurately identify their friends in point-light displays clearly suggests that visual experience influences biological motion-perception processes (Cutting & Kozlowski, 1977).

Given this theoretical context, we conducted several modified replications of the original Cutting and Kozlowski (1977) study to better understand the mechanisms underlying the visual perception of identity from bodily movement. The goal of the current identity perception studies was to determine the conditions under which motor system input and perceptual learning each contribute to the visual analysis of human movement.

In these studies, observers viewed brief point-light movies of their own movements (with which they have the greatest motor experience), the movements of their friends (with which they have the greatest visual experience), and the movements of strangers (with which they have neither specific motor nor visual experience). This use of three display types enabled us to simultaneously assess the contributions of both motor and visual processes to identity perception. If motor experience influences the visual analysis of action, then observers should be better able to recognize their own movements than the movements of friends or strangers. If view-dependent visual experience determines visual sensitivity to human movement, then observers should be more sensitive to the movements of their friends than to the movements of strangers or themselves. Finally, to the extent that both motor experience and visual experience contribute to the visual analysis of human motion, then visual sensitivity to both self- and friend movement should be superior to stranger movement. Although all previous studies of identity perception have relied exclusively on point-light walker stimuli (Beardsworth & Buckner, 1981; Cutting & Kozlowski, 1977; Jacobs et al., 2004; Stevenage, Nixon, & Vince, 1999), the current studies used stimuli depicting a variety of different actions. Previous vision research with point-light displays has demonstrated that locomotor actions are recognized more accurately and quickly than social or instrumental actions (Dittrich, 1993). As such, it is possible that identity perception may be similarly action dependent. For example, actors may be easier to identify when they perform common actions such as walking than infrequent actions such as playing Ping-Pong or jumping in place.

Experiment 1

Actor Identification

How well can observers recognize themselves, their friends, and unknown strangers from the information available in point-light displays of their actions? To determine relative levels of visual sensitivity to actor identity from motion cues alone, we created point-light displays of the participants, their friends, and strangers performing a variety of actions. Two to 3 months later, the par-

ticipants viewed the resultant point-light movies and identified the actor in each movie.

Method

Participants. Nine students (6 women and 3 men) from the Newark campus of Rutgers, The State University of New Jersey participated in this experiment for financial compensation. All participants were naive to the hypothesis under investigation. Three of them were only involved in the generation of the stranger stimuli (and are henceforth referred to as *strangers*) and did not participate in the subsequent testing session. The remaining 6 participants played a dual role in this research. By acting in the initial point-light movies, they served for the stimuli generation. Later, these 6 participants served as observers who attempted to identify themselves, their friends, or strangers.

The 6 actor–observer participants were comprised of three pairs of friends, with *friends* defined as people of the same gender who spent at least 10 hr a week together over the past year. Friendship pairs were also restricted to people of similar ages and similar physical proportions. These restrictions ensured that as observers, participants could not use gender (Kozlowski & Cutting, 1977, 1978) and/or weight (Runeson & Frykholm, 1983) as the basis for their discriminations. None of the participants had a medical condition that prohibited them from engaging in requested motor activities. All participants had normal or corrected-to-normal vision and provided informed consent before beginning the experiment.

Apparatus. All action sequences were filmed with a Canon Optura digital movie camera. Postediting, the stimuli were displayed on a Macintosh 21-in. (34 cm × 26 cm) red–green–blue color palette monitor set at an 800 × 640-pixel resolution. A Power Macintosh G4 was used to control stimulus presentation and data collection. Observer responses were collected with a Macintosh keyboard. A chin rest was used to fix observers' viewing distance at 54 cm from the monitor.

Stimulus generation. All 9 participants were individually filmed as point-light actors. These point-light displays were created by modifying Johansson's (1973, 1975) classic technique. Specifically, each participant was dressed in tight black clothes to which 13 reflective white markers were attached to their major joints and head. Each participant proceeded to a darkened stage and performed a series of 10 actions while being filmed with a digital camcorder. The distance between the camera and actors randomly varied between 1.2 m and 2.5 m so that the absolute height and width of each actor could not be used as identification cues. Participants performed each action for 3 min. The 10 actions included (a) jumping in place (both frontal and sagittal views), (b) walking at 2.4 mph on a flat treadmill (sagittal view), (c) greeting gestures by shaking hands and waving hello (sagittal and frontal views), (d) whole body laughing (frontal view), (e) playing Ping-Pong against a wall (frontal and sagittal views), (f) hugging another person (frontal and sagittal views), (g) walking at 2.4 mph up a treadmill with a 7.5% incline (sagittal view), (h) hitting a punching bag (sagittal view), (i) running at 3.4 mph on a flat treadmill (sagittal view), and (j) dancing to a popular pop song (frontal and sagittal views). Real props (i.e., punching bag, Ping-Pong paddle) were used during filming so that the movement dynamics were realistic. Although the experimenter modeled each action, each actor was instructed to move naturally. Indeed, during filming, all participants were told that their actions would be used in a study of action, rather than actor, identification. Thus, naturalistic actions were emphasized.

Once filming was completed, the resultant digital movies were imported to a Macintosh computer and edited with iMovie, Final Cut Pro, and QuickTime software. To create the point light displays, we edited each video segment so that only the white markers were visible against a homogeneous black background. Each 3-min movie was cut into eight clear and distinct 5-s depictions of each action. Thus, for each participant, a library of 80 movies was created from 8 different performances of each of the 10 different actions. Six of these movies were used for the experi-

mental trials and the remaining two for the displays presented in the practice trials.

Procedure. Two to 3 months after filming, the 6 actor–observer participants (henceforth referred to as *observers*) were invited back to complete the testing phase. This consisted of a forced choice task in which participants attempted to identify whether point-light actors were themselves, a friend, or a stranger. The 2-month delay, along with the cover story, minimized the likelihood that participants would remember the specific movements that they had performed during the filming.

During the testing phase, observers were seated in front of the display monitor in a dimly lit room and were told that they would see some briefly presented point-light actor movies consisting of themselves, a friend, or a stranger performing various actions. Prior to the experimental task, all of the observers were told the name of their assigned friend and that there was an equal probability in any trial of seeing either themselves, their friend, or their assigned stranger. After viewing each movie, observers reported the actor's identity by pressing one of three keys.

Observers made their identity responses on 180 trials, each consisting of one 5-s movie depicting a point-light actor performing 1 of the 10 possible actions. Each participant viewed a total of 3 different actors performing 6 different versions of the 10 actions. Each of the actors was depicted in 60 trials. Thus, observers had the same amount of visual experience, within the experiment, with each actor. Every trial displayed a different movie. Trials were randomized across actors and actions.

Figure 1A presents a schematic of the viewing paradigm. Each trial began with the presentation of a black screen containing a central white fixation point for 500.0 ms. Next, a randomly selected movie was presented for 5.0 s. The screen then reverted to black until the participant made a key press response or 2.5 s was surpassed. Each movie subtended 11 × 15° of visual angle from the observer's chin rest.

Each observer completed two blocks of 30 practice trials before beginning the experimental trials. In the practice trials, observers viewed displays depicting themselves, their assigned friend, and their assigned stranger performing the same 10 actions that were shown in the experimental trials. The practice trials permitted observers to familiarize themselves with the apparatus and the task. Different movies were used in the practice and experimental trials. No feedback was provided during or after the practice or experimental trials. The entire testing session (practice trials plus experiment trials) lasted about 60 min.

Results

Accuracy

The accuracy with which observers identified actors was calculated as follows. Because this was a three-alternative forced choice task, chance performance is 33.3% correct. As shown in Figure 2A, performance was highest for the self-trials (69%), lower for the friend trials (47%), and lowest for the stranger trials (38%). Performance for the stranger trials did not significantly differ from chance ($p > .30$). To assess the effects of actor condition (self, friend, or stranger), we conducted a repeated measures analysis of variance (ANOVA). This analysis revealed significant main effects of actor, $F(5, 2) = 12.8$, $p < .01$, and action, $F(1, 5) = 3.5$, $p < .01$. As summarized in Figure 3A, actor identification varied across the 10 possible actions. Actor identification was best for dancing and still quite good for boxing, Ping-Pong, and jumping. Performance was poorest with walking and running. Overall actor identification performance during running and walking did not significantly differ from chance ($p > .30$). However, actor identification performance was significantly better than chance for the self- and friend trials together (46%; $p < .03$). There was no significant Actor × Action interaction, $F(2, 18) = 0.5$, $p > .93$.

Experiment 1: Actor Identification Task

A

Self,
Friend,
or
Stranger?

Experiment 2: Actor Discrimination Task
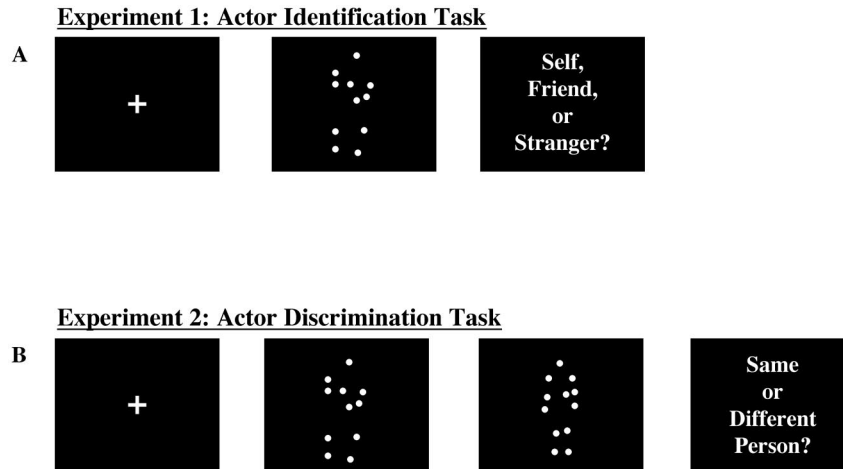
B

Same
or
Different
Person?

Figure 1. A: A schematic of a sample trial from the three-alternative forced choice actor identification task used in Experiment 1. B: A schematic of a sample trial from the two-alternative forced choice actor discrimination task used in Experiment 2.

This lack of a significant Actor × Action interaction plus the significant main effect of action suggests that observers varied in their absolute sensitivities to the different actions but not in their relative sensitivities to the three actors. Consistent with this finding, as indicated in Figure 3B, when the stranger trials are excluded from our analysis (because performance for these trials is at chance), observers' performance is still best for dancing and boxing and relatively poor with walking and running. Paired t tests revealed that the performance difference between the self- and friend conditions, $t(5) = -6.2$, $p < .01$, between the self- and stranger conditions, $t(5) = 8.9$, $p < .01$, and between the friend and stranger conditions, $t(5) = 3.2$, $p < .02$, were all significant. Moreover, an analysis of the magnitude of the differences revealed

that the difference between the self- and stranger conditions was significantly greater than the difference between the friend and stranger conditions, $t(5) = 5.8$, $p < .01$, suggesting that motor experience plays a larger role than visual experience in identity perception. This same pattern of results was observed across all 6 participants.

Errors

When collapsed across all trials and all participants, overall performance accuracy was approximately 55% correct. To identify response biases, we broke responses down, as shown in Figure 4A. This graph indicates that erroneous responses were evenly distrib-
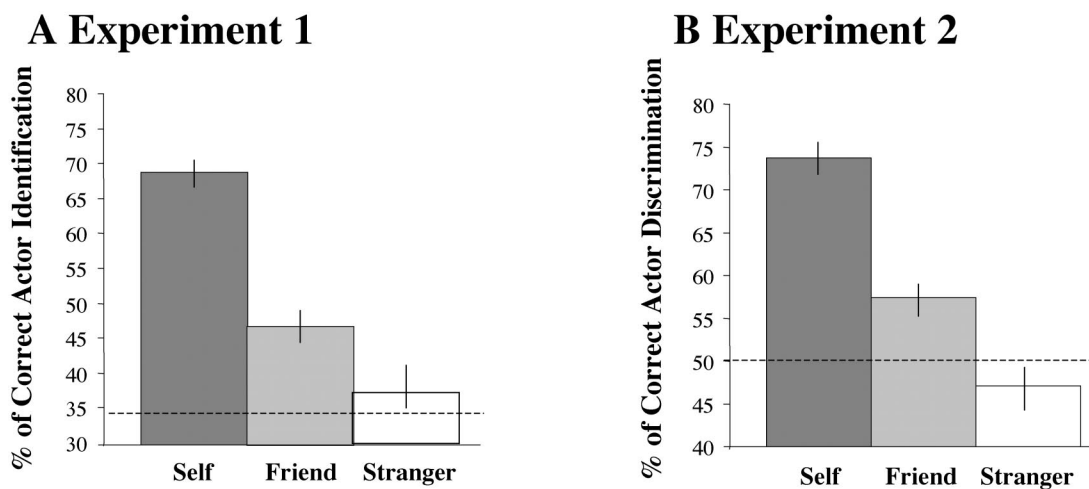
A Experiment 1

B Experiment 2

Figure 2. A: Performance accuracy from the three-alternative forced choice actor identification task of Experiment 1. B: Performance accuracy from the two-alternative forced choice actor discrimination task of Experiment 2. Results from the same actor trials are shown. Dashed horizontal lines indicate chance performance levels. Error bars indicate standard errors. In both studies, identity perception was most accurate when observers viewed their own actions.
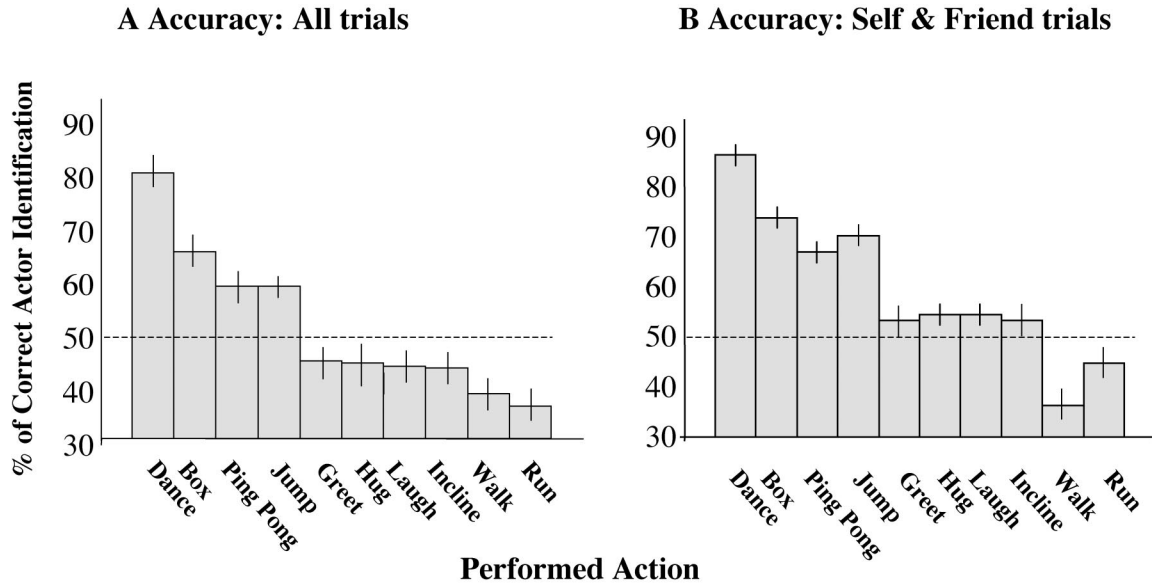
A Accuracy: All trials

B Accuracy: Self & Friend trials

Figure 3. A: The results of Experiment 1 broken down by action instead of actor. Each bar indicates performance for that action collapsed across the self-, friend, and stranger trials. B: The same data are plotted with the stranger trials excluded. Identity perception was significantly more accurate when actors danced, jumped, played Ping-Pong, and boxed than when they walked or ran. Error bars indicate standard errors.

uted with no significant biases. For example, when participants misjudged their own identities in the self-trials, they made equal numbers of erroneous friend and stranger responses ($p > .60$). Similarly, when participants viewed point-light displays of their friends, their errors were evenly distributed across self- and stranger responses ($p > .70$). All 6 participants produced similarly unbiased responses.

Discussion

The results of Experiment 1 indicate that observers are most accurate in recognizing their own movements. Because observers

have the greatest motor experience with their own movements, this result supports the hypothesis that the action system contributes to the visual analysis of human movement (e.g., Knoblich & Flach, 2001; Prinz, 1997; Shiffrar & Pinto, 2002; Viviani & Stucchi, 1992). It is important to note that because friend recognition was superior to stranger recognition, the current results also support the hypothesis that visual sensitivity to human movement draws on visual experience (e.g., Bülthoff et al., 1998; Giese & Poggio, 2003; Jacobs et al., 2004; Johansson, 1973). Lastly, the relative sizes of these effects suggest that motor experience is the larger contributor to the visual analysis of human movement, at least in the case of identity perception. These behavioral results support
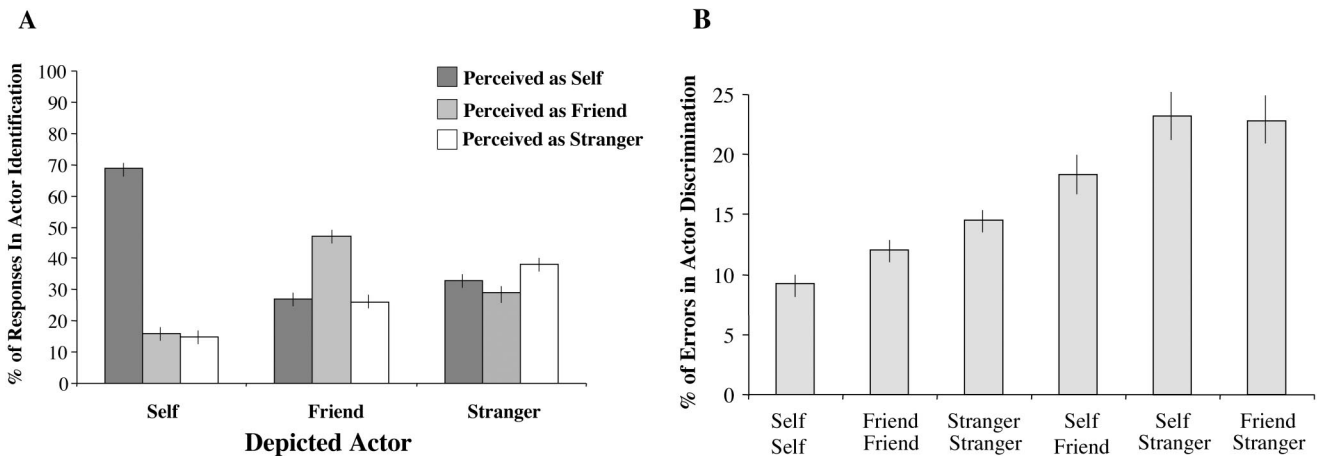
Figure 4. A: A breakdown of the three possible responses to each actor in Experiment 1. Note that in every condition, the two erroneous responses were equally likely to occur. B: A breakdown of the error rates across the six trial types from Experiment 2. Error bars indicate standard errors.

recent neurophysiological findings that both perceptual learning (Grossman & Blake, 2001) and motor system input (e.g., Decety et al., 1997; Rizzolatti et al., 2001; Stevens et al., 2000) influence the visual analysis of human movement.

How can we understand the action-dependent nature of identity perception suggested by the data in Figure 3? Clearly, frequent actions such as walking and running were associated with the poorest performance. Conversely, relatively rare actions such as boxing and Ping-Pong were associated with superior levels of actor identification. This finding suggests that although walking is the best recognized action (Dittrich, 1993), the identities of walking people are not easily recognized. This finding has important implications for the field of biometrics (e.g., Stevenage et al., 1999). That is, although numerous researchers have tried to identify the measures that differentiate walking individuals, the current results suggest that relatively little identity information may be available in gait. It is, of course, possible that identity information is available in gait but that the human visual system is insensitive to it. However, this conclusion is difficult to reconcile with the human visual system's impressive sensitivity to many other important social factors. Instead it appears that biometric cues may be more readily available in other forms of action.

Experiment 2

Actor Discrimination

Experiment 1 relied on a restricted naming task. Previous researchers have expressed concern that observers may feel uncomfortable or too comfortable, depending on their psychological disposition, naming themselves (Beardsworth & Buckner, 1981). Another concern regarding the actor identification task used in Experiment 1 is that it explicitly required participants to label or name strangers. As a result, poor performance in the stranger condition may have reflected the peculiarity of requiring observers to identify people they have never met. To determine whether the results of the previous experiment resulted from these limitations, we asked participants to perform an actor discrimination task, rather than an actor identification task, with the same stimuli used in Experiment 1. This new task did not require the explicit identification of particular actors and therefore provided an unbiased measure of identity perception. Furthermore, this new actor discrimination task required observers to compare actor identity across different actions. Thus, the current experiment enabled us to assess the generality of the previous results.

Method

Six to 8 weeks after completion of Experiment 1, the same 6 participants returned to complete Experiment 2. As in Experiment 1, participants viewed point-light displays of themselves, their assigned friend, and their assigned stranger. The same set of stimuli, 6 movies of each of 10 actions, was used. Unlike the previous experiment, each trial in this experiment depicted two different actions. As shown in Figure 1B, following the onset of a fixation point, two different movies depicting two different actions were played in succession. On half of the trials, the same actor performed the two actions. On the remaining trials, the two actions were performed by two different actors. Because each trial showed two different actions, no low-level action-specific cue could be used to perform this identity discrimination task. This design also controls for egocentric naming biases because participants never explicitly name the actors.

At the end of each trial, participants pressed one key if they thought that the two actions were performed by the same actor and another key if the two actions were performed by different actors (two-alternative forced choice task, 2AFC). Half of the trials displayed the same actor twice, and the remainder displayed two different actors. Participants viewed 120 trials for each actor condition for a total of 360 trials. Trial order was randomized across actions, actors, and participants, and no feedback was provided following responses. The experimental trials followed two blocks of 30 practice trials, consisting of a subset of movies not used in the experimental trials.

Results and Discussion

Performance accuracy in the actor discrimination task was calculated for each participant and each actor condition. Chance performance in this 2AFC task is 50% correct discrimination. Performance clearly exceeded chance for the self-trials (68%), followed by the friend trials (62%). Stranger trials did not surpass chance levels (54%). A repeated measures ANOVA revealed a significant main effect of actor (self, friend, or stranger), $F(5, 2) = 12.0$, $p < .01$, and trial type (same or different actors), $F(1, 5) = 173.1$, $p < .01$, but no significant interaction between actor and trial type, $F(1, 2) = 0.8$, $p > .34$. Errors could not be clearly categorized in the different actor trials because the identity of either actor could have been misperceived. Therefore, discrimination accuracy was calculated only for the trials in which the same actor performed both actions. As shown in Figure 2B, discrimination accuracy (i.e., correctly reporting that the same actor performed both actions) was highest for trials in which the actor was the self (73%), next highest for the trials where the actor was a friend (58%), and lowest for trials where the actor was a stranger (47%). These results closely mirror the accuracy rates obtained in Experiment 1. Performance for the same-stranger trials did not significantly differ from chance ($p > .28$). An ANOVA revealed a significant main effect for actor (self, friend, stranger) in these same-actor trials, $F(5, 2) = 15.7$, $p < .01$. Paired t tests revealed significant accuracy differences between the self- and friend conditions, $t(5) = 2.9$, $p < .01$, between the self- and stranger conditions, $t(5) = 5.4$, $p < .01$, and between the friend and stranger conditions, $t(5) = 2.0$, $p < .05$. The magnitude of the difference between the self- and stranger trials was significantly greater than the magnitude of the difference between the friend and stranger trials, $t(5) = 3.9$, $p < .02$.

Error rates for the matched trials (both displays show the same actor performing different actions) and unmatched trials (each display shows a different actor performing different actions) are shown in Figure 4B. The unmatched trials contained pairings of self- and friend movies, self- and stranger movies, and friend and stranger movies. Within the unmatched trials, the percentage of trials in which participants erroneously judged two different actors to be the same actor was lowest in the trials containing one self- and one friend movie (28%).

The results of this experiment replicated and extended those of Experiment 1. Namely, identity perception was best with one's own actions, lower but still above chance with the actions of a friend, and at chance with the actions of a stranger. Thus, the self-recognition superiority effect found in Experiment 1 cannot be attributed to extraneous action-specific cues or to the use of a particular methodology. Instead, the current results support the

hypothesis that both motor experience and visual experience simultaneously define visual sensitivity to human motion.

Experiment 3

Inverted Actors

Previous research on biological motion perception has found it to be orientation specific (e.g., Bertenthal & Pinto, 1994; Pavlova & Solokov, 2000; Shiffrar, Lichtey, & Heptulla-Chatterjee, 1997). That is, as displays of human movement deviate from canonical orientations, visual analysis of them degrades. For example, when point-light displays are inverted, observers' ability to identify the gender of an actor (Barclay, Cutting, & Kozlowski, 1978) or the type of the action being performed (Dittrich, 1993) is severely disrupted. Disruption in the perception of inverted point-light displays is thought to result from an inability to perform global motion processes on point-light displays having noncanonical orientations (Bertenthal & Pinto, 1994; Pavlova & Solokov, 2000). To the extent that identity perception relies on the same mechanisms underlying performance in classic biological motion perception tasks, performance in our actor discrimination task should be disrupted with inverted displays. Inversion also allows one to determine whether observers relied on local motion cues during task performance. This is a particularly important control for displays that do not involve masking, as in Experiments 1 and 2. Furthermore, inversion enables us to examine the role of velocity in the identification of one's own actions. Specifically, velocity changes are critical for self-identification (Flach, Knoblich, & Prinz, 2003; Knoblich & Prinz, 2001). Because inversion does not alter velocity changes, it provides an assessment of whether velocity is sufficient for identity perception in point-light displays of human action. Thus, to examine all of these issues, we conducted a replication of Experiment 2 with inverted displays. If identity perception depends on local motion processes, then performance with inverted displays should replicate performance from Experiment 2 with upright displays.

Method

Approximately 3 months after the completion of Experiment 2, 4 of the original 6 observers returned to participate in this modified replication. The

same apparatus, point-light movies, and the 2AFC actor discrimination procedure were used. The only change was that participants viewed point-light movies that were presented upside down.

Results and Discussion

Identity discrimination accuracy for each participant was calculated for each actor condition. As shown in Figure 5A, performance in all three of the actor conditions did not significantly differ from chance, or 50% correct in this 2AFC task. A repeated measures ANOVA revealed a nonsignificant main effect of actor, $F(3, 2) = 0.5$, $p > .24$. Chance levels of performance in this experiment are informative because all participants had previously succeeded in performing the same identity discrimination task with upright displays. Thus, poor performance levels in this experiment cannot be attributed to participants failing to understand the task.

The current results indicate that identity perception in point-light displays of human action is orientation specific. This suggests that our identity discrimination task invokes similar mechanisms to those used in previous biological motion studies. Furthermore, the substantial degradation of identity discrimination performance with inverted displays suggests that participants in Experiments 1 and 2 performed global motion analyses, rather than relying on local motion cues, to determine the identities of the point-light-defined actors. Finally, the current results suggest that although velocity alone is sufficient for the identification of handwriting (Knoblich & Prinz, 2001) and piano playing (Repp & Knoblich, 2004), identity perception with full-body displays requires conjoint analyses of global body structure and velocity.

Experiment 4

Static Cues

Did participants rely on any static cues to identify or discriminate the actors in Experiments 1 and 2? Although every attempt was made to minimize static form cues in our displays by matching participants by gender and body type and through the use of variable filming distances, participants may have taken advantage of lingering static cues such as hip width or limb length to identify point-light actors. To examine this possibility, we asked partici-
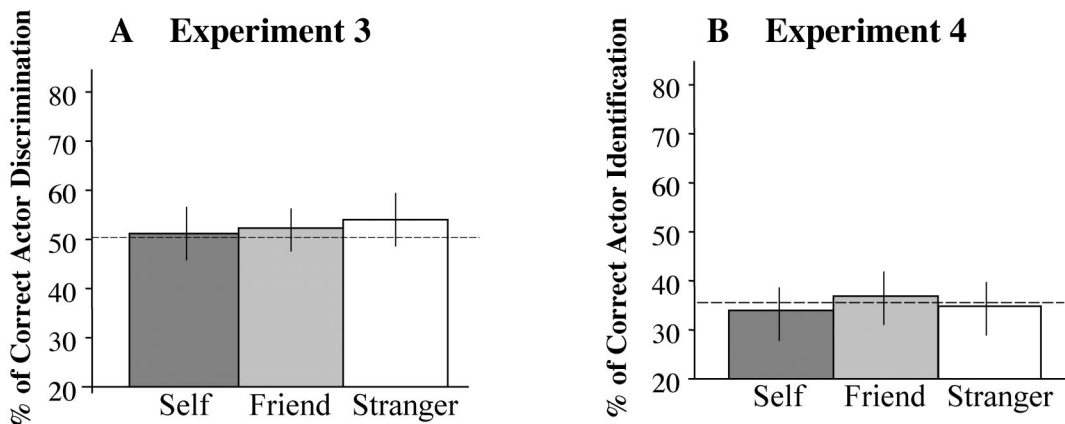

Figure 5. A: Actor identification accuracy (two-alternative forced choice) with inverted movies in Experiment 3. B: Actor discrimination accuracy (three-alternative forced choice) with static images from Experiment 4. Dashed horizontal lines indicate chance performance. Error bars indicate standard errors.

pants to view multiple static images from each movie and attempt to identify the depicted actor. In short, a static replication of Experiment 1 was conducted. To the extent that observers rely on global motion cues to identify actors, performance decrements should be found with static displays because they lack motion information. Conversely, if observers rely on any static cues to identify actors, then above-chance levels of performance should be found in this experiment.

Method

Approximately 1 month after completion of Experiment 3, the same 4 observers participated in this experiment. Following a modified replication of Experiment 1, each trial began with a fixation point and then a sequence of three static images shown in succession. Each image was shown for 1 s. Each image was separated by a 1-s interstimulus interval. This substantial interstimulus interval was used to eliminate the perception of apparent motion across image pairs (Thornton, Pinto, & Shiffrar, 1998). At the end of each trial, participants indicated whether the actor depicted in all three images was themselves, their friend, or their assigned stranger. Each participant completed 30 trials per actor for a total of 90 experimental trials. As before, no feedback was given.

Results and Discussion

Identification accuracy was calculated for each participant for each actor condition. As in Experiment 3, chance performance was found in all three conditions. As indicated in Figure 5B, a repeated measures ANOVA failed to show a significant main effect of actor (self, friend, stranger), $F(3, 2) = 0.9$, $p > .40$. When only static cues were available, participants were unable to perform the actor identification task. Thus, static form cues were not responsible for the patterns of performance found in Experiments 1 and 2. Instead, it appears that observers relied on global motion processes to identify the actors.

General Discussion

The goal of these studies was to better understand the mechanisms underlying the visual analysis of human movement. Two classic theories were examined. Theories based on perception-action coupling argue that visual sensitivity to human movement depends on input from the observer's own motor system (e.g., Knoblich & Flach, 2001; Prinz, 1997; Stevens et al., 2000; Viviani & Stucchi, 1992). Visual-experience based theories assert that visual sensitivity to human movement depends on observers' perceptual experience watching other people move (Bülthoff et al., 1998; Giese & Poggio, 2003; Johansson, 1973).

In a series of four experiments, we tested the roles of motor experience and visual experience in the visual analysis of the identity of point-light-defined actors. In Experiment 1, participants viewed point-light depictions of themselves, a friend, and a stranger performing a variety of actions. Participants displayed the greatest accuracy in identifying themselves and poorer, but still better than chance, performance for friends. Identification of a stranger, in contrast, was at chance. Moreover, identity perception was found to be action dependent. Actors were better identified when they performed expressive actions such as dancing and boxing than typically constrained actions such as walking or running.

The same patterns of performance were found in Experiment 2 in which observers discriminated the identities of pairs of actors performing different actions. In Experiment 3, the point-light movies were inverted and actor identification performance uniformly fell to chance. This result indicates that identity perception is orientation specific and does not depend on local motion cues. In Experiment 4, participants were presented with static images of point-light depictions of themselves, friends, and strangers. Performance was again at chance regardless of actor identity, indicating that performance in the previous experiments did not depend on static cues. Instead, global motion analyses appear to underlie identity perception with point-light displays.

The Conjoint Effects of Motoric and Visual Information

The above results suggest that both motor experience and visual experience define visual sensitivity to human movement. Specifically, the finding that observers can best recognize their own actions, even when those actions are depicted from an unusual sagittal perspective, supports the hypothesis that each observer's own action system contributes to the visual analysis of human movement. Every person has the most motor experience with his or her own actions. Conversely, one has relatively little visual experience watching oneself from a sagittal perspective. This follows from the fact that most individuals spend more time watching their friends and colleagues than watching themselves in a mirror. Thus, enhanced visual sensitivity to one's own actions, relative to the actions of friends and strangers, supports the hypothesis that the visual analysis of moving people depends on contributions from the observer's own action system.

This conclusion is further supported by previous research indicating that the neural mechanism responsible for the identification of the author of an action is deeply entrenched within the action production system (Blakemore, 2003; Daprati & Sirigu, 2002). Indeed, even the simple observation of another person's actions activates the observer's motor system (e.g., Hari et al., 1998; Stevens et al., 2000). Furthermore, that activation is somatotopically organized (Buccino et al., 2001). Such findings support the hypothesis that the recognition of people from their actions depends on the observer's action production system.

A different potential interpretation, however, is that enhanced perceptual sensitivity to one's own movements results from conscious awareness of how one moves. The hypothesis that observers rely on explicit awareness of their own movement style to identify their own actions obviously requires significant self-awareness of the output of one's own motor system. Yet, numerous findings suggest that observers are frequently unaware of the movements they produce (e.g., Bridgeman, Lewis, Heit, & Nagle, 1979; Jeannerod & Pacherie, 2004; Knoblich & Kircher, 2004; Tessari, Rumiati, & Haggard, 2002). For example, observers can confuse their own actions with similar actions produced by others, especially when those actions are depicted from nonegocentric perspectives (e.g., Fourneret & Jeannerod, 1998). In the current experiment, point-light displays were shown from the sagittal perspective rather than from the egocentric axial perspective. Thus, it is unlikely that conscious awareness of one's own movement styles defined performance in the current experiments.

Other key aspects of the current data cannot be readily explained by conscious awareness of movement styles. For example, perfor-

mance in the current tasks was action dependent. If action-dependent performance depended on conscious awareness of movement style, then one would have to explain why observers exhibit greater awareness of movement styles for jumping, Ping-Pong, and boxing than for greeting, hugging, laughing, and walking. It is far from clear how observers could have greater awareness of the stylistic cues associated with rare actions than with common actions. Given this finding, as well as results of numerous previous studies of the relationships between action production and action perception, it appears that enhanced visual sensitivity to one's own actions is best ascribed to input from the observer's action production system.

Nonetheless, explicit awareness of movement style probably does underlie two aspects of the current results. Visual experience increases visual sensitivity to functionally relevant but not irrelevant aspects of human action (Jacobs et al., 2004). College students, who comprised the participant pool used in the current studies, place great social significance on the ways in which they and others move on the dance floor. This raises the distinct possibility that enhanced performance in the discrimination of dancing actors reflects heightened awareness of the actors' dance styles. Secondly, discrimination of friends and strangers must depend on some awareness of movement differences. Indeed, the finding that observers demonstrate greater visual sensitivity to the movements of their friends than to the movements of strangers indicates that visual experience plays an important role in the visual analysis of human action. Participants share the same degree of motor familiarity with the actions performed by their matched friends and strangers. On the other hand, participants have substantially more visual experience watching their friends than watching previously unknown strangers. Thus, enhanced visual sensitivity to the actions of one's friends relative to the actions of strangers supports a significant role for visual experience in the visual analysis of other people's actions. Finally, the relative magnitude of these effects suggests that, at least during identity perception, motor experience plays a relatively larger role than does visual experience.

It is important to note that numerous studies have previously suggested that motoric processes influence the visual analysis of human movement (e.g., Jacobs & Shiffrar, 2005, this issue; Knoblich & Flach, 2001; Knoblich & Prinz, 2001; Prinz, 1997; Shiffrar & Freyd, 1990; Stevens et al., 2000; Viviani & Stucchi, 1992). Furthermore, previous work has also indicated that visual experience defines visual sensitivity to human movement (e.g., Giese & Poggio, 2003; Grossman & Blake, 2001; Jacobs et al., 2004). The innovation of the current results is their demonstration that both visual experience and motor experience can simultaneously define the sensitivity with which people perceive human movement. Thus, it is not the case that motor processes and visual experience contribute to biological motion perception under mutually exclusive conditions. Instead, the visual analysis of human movement may best be understood as reflecting both humans' ability to move like other people and their extensive experience watching other people move.

Actions Moderate Identity Perception

The current results also demonstrate that identity perception varies as a function of the actions that people perform. The

hypothesis that actor identification is best when actors perform common actions was not supported because performance was worst with frequently occurring actions. What other factors might be responsible for performance differences across actions? One consideration is that the 10 actions used in this experiment varied nonsystematically in terms of their degree of biomechanical constraint. The three actions that were performed on the treadmill (walking, running, and walking up an incline) were associated with the poorest performance levels. Conversely, when people performed more expressive and less constrained actions such as dancing or boxing, the best performance was found. Thus it appears that each person's unique movement signature is more evident in less constrained actions.

Recent evidence suggests that timing may play a fundamental role in the determination of an action's author (Flach et al., 2003). When participants in this study were asked to perform an auditory discrimination task, they could identify their own clapping even when that sound was reduced to a sequence of tones. Thus, temporal properties are sufficient for the auditory identification of one's own actions. If the actors in the present study differed from one another in the temporal or rhythmic properties of their actions, and if the magnitude of these differences was larger during the performance of less constrained actions, then temporal differences may have been responsible for differences in identity perception across actions. Furthermore, the results of Experiment 3 indicate that timing must be considered relative to global bodily analyses, and not in abstract isolation, for the perception of whole-body actions. The performance decrement for treadmill-based actions is consistent with this interpretation because treadmills impose a temporal structure on locomotor activities. Furthermore, chance levels of performance found in Experiment 4, where temporal information was completely eliminated, provides additional support. However, more studies are needed to test this possibility systematically.

At a theoretical level, action-dependent performance clarifies a previous ambiguity in the literature concerning whether visual sensitivity is greatest for point-light displays of one's own actions. The previous conflict concerns whether visual recognition of one's own actions is (Beardsworth & Buckner, 1981) or is not (Cutting & Kozlowski, 1977) superior to visual recognition of a friend's actions. Because all previous studies focused on identity perception during the observation of walking, sensitivity differences may have been unreliable because actor identification is poor with walking actors. The action-dependent pattern of performance found in Experiment 1 suggests that walking may not carry enough identification information for differences between self-recognition and friend recognition to be reliable. When actions such as dancing and jumping are used, differences among self-, friend, and stranger recognition become readily apparent. Thus, the results of this experiment resolve earlier conflicts and support the notion that each individual's visual system may be optimized for the perception of his or her own action.

Social–Psychological Implications

Person perception is a topic that saturates modern social psychology. However, studies of how others are perceived have focused almost exclusively on determinations of character, intention, proclivity, and other dispositional attributes (i.e., Fiske &

Taylor, 1991). People's actual identities are taken as a given and represent the starting point for research on how their underlying qualities are inferred. The determination of a person's physical identity is rarely a topic of research in its own right. The present study therefore is one of the few to break ground in this fundamental yet underinvestigated domain.

Person identification is one of the daily tasks that young infants must learn to build relationships. An understanding of one's own human body is also important in early social development. For example, it is thought that infants are born with an amodal body schema that allows them to map the similarity between themselves and other people (Meltzoff & Moore, 1999). This mapping allows for early recognition and imitation of individuals such that infants can begin to enter into and make sense of their social world. To examine these ideas, we are conducting modified replications of the current studies with children.

Constructs such as empathy and emotional intelligence are also viewed as having affective and cognitive components that play a central role in self–other perceptions and the developmental progression of social behavior (Salovey et al., 2002). Being aware of oneself entails the reflection and understanding of one's own emotions. Subsequently, through this understanding, self-aware people can understand and empathize with the psychological experiences of other people. The mirror system is thought to underlie this process (Williams, Whiten, Suddendorf, & Perrett, 2001). Because the current results suggest that such perception-action coupling plays a core role in person perception, this raises the question of whether emotional processes also contribute to the visual analysis of the self and other people in action. People generally have the strongest emotional reactions to themselves, then to their close others, and lastly to strangers. These emotional signals, both in their varied intensity (i.e., strongest for self, weakest for stranger) and in their distinct configurations (i.e., the unique feelings generated by seeing oneself, a particular friend, or any stranger) may contribute to the process of person identification. This affective contribution need not be conscious; as shown in Zajonc's (1980) classic "mere exposure" studies, the feeling accompanying familiarity can itself advance the physical identification of objects and, we argue, people. Thus, actor recognition may be abetted by actors who evoke strong feelings and move in ways that most distinctly elicit these feelings.

The current results show that identity can be accurately determined across a wide variety of actions even when the information available in those actions is reduced to the movements of a few point-lights. Thus, this research supports previous conclusions that the human visual system is attuned to social information (Adolphs, 1999, 2003). At an applied level, the field of biometrics has exerted substantial effort in the identification of cues that can be used to identify people and their intentions from their gaits (e.g., Sun & Metaxas, 2001; Vasilescu, 2002). The current results suggest that this emphasis on walking may be misdirected. Instead, identity may be more accurately and readily assessed from expressive behaviors such as jumping and dancing.

A tendency to study action perception that favors either visual inputs or motor inputs has developed recently, probably as a function of whether researchers focused on the processes associated with higher level visual areas (e.g., pSTS) or integrative motor areas (e.g., mirror neurons). The current results suggest that neither approach, in and of itself, will be sufficient to explain how observers perceive the actions of other people. Instead, a combined approach is needed to understand this inherently integrative social behavior.

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