

Experience, Context, and the Visual Perception of Human Movement

Alissa Jacobs

Rutgers, The State University of New Jersey, Newark

Jeannine Pinto

Lafayette College

Maggie Shiffrar

Rutgers, The State University of New Jersey, Newark

Why are human observers particularly sensitive to human movement? Seven experiments examined the roles of visual experience and motor processes in human movement perception by comparing visual sensitivities to point-light displays of familiar, unusual, and impossible gaits across gait-speed and identity discrimination tasks. In both tasks, visual sensitivity to physically possible gaits was superior to visual sensitivity to physically impossible gaits, supporting perception–action coupling theories of human movement perception. Visual experience influenced walker-identity perception but not gait-speed discrimination. Thus, both motor experience and visual experience define visual sensitivity to human movement. An ecological perspective can be used to define the conditions necessary for experience-dependent sensitivity to human movement.

Human observers exhibit an impressive level of visual sensitivity to human movement. In a classic demonstration of this, Johansson (1973, 1976) created displays of human movement by attaching lights to the major joints of human models. The models were filmed so that only these point lights were visible to observers, as illustrated in Figure 1. Although observers rarely perceived a human form when these displays were static, when the displays were set in motion, observers were rapidly able to detect and identify various human movements. Indeed, with a stimulus duration of only 200 ms, observers could perceptually organize and accurately identify the particular action, such as walking or running, being performed by the point-light model (Johansson, 1976).

Since then, researchers have identified a wide range of actions, such as dancing and using American Sign Language (e.g., Dittrich, 1993; Poizner, Bellugi, & Lutes-Driscoll, 1981; Jacobs, Chouchourelou, & Shiffrar, 2004), and traits, including emotion and intention (Brownlow, Dixon, Egbert, & Radcliffe, 1997; Dittrich, Troscianko, Lea, & Morgan, 1996; Runeson & Frykholm, 1981, 1983), that are readily recognizable from point-light displays of moving people. Even qualities of invisible objects that are acted

upon, such as the weight of a lifted box (Runeson & Frykholm, 1981), the distance that a sandbag is thrown (Runeson & Frykholm, 1983), and the elasticity of a support surface (Stoffregen & Flynn, 1994), can be immediately determined from the motions of a point-light model. The robustness of human motion perception is further illustrated by the finding that perception of point-light-defined human action survives masking with similarly moving point lights (Bertenthal & Pinto, 1994; Cutting, Moore, & Morrison, 1988; Thornton, Pinto, & Shiffrar, 1998).

Such findings demonstrate that observers exhibit an exceptional level of visual sensitivity to human movement. What might account for this sensitivity? Two classes of theories have been posited. One class of theories, known as perception–action coupling, suggests that visual sensitivity to human movement results from a functional linkage between the visual and motor systems (e.g., Prinz, 1997; Shiffrar & Pinto, 2002; Viviani & Stucchi, 1992). In other words, observers' ability to perform the same movements that they see may facilitate their perception of other people's movements (e.g., Reed & Farah, 1995; Wilson, 2001). In the second class of theories, visual sensitivity to human movement depends on visual experience (e.g., Bulthoff, Bulthoff, & Sinha, 1998; Giese & Poggio, 2003; Johansson, 1973). According to this view, the elevated frequency with which human movement occurs in inherently social environments enhances visual sensitivity to human movement relative to less frequent motion events, such as trees blowing in the wind and balls bouncing. As such, observers may exhibit particularly high levels of visual sensitivity to human movement simply because they see so much of it.

Several lines of research support the visual–motor linkage hypothesis of human movement perception. For instance, Prinz's (1997) findings that action performance can both improve and hinder action perception led to the development of a theoretical framework in which action and perception are represented by common neural codes. Relatedly, Reed and Farah (1995) demon-

Alissa Jacobs and Maggie Shiffrar, Department of Psychology, Rutgers, The State University of New Jersey, Newark; Jeannine Pinto, Department of Psychology, Lafayette College.

Some of the experiments reported in this article were previously presented at the 43rd Annual Meeting of the Psychonomic Society, Kansas City, Missouri, November 2002, and the Second Annual Meeting of the Vision Sciences Society, Sarasota, Florida, May 2002. This research was funded by National Institutes of Health Grant EY12300. We thank Leslie Cohen, Tom Stoffregen, and Mukul Bhalla for their very helpful comments, as well as Steve Hanson for his useful advice on data analysis.

Correspondence concerning this article should be addressed to Maggie Shiffrar, Department of Psychology, Rutgers, The State University of New Jersey, 301 Smith Hall, Newark, NJ 07102. E-mail: mag@psychology.rutgers.edu

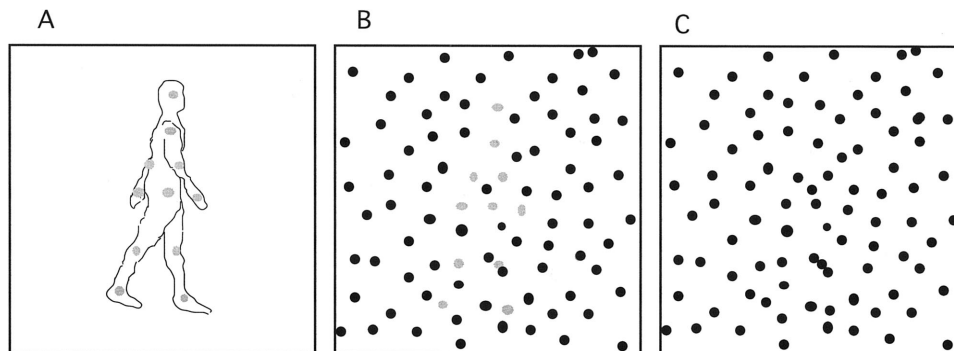


Figure 1. A: A point-light walker (gray points; the outline is not presented during experiments). B: The walker is placed in a mask (black points) of similarly moving points. C: In experiments, the walker and mask points have the same color and luminance. When presented statically, the walker is not visible. However, when this display is set in motion, observers can rapidly locate the walker.

strated that a person's body schema, or representation of the human body and its possible movements, is used to code both that person's own movements and the movements of other people as well. Support for this proposal comes from a dual-task paradigm used by Reed and Farah (1995), in which observers, who moved their own limbs, judged whether a model's limb positions changed across displays. It is interesting to note that when observers moved their legs, their ability to detect changes in the model's leg positions was affected. When observers moved their arms, their detection of the model's arm-position changes was impacted. Such results support the existence of a tight coupling between movement perception and performance.

Theories of perception–action coupling are further strengthened by studies of the two-thirds power law (Viviani, 2002; Viviani & Stucchi, 1992). This law describes the algebraic relationship between the instantaneous velocity and radius of curvature for trajectories produced by unconstrained human movements. An extensive series of psychophysical studies has indicated that visual perception is optimal for movements that are consistent with the two-thirds power law. Movements that violate this fundamental principle of human movement are not accurately perceived (see Viviani, 2002, for review). Thus, it can be argued that the human visual system is optimized for the analysis of human-generated movements.

The second approach to understanding visual sensitivity to human movement depends on visual, rather than motor, experience. According to Johansson (1973), observers form vivid percepts of human movement from point-light displays because they have extensive prior visual experience with, or *overlearning* of, those movements. It is important to note that although Johansson's (1973) theory proposes that the same grouping principles apply to both biological and mechanical movements, the vividness with which point-light displays of human action are perceived is thought to result from observers' greater visual experience with human motion.

More recent support for a visual experience hypothesis of human motion perception comes from a study in which observers rated the degree to which point-light displays looked human (Bulthoff et al., 1998). Sagittal displays that retained their normal 2-D projection, even when scrambled in depth, were rated as

highly human. Such data suggest that visual experience with sagittal views of the human form significantly impacts the perceptual organization of human movement. Indeed, visual experience is strong enough to override substantial depth distortions.

Thus, two classes of theories have been used to understand visual sensitivity to human motion perception. One class emphasizes the fact that human motion is the only category of motion that humans both produce and perceive. These theories predict that visual sensitivity to human movement will depend on whether a movement is consistent with the biomechanical constraints of the human body. The other class of theories emphasizes the fact that observers have more visual experience with human motion than with any other dynamic event. These theories predict that visual sensitivity to human movement will be defined by the frequency with which particular motions are observed. Although visual and motor theories differ in their accounts of visual sensitivity to human motion, these theories need not be mutually exclusive. Thus, to determine how motor processes and visual experience contribute to the visual analysis of human movement, we designed a series of discrimination tasks in which observers judged gaits with which they had varying degrees of visual and motor experience.

The current approach has two primary advantages over previous approaches. First, because people have very little experience watching other people perform biomechanically impossible actions, previous findings of reduced perceptual sensitivity to impossible actions (Bertenthal & Pinto, 1994; Kourtzi & Shiffrar, 1999; Pavlova & Sokolov, 2000; Sumi, 1984) can be interpreted as support for both visual learning theories and perception–action coupling theories of action perception. To overcome this limitation, we varied visual familiarity and motoric feasibility independently in the current stimulus set. Second, we used a single class of stimuli to overcome the difficulties associated with comparing sensitivities across stimuli of differing complexity (e.g., Cohen, 2001; Shiffrar, Lichtey, & Heptulla-Chatterjee, 1997; Stoffregen & Flynn, 1994). One caveat regarding our approach is that, normally, visual experience and motor experience are confounded. Frequently observed human actions are necessarily frequently performed. The results of our later experiments are used to tease apart this confound. Nonetheless, it is important to remember that three

naturally interrelated factors—the ability to perform an observed action, the frequency with which one observes an action, and the frequency with which one performs an action—all potentially define visual sensitivity to human motion.

Manipulations of human walking were selected as the stimuli under investigation. By taking advantage of the frequency with which different forms of walking occur in the real world, we hoped to determine whether visual sensitivity to human movement is experience dependent.

The basic component of human locomotion is the stride cycle. It consists of stride frequency (how many steps a person takes within a given period of time) and stride amplitude (the distance between successive heel strikes of the same foot). Together, stride frequency and stride amplitude define a 2-D space that describes human gait, as illustrated in Figure 2. Under normal conditions, for a given speed, people naturally adopt the combination of stride frequency and amplitude that is most energetically efficient (Bertram & Ruina, 2001; Hreljac, 1993; Hreljac & Martin, 1993; Perry, 1992). Thus, energetically efficient stride frequency–amplitude combinations represent a category of human action with which humans have extensive experience.

Inefficient stride frequency–amplitude combinations exist as well. For instance, to avoid burning one’s feet on hot sand, one might produce relatively small steps at a quick pace. Conversely, to avoid stepping in muddy patches near a stream, one might adopt long, slow steps. Because such inefficient gaits, as depicted in Figure 3, are considerably more difficult to produce, people rarely experience them (Nilsson & Thorstensson, 1987).

To investigate whether visual sensitivity to human movement depends on experience with particular movements, we had observers in seven experiments perform a series of speed and identity discrimination tasks with point-light-defined models walking at different speeds with either efficient or inefficient gaits. To the

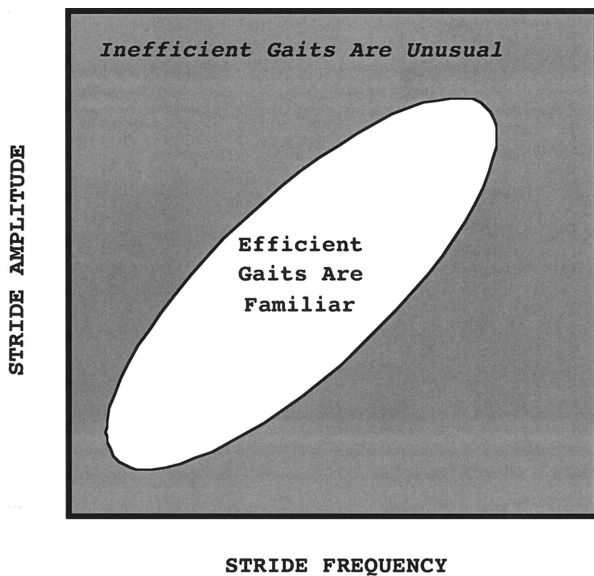


Figure 2. A schematic of the relationship between stride frequency (how many steps a person takes within a given period of time), stride amplitude (the distance between successive heel strikes of the same foot), and stride efficiency.

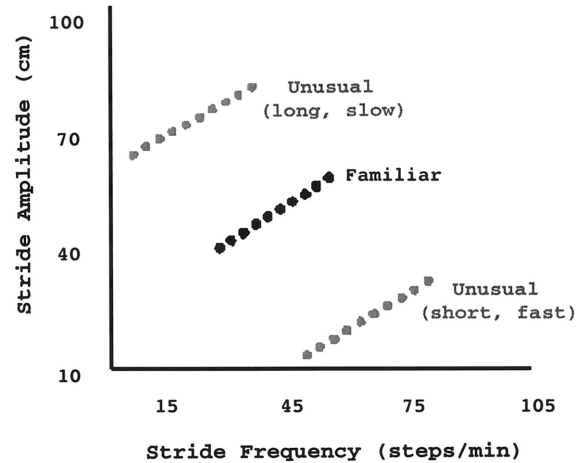


Figure 3. Graph of three gait types, each filmed at 10 different speeds (represented by dots). Efficient gaits are familiar. Inefficient gaits can have unusually fast or slow stride frequencies.

extent that visual sensitivity to human movement is experience dependent, performance with efficient gaits should be superior to that with inefficient gaits. However, before the main experiments could be conducted, the utility of our stimulus set had to be determined.

Experiment 1: Gait-Efficiency Discrimination

The goal of this experiment was to build the necessary foundation for subsequent tests of visual sensitivity to human movement as a function of experience. In these experiments, frequency is defined in terms of efficiency. That is, efficient gaits are familiar to observers, whereas inefficient gaits are rare. To draw conclusions about the effects of visual frequency on observers’ visual sensitivity to human movement, we must first demonstrate that observers are aware of efficiency differences across gait type. Thus, this first experiment was designed to simply determine whether observers could discriminate efficient from inefficient gaits.

Method

Participants. Sixteen Rutgers University undergraduates participated in this experiment for credit toward a class requirement. In this and all of the other experiments reported here, observers had normal or corrected-to-normal vision and were naive as to the hypothesis under investigation.

Apparatus. Stimuli were presented on a G-3 Macintosh computer with a 41-cm monitor. The monitor’s resolution was set at 832 × 624 pixels, with a refresh rate of 75 Hz. Observers’ responses were collected with a Macintosh keyboard. A chin rest was used to fix observers’ viewing distance at 58 cm from the screen. This apparatus was used in all of the experiments reported here.

Stimulus construction. The stimuli consisted of point-light walker movies that were constructed by filming two human models with a Canon Optura digital camera. The models were filmed walking on a Quinton Hyperdrive Club Track Treadmill. The distance between the model and the video camera was approximately 4 ft (1.2 m).

The models were dressed in black clothing and had luminous spheres attached to their major joints, as illustrated in Figure 1A. Each model was filmed while walking at 10 different speeds ranging from 2.0 to 6.5 km/hr

and varying by 0.5 km/hr intervals. At each speed, each model engaged in three forms of walking. To generate the efficient gait stimuli, the models walked naturally on the treadmill for 1 min, thereby adopting the stride frequency–amplitude combination that was the most energy efficient for their bodies at each speed. Each model’s step frequency at each speed was counted and recorded. This was repeated three times on 3 different days, and the order of the speeds was randomized. From these nine measurements per speed, an average efficient step frequency was calculated for each model at each speed. Step amplitude was derived from step frequency and treadmill–gait speed. For each speed, the stride frequency–amplitude combination for each model was found to fall well within the normal range (Perry, 1992).

For each model, a linear regression equation was used to compute two inefficient walking styles, such that each inefficient stride frequency–amplitude combination was 4 standard deviations from the efficient norm at each of the 10 speeds (Perry, 1992). One class of inefficient gaits was faster and shorter than normal. The other inefficient gaits comprised fewer and longer steps than normal. The use of two types of inefficient gaits ensured that observers had to take both stride amplitude and stride frequency into account when judging gait speed. Thus, at a given speed, each model was filmed while performing one efficient gait and two inefficient gaits, as illustrated in Figure 3.

During filming, each model used a Seiko DM-11 digital metronome to set the appropriate step frequency and then walked in pace with this metronome beat. To ensure that inefficient stride frequency–amplitude combinations were in fact less energy efficient, we simultaneously recorded each model’s heart rate during filming. At every speed, heart rate was significantly higher for the inefficient gaits ($M = 100$ beats per minute [bpm]) than for the efficient gaits ($M = 92$ bpm). Additionally, within each gait type, heart rate rose as speed increased.

Video editing. The resultant movies were exported from the digital camera into a G-3 Macintosh computer using Adobe Premiere. Extraneous background information was filtered out so that only the white spheres remained visible as dots with an average diameter of 0.3 cm. The final Quick Time movies were 320×240 pixels in size. From the observer’s viewpoint, the average height of the point-light walkers was approximately

3.9° of visual angle, and the maximum width of each walker, at the time when their hands and feet were maximally separated, was approximately 2.5° of visual angle.

Procedure. Observers, individually run, were seated in front of the computer monitor and instructed that they would view pairs of point-light walkers. As illustrated in Figure 4A, in each trial, observers first saw a fixation point, followed by one walker, then a 350-ms blank interstimulus interval (ISI), then the second walker, and finally the question *Who will get tired sooner?* This question was thought to tap observers’ understanding of gait efficiency in a way that would be most conceptually accessible. Observers pressed one of two keys on the keyboard to indicate whether the first or second walker would tire sooner.

Each trial consisted of the presentation of one efficient and one inefficient walker. The two walkers in each trial maintained the same gait speed. Each walker was displayed for three stride cycles. Treadmill speed and model were randomized across trials and fixed within trial. Each observer completed 10 practice trials, followed by two blocks of 80 experimental trials each. Accuracy was recorded on each trial. No feedback was provided.

Results

Performance accuracy was compared to chance using one-sample t tests to determine whether observers were able to discriminate the inefficient from the efficient gaits. The analyses revealed that observers were able to discriminate both types of inefficient gaits from the efficient ones at all 10 speeds. Specifically, gaits that were inefficient because they comprised either unusually fast and short steps, $t(15) = 11.86, p < .01$, or unusually slow and large steps, $t(15) = 4.68, p < .01$, were discriminated from the efficient gaits of the same speed at levels significantly above chance. Thus, observers determined that the walker taking unusually small and fast steps ($M = 78.5\%$ correct) or unusually long and slow steps ($M = 71.3\%$) was expending more energy and, hence, would tire sooner than the efficient walker.

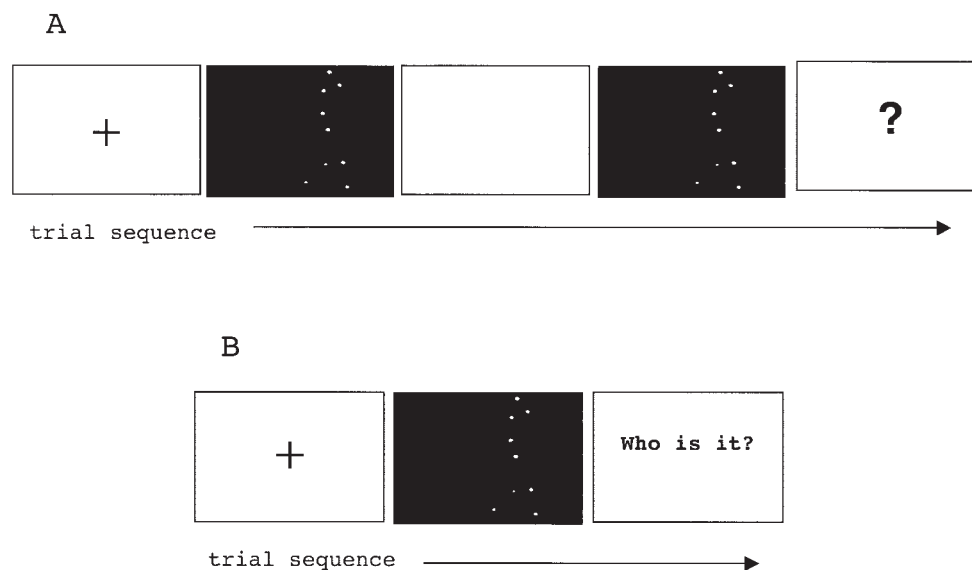


Figure 4. A: A schematic of a trial used in each of the discrimination experiments. After a fixation point, observers viewed pairs of point-light walkers (separated by a blank interstimulus interval) and discriminated gait efficiency, gait speed, or walker identity. B: A schematic of a trial used in Experiment 4. Observers determined the identity of the point-light walker.

Discussion

The results of this experiment indicate that observers could distinguish locomotor efficiency in our point-light walker displays. This held true regardless of the particular stride frequency–amplitude combination adopted. Such findings are consistent with previous research demonstrating that observers are particularly sensitive to the exertions of point-light models (Runeson & Frykholm, 1981, 1983) and with an ecological perspective in which perception is understood as tuned to those factors that promote successful functioning (J. J. Gibson, 1986). Sensitivity to the exertions of other people enables humans to interact (McArthur & Baron, 1983). For our current purposes, this finding is important because it demonstrates that our efficient and inefficient point-light walkers were discriminable. This point is important for understanding our subsequent results.

Experiment 2: Speed Sensitivity as a Function of Experience and Motoric Feasibility

Having established that observers could discriminate between the efficient and inefficient gaits in our stimulus set, we could now use these stimuli to examine the extent to which the visual perception of human movement is constrained by experience and motoric feasibility. All of the gaits used in Experiment 1 were biomechanically possible. To create a set of comparable impossible human gaits, we simply showed the point-light movies in reverse. The resulting displays depicted the same gait frequencies and amplitudes by the same walkers, yet these backward gaits were impossible because the biodynamics of real forward and backward walking differ significantly.¹

By varying the motoric feasibility (possible vs. impossible) and familiarity (familiar vs. unusual) of the point-light gaits independently, we were able to examine the extent to which visual sensitivity to human movement is determined by motor constraints and visual experience. To that end, observers performed a classic speed discrimination task. Specifically, they judged which of two walkers had the faster gait speed.

If observers' visual sensitivity to human movement is influenced by motor constraints, then speed discrimination should be better for possible gaits than it is for impossible gaits. It is important to note that enhanced speed sensitivity to possible gaits could also be explained by experience, because people see and produce possible gaits frequently but have no experience with impossible gaits. By examining whether speed discrimination performance is better with familiar gaits than with unusual gaits, we can begin to disentangle the contributions of perception–action coupling (the sheer ability to perform an observed action) and the contributions of experience (the frequency with which one has seen or produced an action).

Method

Thirty-two undergraduate students from Rutgers University participated in this experiment for class credit.

A 2 (motoric feasibility) \times 3 (gait type) mixed-subjects design was used. Motoric feasibility (possible or impossible gaits) served as a between-subjects variable, and gait type (familiar, unusually fast, or unusually slow) served as a within-subject variable. Observers were randomly assigned to

one of two conditions. Half of the observers viewed possible gaits, and half viewed impossible gaits.

The basic design and procedure of Experiment 1 were replicated. Each point-light walker movie was displayed for three stride cycles, with a 350-ms ISI between the two movies. Unlike in Experiment 1, the two point-light walkers shown in each trial differed in their gait speeds by 0.5 km/hr, and each observer's task was to decide which walker had the faster gait speed.

Gait speeds ranged from 2.0 to 6.5 km/hr. Both walkers in each trial had the same gait type (both familiar or both unusual). To ensure that observers used both stride frequency and stride amplitude to assess gait speed (rather than simply assuming that higher stride frequencies meant faster gait speeds), we varied stride frequency and amplitude across all trials. As a result, the same gait speed could be depicted with short or long stride amplitudes and fast or slow stride frequencies, as indicated in Figure 3.

Gait speed and model were randomized across trials and fixed within trial. Observers completed 10 practice trials, followed by two blocks of 60 experimental trials each. In half of the trials, the first walker had the faster gait; in the other half, the second walker had the faster gait. Accuracy and reaction times were recorded on each trial.

Results

To analyze the data, we conducted a repeated measures analysis of variance (ANOVA). Accuracy served as the dependent measure. Gait type (familiar, unusually fast, or unusually slow) and motoric feasibility (possible or impossible) served as the independent variables. The analysis revealed a statistically significant main effect of motoric feasibility, $F(1, 30) = 6.97, p < .01$. Observers were better able to discriminate the relative speeds of the possible ($M = 74.8\%$) than the impossible gaits ($M = 68.9\%$).

Across both the possible and impossible gaits, there was a significant effect of gait type, $F(2, 30) = 4.50, p < .05$. However, post hoc analyses revealed that for each condition separately, this effect was statistically nonsignificant. Discrimination performance by observers who viewed possible gaits did not significantly differ across gait types, $F(2, 15) = 1.74, p = .19$. Observers were just as sensitive to the 0.5 km/hr speed difference between pairs of familiar gaits ($M = 72.2\%$) as they were with pairs of unusually fast ($M = 76.9\%$) and unusually slow gaits ($M = 75.8\%$). Likewise, speed sensitivity to impossible gaits did not vary with gait type, $F(2, 15) = 2.89, p = .07$. Thus, no significant differences in visual sensitivity were found for comparisons of impossible gaits having otherwise familiar ($M = 65.5\%$), unusually fast ($M = 70.5\%$), or unusually slow characteristics ($M = 70.8\%$). A nonsignificant Gait Type \times Motoric Feasibility interaction, $F(2, 60) = 0.12, p = .88$, indicated that when familiar and rare gaits were displayed backward, and thus rendered impossible, accuracy dropped significantly.

In the possible condition, one-sample t tests revealed that discrimination performances for familiar gaits, $t(15) = 12.36, p > .01$, unusually fast gaits, $t(15) = 17.80, p < .01$, and unusually slow gaits, $t(15) = 14.35, p < .01$, were all significantly above chance. Likewise, in the impossible condition, performances with familiar gaits, $t(15) = 7.98, p < .01$, unusually fast gaits, $t(15) = 8.18, p < .01$, and unusually slow gaits, $t(15) = 7.47, p < .01$, were significantly above chance.

¹ For methodological balance, impossible versions of both efficient and inefficient gaits were created.

An analysis of the reaction time data failed to yield significant effects of motoric feasibility, $F(1, 30) = 0.34$, $p = .56$, or gait type, $F(2, 30) = 0.35$, $p = .70$, or a Motoric Feasibility \times Gate Type interaction, $F(2, 60) = 0.07$, $p = .93$. Thus, poorer performance accuracy with impossible gaits does not reflect a speed-accuracy trade-off.

Discussion

The results of this experiment can be summarized as two main findings. First, visual sensitivity to gait speed was superior for possible gaits relative to impossible gaits. Second, observers demonstrated equal speed sensitivity to familiar and unusual gaits. These results, individually and in combination, have important implications for theories of the visual analysis of human movement.

Perception-action coupling theories suggest that the visual analysis of human movement depends on interactions between the visual and motor systems. As such, these theories predict superior sensitivity for all possible human motions, because motoric processes can be brought to bear on their analysis. Conversely, because an observer's motor system cannot contribute to the visual analysis of impossible actions, perceptual sensitivity drops. These predictions are consistent with the current findings. That is, observers demonstrated significantly greater sensitivity to speed differences with possible gaits than they did with impossible gaits. This result is consistent with a large number of studies, using a variety of stimuli and methodologies, that have found small but consistent decrements in the perception of impossible human motion (e.g., Barclay, Cutting, & Kozlowski, 1978; Bertenthal & Pinto, 1994; Dittrich, 1993; Pavlova & Sokolov, 2000; Reed, Stone, Bozova, & Tanaka, 2003; Shiffrar et al., 1997; Viviani, 2002; Viviani & Stucchi, 1992).

In the current experiment, the significant performance decrement with the impossible gaits is impressive because these matched the possible gaits across several important parameters. For example, because humans can easily walk backward, the impossible gaits were meaningful. Furthermore, unlike in previous studies in which motoric feasibility was confounded with the gravitational orientation (e.g., Barclay et al., 1978; Bertenthal & Pinto, 1994; Dittrich, 1993; Pavlova & Sokolov, 2000; Reed et al., 2003; Shiffrar et al., 1997; Sumi, 1984), the point-light walkers in the current study were always properly oriented with respect to gravity. Lastly, the speeds and spatial extents of individual walker displays were perfectly equated across conditions. Thus, differences in meaningfulness, gravitational orientation, and spatiotemporal parameters cannot be used to explain performance decrements with impossible gaits. Instead, the backward-played stimuli depicted impossible actions simply because one cannot walk backward in exactly the same way that one walks forward. Thus, the significant performance decrement found with our impossible gaits both supports and extends previous conclusions that action production constrains action perception.

Of course, performance decrements with impossible actions could also be taken as support for experience-based theories of human motion processing. Because observers have no visual experience with impossible actions, differences in visual experience alone could be used to account for diminished sensitivity to impossible human movement. Partial resolution of this apparent

theoretical impasse is suggested by the second major finding of this experiment. Specifically, when viewing the possible gait stimuli, observers in Experiment 2 were equally sensitive to speed differences of familiar and of unusual gaits. If experience dictated visual sensitivity to human movement under the current conditions, then observers should have demonstrated greater visual sensitivity to differences in gait speed with frequently occurring gaits than with rare gaits. But this was not the case.

This conclusion, however, does not mean that visual experience plays no role in the visual analysis of human movement. Indeed, given the numerous demonstrations that visual experience can enhance many different types of visual sensitivity (e.g., Blakemore & Cooper, 1970; Bulthoff et al., 1998; Johansson, 1973; Mutti, Zadnik, & Adams, 1996; Jacobs et al., 2004; Wiesel & Raviola, 1977), the absence of a visual familiarity effect in the current experiment is surprising. Thus, for any number of reasons, our experimental paradigm may have missed significant sensitivity differences between the analysis of familiar and unusual gaits. In the following experiment, several manipulations were used to rule out potential biases that may have existed in Experiment 2.

Experiment 3: Alternative Speed Discriminations of Possible Gaits

Was the lack of a significant difference in speed discrimination performance between familiar and unusual gaits in Experiment 2 a result of some peculiarity in the experimental design? To answer this question, we performed a series of modified replications. The modifications involved changes in the display duration, the speed difference, and the question that observers answered at the end of each trial.

Method

Sixty-four undergraduate students from Rutgers University participated in this experiment for class credit. Sixteen students served as observers in each condition.

A 2 (gait type) \times 4 (condition) mixed-subjects design was used. Gait type served as a within-subject variable; that is, all observers viewed point-light displays of familiar and unusual gaits. Observers performed the same basic speed discrimination task as in Experiment 2. However, unlike in Experiment 2, only stimuli from the possible gait conditions were displayed. It is important to note that in this experiment, one variable from the original experimental design was modified in each of the four conditions. These modifications served as a between-subjects variable.

In the first condition, the question at the end of each trial was modified. Rather than reporting which point-light model walked at the faster speed, observers now determined which walker would tire sooner. This indirect measure of gait-speed sensitivity was chosen because observers in Experiment 1 could judge locomotor efficiency.

In Experiment 2, each point-light walker movie was presented for three stride cycles. As a consequence, the display duration of each stimulus varied from 1.24 to 8.00 s. It is possible that this duration variability biased the results in some way. Thus, in a second condition, the point-light walker displays were presented for a fixed duration of 3.24 s while the number of displayed gait cycles was allowed to vary. This duration corresponds to the median display duration of the speeds that bore the highest accuracy in Experiment 2.

In Experiment 2, the average accuracy was only 74% correct. Realistically, it would be difficult to walk down a crowded street if one were only able to judge the gait speeds of nearby walkers accurately at this rate. It is

therefore possible that a 0.5 km/hr difference in gait speeds was too small to tap everyday behavioral needs. Therefore, in a third condition, the difference in speed between the two gaits in each trial was increased from 0.5 to 1.0 km/hr.

Finally, judging the relative speeds of two walkers may be a somewhat artificial task because, normally, observers assess gait relative to some destination. Thus, in a final condition, observers were instructed to imagine that both walkers were walking toward a door. An illustration of this target door was displayed on the screen and remained present throughout the entire trial. Observers reported which of the two walkers would reach the door first.

Results

A 2 (gait type) \times 4 (condition) repeated measures ANOVA was conducted. Because Experiment 2 revealed no performance differences between the two unusual gaits, results from the unusually fast and unusually slow gaits were combined for analyses in this experiment. As illustrated by the mean accuracies shown in Table 1, the findings of Experiment 2 were replicated across all four conditions described above.

Specifically, the analysis failed to reveal a statistically significant main effect of gait type, $F(1, 60) = 1.84, p = .18$, or a Gait Type \times Condition interaction, $F(3, 60) = 72.34, p = .08$. Although the analysis did reveal a significant main effect of condition, $F(3, 60) = 7.50, p < .01$, such an effect is not surprising considering that increasing the gait-speed difference necessarily decreased task difficulty. One-sample t tests revealed that performance in the 1-km/hr, $t(15) = 12.56, p < .01$; fixed duration, $t(15) = 14.74, p < .01$; tired sooner, $t(15) = 8.85, p < .01$; and destination, $t(15) = 10.20, p < .01$, conditions were all significantly above chance. Nonetheless, performance did not vary with gait familiarity.

Discussion

The results of this experiment suggest that visual sensitivity to human movement is not simply a function of the frequency with which observers experience particular movements. Across a variety of manipulations, discrimination performance was unrelated to gait familiarity.

Given that human movement can be understood as the most frequently occurring motion event in people's social environments, how is it possible that the human visual system does not develop

greater sensitivity to such a frequently occurring event? Indeed, at first glance, the results of Experiments 2 and 3 seem to fly in the face of classic findings demonstrating that everything from myopia to orientation specificity is experience dependent (e.g., Blakemore & Cooper, 1970; Mutti et al., 1996; Wiesel & Raviola, 1977). Although the current findings challenge frequency-dependent theories of human motion perception, they do not rule out the possibility that visual experience facilitates some aspects of human movement perception.

Indeed, ecological perception theories argue that observers learn to extract only the information that enables them to behave successfully (E. Gibson, 1969; J. J. Gibson, 1986). Such biased perception is thought to extend to the perception of socially relevant human action (J. J. Gibson, 1986; McArthur & Baron, 1983). This raises the possibility that although observers might not readily pick up or learn abstract information, they may show experience-dependent effects for behaviorally relevant aspects of human gait.

Studies on geographical slant perception demonstrate this point well because they indicate that the perception of hill slope is related to an observer's physical ability to traverse a hill (Bhalla & Proffitt, 1999; Proffitt, Bhalla, Gossweiler, & Midgett, 1995). Thus, perception of behaviorally relevant stimuli can be significantly influenced by observer interaction with those stimuli (e.g., E. Gibson, 1969; Kellman & Arterberry, 1998). In the case of action perception, observers should be most sensitive to those attributes of another person that allow for successful interaction. The goal of the next three experiments was to determine whether experience-dependent performance occurs with functionally relevant judgments of the same stimuli used in Experiments 1–3.

Experiment 4: Walker Identification

If one assumes that the average adult height is 5½ ft (165 cm), then our 8-cm-tall point-light displays correspond to walkers located at a distance greater than 24 m from our observers. Slight differences in the gait speeds of such distant walkers probably have little potential relevance for observer behavior. Unlike speed discrimination, the discrimination of distant walkers' identities can be easily understood as behaviorally relevant because the identification of friends triggers approach behaviors, and the identification of enemies cues avoidance behaviors. Previous research illustrates that observers can identify friends from point-light depictions of their gait (Beardsworth & Buckner, 1981; Cutting & Kozlowski, 1977). Can observers accurately discriminate the identities of the two models depicted in our stimuli? If so, is identity discrimination performance influenced by visual experience?

To answer these questions, we had observers in this experiment view the same point-light walker stimuli as in the previous experiments. However, this time, observers performed a walker identification task instead of a speed discrimination task. This modification enabled us to examine whether experience influences behaviorally relevant discriminations of human movement. If it does, then performance should be best when observers view familiar gaits. If human motion perception is simply not affected by visual experience, then walker identification should not vary with gait familiarity.

Table 1
Mean Percentages of Correct Gait-Speed Discrimination Responses in Experiments 2, 3, and 6

Experiment and question/condition	Gait type	
	Familiar	Unusual
2 (nonexperienced observers) <i>Who is walking at the faster speed?</i>	72.2	76.3
3 <i>Who will tire sooner?</i>	67.8	68.5
Fixed display duration	72.7	72.4
1.0 km/hr gait-speed difference	76.3	80.5
Target destination specified	68.1	71.6
6 (highly experienced observers) <i>Who is walking at the faster speed?</i>	72.5	76.0

Method

Participants. Two groups of students, all of whom were colleagues of the two point-light models, volunteered to serve as observers in this experiment. Two observers were highly familiar with the models because they spent over 20 hr per week interacting with both of them. Another group of 3 observers had less familiarity with the models because they spent 5 hr or less per week with them. For both groups, experience was defined by the amount of time observers physically engaged in normal, real-world interactions with the models. Obviously, under such realistic conditions, the models were not dressed as point-light walkers.

Procedure. A 2 (observer experience level) \times 3 (gait type) mixed-subjects design was used. The same stimuli and equipment from the previous experiments were used here. However, the trial design differed. As illustrated in Figure 4B, in each trial, observers first saw a fixation point and then a single point-light walker movie was presented until the walker had completed three stride cycles. Following this, observers reported, with a button press, whether the displayed point-light walker was Model 1 or Model 2. Observers completed two blocks of 60 experimental trials each. Half of the trials displayed Model 1, and half showed Model 2. For both models, one third of the trials showed familiar gaits, another third comprised unusually short and fast gaits, and the final third comprised unusually long and slow gaits. Gait type was randomized across trials. No feedback was provided.

Results

A repeated measures ANOVA was conducted using accuracy as the dependent variable, gait type (familiar, unusually fast, or unusually slow) as a within-subject variable, and observer experience level (high or low) as a between-subjects variable. The results can be seen in Figure 5A. The analysis revealed a nonsignificant main effect of experience level, $F(1, 3) = 4.94, p = .10$. Across all gait types, observers who spent over 20 hr per week interacting with the models were not significantly better at identifying them ($M = 65.0\%$) than were observers who spent only 5 hr per week interacting with the models ($M = 52.0\%$). The analysis failed to reveal a statistically significant main effect of gait type, $F(2, 3) = 3.44, p = .10$. Across both observer groups, models were no better identified when using familiar gaits ($M = 61.0\%$) than they were when using unusual gaits ($M = 55.0\%$). One-sample t tests revealed that identification accuracy was significantly above chance for observers who spent over 20 hr per week interacting with the models, $t(3) = 2.64, p < .05$, but did not significantly differ from chance for observers who spent only 5 hr per week interacting with the models, $t(5) = 1.35, p = .23$.

It is important to note that a significant Gait Type \times Observer Experience Level interaction was found, $F(2, 6) = 6.05, p < .05$. As indicated by post hoc tests, performance with unusual gaits did not significantly differ between observer groups, $t(3) = 0.97, p = .40$. When the point-light walkers adopted unusually fast gaits, high- ($M = 57.5\%$) and low-experience ($M = 60.0\%$) observers performed similarly. Likewise, performance was equivalent when high- ($M = 57.5\%$) and low-experience ($M = 46.7\%$) observers viewed unusually slow gaits. Conversely, post hoc analyses revealed a statistically significant difference between observer groups for performance with familiar gaits, $t(3) = 3.82, p < .05$. When the point-light walkers adopted familiar gaits, high-experience observers ($M = 73.0\%$) performed significantly better than low-experience observers ($M = 50.0\%$).

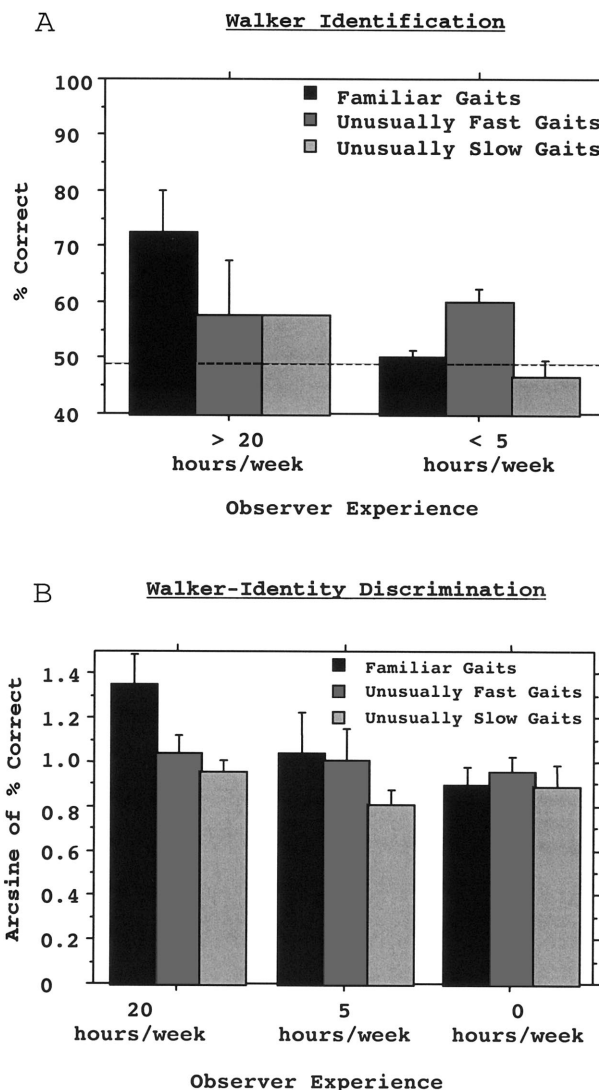


Figure 5. Results of Experiments 4 and 5, showing significant experience dependence of walker identification. A: Mean percentages of correct walker-identification responses as a function of gait type and observer experience with both models in Experiment 4. The dashed line represents the level of chance performance. B: Mean arcsine transformed percentages of correct walker-identity discrimination responses as a function of gait type and observer experience in Experiment 5. Error bars represent standard errors.

Discussion

The results of this experiment indicate that some aspects of the visual analysis of human movement can be understood as experience dependent. Namely, when observers with extensive, real-world experience with both models were asked to discriminate the identities of point-light depictions of them, performance was best when the walkers performed familiar gaits. Identification performance by observers with less experience did not vary with gait familiarity. Indeed, observers lacking extensive experience with the two models produced chance levels of performance in this identity discrimination task. This attests to the difficult nature of

the task and the number of experimental trials (Knoblich & Flach, 2001).

The data from this experiment are consistent with ecological theories in which perception is understood as optimized for the detection of socially relevant stimuli and shaped by a person's past experiences with those stimuli (McArthur & Baron, 1983). Recognition of a distant friend usually results in the initiation of new behaviors, such as waving or approaching. Thus, one can argue that observers have extensive experience interpreting the movements of distant people for the purpose of identifying them. Conversely, discrimination of the speeds of two distant walkers does not trigger any systematic changes in an observer's behavior, and as such, it can be considered to have little behavioral relevance in everyday life. If so, then the results of this experiment suggest that behaviorally relevant experience can significantly enhance the visual analysis of human movement. It is important to note that it appears that such behaviorally relevant experience must be extensive before experience-dependent effects on human motion perception are found.

Experiment 5: Walker-Identity Discrimination

Taken together, the results of the previous experiments suggest that walker identification is affected by visual experience, but gait-speed discrimination is not. To what extent are the differences in the design of the walker identification and gait-speed discrimination tasks responsible for these different patterns of results? Although the first three experiments required direct comparisons, Experiment 4 did not. Moreover, the naming procedure in Experiment 4 limited the number of potential observers because each had to know both models equally well.

To examine the potential impact of these methodological differences, we conducted a new experiment. Rather than naming each walker, observers in Experiment 5 discriminated whether or not the identities of two walkers were the same. This more closely approximated the design of the gait-speed discrimination tasks and allowed for the use of observers who did not know the point-light models. To the extent that behaviorally relevant experience facilitates the visual analysis of human movement, performance in this experiment should be best when frequent gaits are discriminated by observers having extensive visual experience with the two models.

Method

Twelve observers participated in this experiment. A 3 (observer experience level) \times 3 (gait type) mixed-subjects design was used. The same stimuli and apparatus used in the previous experiments were used in this experiment. Four observers participated in each of the three groups. Observers in the *highly experienced* group saw both models for 20 or more hours per week. Observers in the *nonexperienced* group had never seen either model before. Observers in the *moderately experienced* group saw the models for approximately 5 hr per week.

The procedure replicated that of the gait-speed discrimination task used in Experiment 2. On each trial, observers first saw a fixation point, followed by one point-light walker display, then a 350-ms blank ISI, followed by the second point-light walker display. Just as in Experiment 2, the two walkers in each trial differed in gait speed by 0.5 km/hr. Again, gait speeds ranged from 2.0 to 6.5 km/hr. On half of the trials, the first walker had the faster gait, and on the other half of the trials, the second walker had the faster gait.

The critical difference between this task and the gait-speed discrimination task was the response made by observers. Here, observers decided whether the identity of two walkers was the same or different. On half of the trials, the two point-light displays were created from the same model, and thus, walker identity was constant. On the other half of the trials, the two point-light walkers were created from different models, and thus, identity changed. In all cases, two different movies depicting two different gait speeds were shown on every trial. Observers pressed one key on the keyboard when the identity of the two walkers remained the *same* and another key when they were *different*.

As in Experiment 2, each point-light walker remained visible on the computer screen until three stride cycles were completed. Gait type remained constant within each trial. Following Knoblich and Flach (2001), observers completed two blocks of practice trials before beginning 60 experimental trials.

Results

One-sample *t* tests revealed that highly experienced, $t(11) = 11.35$, $p < .01$, moderately experienced, $t(11) = 8.86$, $p < .01$, and nonexperienced, $t(11) = 9.31$, $p < .01$, observers were all able to successfully complete the walker-identity discrimination task at levels well above chance. As depicted in Figure 5B, the data were then arcsine transformed and a repeated measures ANOVA was conducted. An arcsine transformation was used to stabilize the unequal variances among our observer groups (Ott, 1984; Winer, 1962). For purposes of comparison, the mean accuracy data are shown in Figure 6. In the ANOVA, gait type (familiar, unusually fast, or unusually slow) served as a within-subject variable, and observer experience level (highly experienced, moderately experienced, or nonexperienced) served as a between-subjects variable. No main effect of observer experience level was found, $F(2, 9) = 1.19$, $p = .35$. Overall, nonexperienced observers were just as accurate at discriminating the walker identity as were highly experienced observers. The analysis did reveal a main effect of gait type, $F(2, 9) = 8.89$, $p < .05$. Over all observer groups, discrimination performance was better with familiar gaits than it was with unusual gaits.

Of primary importance, the ANOVA revealed a statistically significant Gait Type \times Observer Experience Level interaction, $F(4, 18) = 3.58$, $p < .05$. Post hoc analyses revealed that discrimination performance by nonexperienced observers was equivalent for all gait types, $F(2, 3) = 0.32$, $p = .74$. Conversely, highly experienced observers were significantly more accurate at discriminating the identities of walkers adopting familiar gaits than of walkers adopting unusual gaits, $F(2, 3) = 10.79$, $p < .05$. This difference was found between familiar and unusually fast gaits, $t(3) = 4.55$, $p < .05$, and between familiar and unusually slow gaits, $t(3) = 3.57$, $p < .05$. It is important to note that post hoc *t* tests revealed that although highly experienced and nonexperienced observers did not significantly differ in their performance with unusual gaits, $t(6) = 0.75$, $p = .48$, their identity discrimination performance with familiar gaits did significantly differ, $t(6) = 2.87$, $p < .05$.

Moderately experienced observers showed an intermediate pattern of results. Post hoc tests revealed a nearly significant effect of gait type, $F(2, 3) = 4.29$, $p = .06$. Performance was worst with unusually slow gaits and best with familiar gaits. Post hoc analyses revealed that for judgments of unusual gaits, performance by moderately experienced observers was equivalent to that of highly

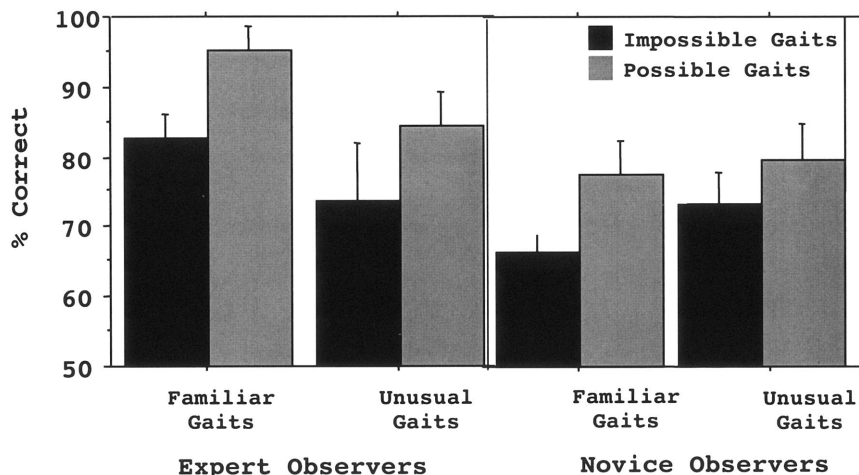


Figure 6. Mean percentages of correct walker-identity discrimination responses of expert and novice observers as a function of gait type and motoric feasibility in Experiments 5 (possible gaits) and 7 (impossible gaits). For both observer groups, identity-discrimination performance was worse with physically impossible gaits than with physically possible gaits. Error bars represent standard error.

experienced observers, $t(6) = -0.73, p = .49$, and of nonexperienced observers, $t(6) = -0.11, p = .91$. For judgments of familiar gaits, performance by moderately experienced observers (mean arcsine of percentage correct = 1.03) fell between that of highly experienced ($M = 1.35$) and nonexperienced ($M = 0.90$) observers.

Discussion

The results of this experiment replicate and extend those of Experiment 4. Although all observers performed this identity discrimination task at above chance levels, patterns of performance varied as a function of the amount of previous visual experience that the observers had with the models, in particular, and with various gaits, in general.

Highly experienced observers exhibited superior performance at discriminating walker identity during the perception of familiar relative to unusual gaits. Conversely, observers having no previous visual experience with the models exhibited equivalent levels of visual sensitivity to the familiar and unusual gaits. Finally, observers with moderate levels of visual experience with the models produced an intermediate pattern of discrimination performance. This overall pattern of results has clear implications for the concerns that originally motivated this experiment, namely, that visual experience does (Experiment 4) and does not (Experiments 2 and 3) influence the visual analysis of human motion. The current experiment used the same two-interval, forced-choice discrimination paradigm used in Experiments 2 and 3. Nonetheless, identity perception was found to be experience dependent. Thus, the results of Experiment 4 cannot be attributed to methodological differences. Instead, one can reasonably conclude that visual sensitivity to walker identity is experience dependent under behaviorally relevant conditions.

Another important conclusion to be drawn from this experiment concerns our definition of experience. As described in the introduction, effects of gait type can be understood as reflecting either

visual experience or motor experience because people both see and produce efficient gaits more frequently than they do inefficient gaits. However, the need for person-specific experience, as suggested by the results of this and the previous experiment, establishes that visual experience per se can enhance some aspects of visual sensitivity to human movement.

Thus, the results of this experiment suggest that as an observer acquires experience watching acquaintances walk, his or her ability to distinguish their gaits improves. It is important to note that this is only true during the perception of efficient gaits. This latter finding suggests that observers are not learning to extract some abstract variable that characterizes all of the possible movements that a particular individual might produce. Instead, it appears that observers slowly learn to identify people on the basis of some variable that characterizes, or is most evident in, their most frequent movements.

Experiment 6: Gait-Speed Sensitivity and Person-Specific Experience

In Experiments 1–3, observers had no prior experience with the point-light models. Yet the results of Experiments 4 and 5 suggest that, at least for identity perception, such person-specific experience can be critically important. To determine whether person-specific experience is similarly needed for the enhancement of speed sensitivity to frequent gaits, we conducted the following experiment.

Observers who knew the point-light models were asked to perform the gait-speed discrimination task from Experiment 2. Thus, observers in this experiment discriminated the relative speeds of two colleagues. If person-specific experience is needed before one can develop enhanced speed sensitivity to frequent gaits, then observers in this experiment should demonstrate greater gait-speed sensitivity with the familiar gaits than with the unusual gaits. That is, they should show a qualitatively different pattern of results than did the observers in Experiment 2. Conversely, if the

experience-independent findings from Experiments 2 and 3 actually resulted from the behavioral irrelevance of the task, then observers in this experiment should replicate the findings of Experiment 2 and demonstrate equivalent levels of speed sensitivity with familiar and unusual gaits.

Method

Four observers participated in this experiment. Two had previously participated in Experiment 4, and 2 had previously participated in Experiment 5.

The design and procedure of this experiment were a complete replication of Experiment 2. The only difference was in the experience of the observers. In the current experiment, a group of highly experienced observers completed the gait-speed discrimination task from Experiment 2.

Results

A repeated measures ANOVA was conducted on the data with gait type (familiar, unusually fast, or unusually slow) serving as a dependent variable. The analysis of accuracy revealed a nonsignificant effect of gait type, $F(2, 3) = 1.54, p = .29$. As indicated in Table 1, observers were just as accurate at discriminating the relative speeds of unusually fast ($M = 73.1\%$) and unusually slow ($M = 79.0\%$) gaits as they were at discriminating the relative speeds of familiar gaits ($M = 72.5\%$).

A 2 (observer experience level) \times 3 (gait type) repeated measures ANOVA was used to compare discrimination performance of highly experienced observers in this experiment with discrimination performance of the nonexperienced observers in Experiment 2. Experience level (highly experienced vs. nonexperienced) served as a between-subjects variable, and gait type (familiar, unusually fast, or unusually slow) served as a within-subject variable. This analysis of accuracy revealed no significant effects of observer experience level, $F(1, 17) = 0.62, p = .44$, or gait type, $F(2, 17) = 0.96, p = .38$, and no Experiment \times Gait Type interaction, $F(2, 34) = 0.91, p = .41$. Overall, nonexperienced observers ($M = 74.1\%$) were just as accurate as highly experienced observers ($M = 74.5\%$) at discriminating the relative gait speeds of the point-light walkers. For both groups of observers, speed discrimination of familiar ($M = 72.4\%$) and unusual gaits ($M = 76.1\%$) did not significantly differ.

Discussion

The results of this experiment add further support for the hypothesis that visual experience does not influence all aspects of human motion perception. Instead, visual experience only impacts the visual analysis of human motion under behaviorally relevant conditions. More specifically, in the current experiment, observers having extensive visual experience with the people depicted in our point-light stimuli performed the gait-speed discrimination task from Experiment 2. These highly experienced observers were found to be no more sensitive to gait speed than the observers from Experiment 2, who had never seen these individuals before. Moreover, replicating the performance pattern from Experiment 2, the highly experienced observers in this experiment exhibited equivalent levels of gait-speed discrimination accuracy for familiar and unusual gaits. Thus, in contrast to the findings from Experiments 4 and 5, in which experience effects were found, neither experi-

ence with particular gait types nor experience with particular people, nor their combination, influenced visual sensitivity to gait speed under the conditions used in this experiment. This pattern of results suggests that under behaviorally irrelevant conditions, the visual analysis of human motion is unaffected by the extent of an observer's real-world experience watching other people move.

Experiment 7: Identity Discrimination With Impossible Gaits

Thus far, our results indicate that walker-identity perception is constrained by visual experience. In this last experiment, we tested whether motor processes also contribute to the visual analysis of identity. To that end, we asked observers to perform the identity discrimination task with gait stimuli played in reverse. As described in Experiment 2, this manipulation renders the gaits physically impossible to perform. If motor processes contribute to the visual analysis of walker identity, then performance in this experiment should be impaired relative to corresponding data from Experiment 5, in which observers discriminated the identities of walkers performing physically possible gaits.

Method

Eight observers participated in this experiment. Half had participated as highly experienced observers and half as nonexperienced observers in Experiment 5. The procedure in this experiment replicated that of Experiment 5. The design differed only in that no moderately experienced observers were run in this study. Each of the point-light walker clips from Experiment 5 was simply played in reverse so that observers viewed impossible backward gaits. As before, on each trial, observers reported whether two point-light movies depicted the same person or two different people.

Results and Discussion

The results, depicted in Figure 6, indicate systematic decrements in identity discrimination with impossible gaits relative to possible gaits. A repeated measures ANOVA was conducted to compare identity discrimination accuracy with impossible gaits (current experiment) and identity discrimination accuracy with possible gaits (Experiment 5). Gait type (familiar, unusually fast, or unusually slow) served as a within-subject variable. Observer experience level (highly experienced vs. nonexperienced) and motoric feasibility (possible vs. impossible) served as between-subjects variables. The analysis revealed a statistically significant Gait Type \times Observer Experience Level \times Motoric Feasibility interaction, $F(6, 24) = 2.94, p < .05$. For both highly experienced and nonexperienced observers, identity discrimination accuracy was significantly lower with impossible gaits than with possible gaits. This was true for both familiar and unusual gait types. One-sample t tests revealed that identity discrimination accuracy for the impossible gait stimuli was significantly above chance for both nonexperienced observers ($M = 71.0\%$), $t(11) = 8.33, p < .01$, and highly experienced observers ($M = 76.7\%$), $t(11) = 6.82, p < .01$.

When considered with the results from the previous experiments, the current results provide additional support for perception-action coupling theories of human motion perception (e.g., Prinz, 1997; Viviani, 2002). Because identity discrimination with possible gaits was found to be superior to identity discrimi-

nation with impossible gaits, these data suggest that motor processes may contribute to the visual analysis of identity.

General Discussion

Extensive previous research has demonstrated that human observers are particularly sensitive to the movements of other people (e.g., Bertenthal & Pinto, 1994; Brownlow et al., 1997; Cutting et al., 1988; Dittrich, 1993; Dittrich et al., 1996; Johansson, 1973, 1976; Runeson & Frykholm, 1981, 1983; Shiffrar & Freyd, 1990, 1993; Shiffrar & Pinto, 2002). The goal of the current series of experiments was to begin to understand why. Two classes of theories were considered. One class, perception–action coupling theories, suggests that the reason is enhanced visual sensitivity to all physically possible human movements. A second class of experience-dependent theories suggests that visual sensitivity to human movement reflects observers' extensive experience watching other people move in particular ways. To examine these two hypotheses, we had participants perform a series of discrimination tasks with point-light displays of real walkers using rare and common gaits. Because gait frequency varied with energetic efficiency, Experiment 1 was used to establish that the efficient and inefficient gaits were discriminable.

Experiments 2–7 then used gait-speed and walker-identity perception tasks to examine the roles of visual experience and motoric feasibility in observers' visual analyses of human gait. In these experiments, visual experience was manipulated by varying gait efficiency. Because humans spontaneously adopt the most energetically efficient gait for their body at a given speed (Bertram & Ruina, 2001; Hreljac, 1993; Hreljac & Martin, 1993; Perry, 1992), observers have much more experience watching people perform efficient gaits than inefficient gaits. Thus, visual-experience accounts of human movement perception predict superior visual sensitivity to familiar, efficient gaits than to unusual, inefficient gaits. As discussed in detail below, the results of the current experiments suggest that visual experience constrains some, but not all, of observers' visual analyses of human action. Motoric feasibility was manipulated by showing the original efficient and inefficient point-light gaits in reverse, thereby creating displays of human gait that are not actually possible for humans to perform. This manipulation was then used to test perception–action coupling accounts of human movement perception. If motor input facilitates the visual analysis of human action, then observers should exhibit superior visual sensitivity to possible gaits relative to impossible gaits.

In Experiment 2, participants performed a speed discrimination task with physically possible and impossible gaits. Observers in Experiments 5 and 7 performed an identity discrimination task with these same gait stimuli. In both types of discriminations, visual sensitivity to possible gaits was superior to visual sensitivity to impossible gaits. Such results are consistent with many well-established psychophysical (e.g., Bertenthal & Pinto, 1994; Pavlova & Sokolov, 2000; Shiffrar et al., 1997) and neuroimaging (e.g., Stevens, Fonlupt, Shiffrar, & Decety, 2000) findings, and they strengthen the hypothesis that many of people's visual analyses of human movement are influenced by motor information.

In regard to visual experience hypotheses of human movement perception, the current findings suggest that some, but not all, aspects of human movement perception are influenced by visual

experience. In Experiments 2, 3, and 6, observers compared the relative speeds of either two familiar gaits or two unusual gaits. The results of these speed discrimination experiments repeatedly indicated equivalent speed discrimination performance levels with unusual and familiar gaits. These findings support the hypothesis that visual sensitivity to human movement can be experience independent.

The findings from Experiments 4 and 5, however, suggest that visual sensitivity to walker identity is influenced by visual experience. Observers in these experiments viewed the same point-light walker stimuli as before and either individually named the walkers (Experiment 4) or directly compared them (Experiment 5). For observers having extensive, real-world experience with both walking models, identity discrimination performance depended on gait type. When observers viewed walkers with familiar gaits, identification performance was best. Conversely, when the walkers adopted unusual gaits, performance dropped. Thus, the visual analysis of walker identity appears to be experience dependent. It is important to note that although it is difficult to ascertain whether heightened levels of visual sensitivity to familiar gaits are a function of visual or of motor experience, because humans have equivalent levels of experience producing and perceiving familiar gaits, the need for person-specific experience in the identity perception tasks suggests that visual experience plays the critical role in human movement perception.

How can these apparently conflicting results be understood? That is, the findings of Experiments 2, 3, and 6 suggest that the visual analysis of gait speed is experience independent, whereas those of Experiments 4 and 5 indicate a significant dependence on visual experience of walker-identity perception. An ecological theory of perception may provide a unifying framework for understanding these results. The basic premise of ecological approaches is that sensitivity to behaviorally relevant, but not irrelevant, stimuli is shaped by a person's past interactions with those stimuli (E. Gibson, 1969; Proffitt et al., 1995). In the current series of experiments, the walker-identity and gait-speed discrimination tasks may have tapped processes that differ in their potential behavioral relevance to observers. Determination of the identity of a distant walker, as in Experiments 4 and 5, can significantly influence an observer's subsequent behavior (e.g., approach or avoidance). However, determination of the speed of a distant walker, as in Experiments 2, 3, and 6, has no obvious impact on an observer's behavior. Indeed, it is difficult to imagine how an observer might be impacted differentially by a distant and sagittally oriented individual walking 0.5 km/hr faster or slower than some other walker.

To examine this issue further, we examined gait-speed sensitivity under behaviorally relevant conditions (Jacobs & Shiffrar, 2004). In order to walk down the street without bumping into someone, one must be able to compare one's own gait speed with the gait speeds of the people around one. Thus, egocentric gait-speed comparisons can be considered behaviorally relevant, whereas the exocentric gait-speed comparisons performed in Experiments 2, 3, and 6 cannot. To create a behaviorally relevant gait-speed discrimination task, we asked observers to walk on a treadmill and compare their own gait speeds with the gait speeds of a nearby point-light-defined walker. Under these conditions, observers were best able to discriminate gait speeds whenever they walked at a common walking speed. When observers walked at

unusually fast or slow speeds, their comparisons of their own gait speeds with the gait speeds of a nearby walker were systematically biased. Thus, egocentric assessments of gait speed are experience dependent. Such results suggest that differences across the gait-speed and walker-identity discrimination tasks in Experiments 1–7 reflect differences in behavioral relevance rather than differences in visual sensitivity to speed and identity. Hence, the results of this series of experiments suggest that the visual perception of human movement does benefit from visual experience under behaviorally relevant conditions.

This conceptual approach also serves to extend and unify previous findings. For example, prior research suggests that visual discrimination of identity can be experience independent (Knoblich & Prinz, 2001). In these experiments, observers discriminated between self-generated and other-generated kinematic displays of handwriting. Observers viewed the trajectories of familiar characters (e.g., Latin print) and unfamiliar characters (e.g., Old Thai script) that either they or someone else produced at an earlier date. The results indicated that observers' ability to discriminate between self-generated and other-generated displays of handwriting did not depend on the familiarity of the character sets. Because the primary task of readers is to determine what is written, readers have relatively little experience determining whether they or someone else wrote a letter. Thus, under these conditions, determination of who wrote a character can be understood as a behaviorally irrelevant task. Thus, once again an association is found between the behavioral irrelevance of a task and experience-independent performance. Such results are important because they suggest that experience-independent performance is not limited to gait-speed perception but generalizes to other behaviorally irrelevant aspects of human action perception.

Additional confirmatory evidence for this emphasis on behavioral relevance in perceptual learning comes from studies of emotion recognition by abused and nonabused children (Pollak & Sinha, 2002). In this study, children from abusive homes were found to be significantly more sensitive to the onset of angry facial gestures than were children from nonabusive homes. It is important to note that abused and nonabused children did not differ in their perception of any other facial expressions. The authors interpreted this result in terms of behavioral relevance. Namely, abused children must accurately predict the onset of anger in their parents in order to avoid future abuse. These children do not develop hypersensitivity to other emotions, such as sadness or happiness, because these emotions do not require a change in their behavior. Thus, increased visual sensitivity to anger reflects behavioral needs in the same way as increased visual sensitivity to identity reflects social needs.

In sum, the goal of this series of experiments was to begin to understand why observers demonstrate such impressive levels of visual sensitivity to the movements of other people. Our results suggest that visual experience and motor processes both contribute to the visual analysis of human movement. Moreover, the current manipulations provide a theoretical framework for the conditions under which each factor constrains perception of human movement. In the present experiments, visual experience impacted visual sensitivity to walker identity but not to gait speed. Within an ecological framework, the current findings can be taken to support the hypothesis that visual sensitivity to human movement is situationally dependent and specifically depends on the behavioral

relevance of the analysis. Finally, motor constraints were found to influence the visual analysis of both walker-identity and gait-speed perception, suggesting that the impact of motor processes on the visual analysis of human action may extend across perceptual judgments and situational constraints.

References

- Barclay, C. D., Cutting, J. E., & Kozlowski, L. T. (1978). Temporal and spatial factors in gait perception that influence gender recognition. *Perception & Psychophysics*, *23*, 145–152.
- Beardsworth, T., & Buckner, T. (1981). The ability to recognize oneself from a video recording of one's movements without seeing one's body. *Bulletin of the Psychonomic Society*, *18*, 19–22.
- Bertenthal, B. I., & Pinto, J. (1994). Global processing of biological motions. *Psychological Science*, *5*, 221–225.
- Bertram, J. E. A., & Ruina, A. (2001). Multiple walking speed–frequency relations are predicted by constrained optimization. *Journal of Theoretical Biology*, *209*, 445–453.
- Bhalla, M., & Proffitt, D. (1999). Visual–motor recalibration in geographical slant perception. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1076–1096.
- Blakemore, C., & Cooper, G. F. (1970, October 31). Development of the brain depends on the visual environment. *Nature*, *228*, 477–478.
- Brownlow, S., Dixon, A. R., Egbert, C. A., & Radcliffe, R. D. (1997). Perception of movement and dancer characteristics from point-light displays of dance. *Psychological Record*, *47*, 411–421.
- Bulthoff, I., Bulthoff, H. H., & Sinha, P. (1998). Top-down influences on stereoscopic depth perception. *Nature Neuroscience*, *1*, 254–257.
- Cohen, L. (2001). *The role of experience in the perception of biological motion*. Unpublished doctoral dissertation, Temple University.
- Cutting, J. E., & Kozlowski, L. T. (1977). Recognizing friends by their walk: Gait perception without familiarity cues. *Bulletin of the Psychonomic Society*, *9*, 353–356.
- Cutting, J. E., Moore, C., & Morrison, R. (1988). Masking the motions of human gait. *Perception & Psychophysics*, *44*, 339–347.
- Dittrich, W. H. (1993). Action categories and the perception of biological motion. *Perception*, *22*, 15–22.
- Dittrich, W. H., Troscianko, T., Lea, S. E. G., & Morgan, D. (1996). Perception of emotion from dynamic point-light displays represented in dance. *Perception*, *25*, 727–738.
- Gibson, E. (1969). *Principles of perceptual learning and development*. New York: Appleton-Century-Crofts.
- Gibson, J. J. (1986). *The ecological approach to visual perception*. Hillsdale, NJ: Erlbaum.
- Giese, M. A., & Poggio, T. (2003). Neural mechanisms for the recognition of biological movements. *National Review of Neurosciences*, *4*, 179–192.
- Hreljac, A. (1993). Preferred and energetically optimal gait transition speeds in human locomotion. *Sport Exercise*, *25*, 1158–1162.
- Hreljac, A., & Martin, P. E. (1993). The relationship between smoothness and economy during walking. *Biological Cybernetics*, *69*, 213–218.
- Jacobs, A., Chouhourelou, A., & Shiffrar, M. (2004). *Is it "biological" motion?* Manuscript submitted for publication.
- Jacobs, A., & Shiffrar, M. (2004). *Walking perception by walking observers*. Manuscript submitted for publication.
- 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.
- Kellman, P. J., & Arterberry, M. E. (1998). *The cradle of knowledge: Development of perception in infancy*. Cambridge, MA: MIT Press.

- Knoblich, G., & Flach, R. (2001). Predicting the effects of actions: Interactions of perception and action. *Psychological Science, 12*, 467–472.
- Knoblich, G., & Prinz, W. (2001). Recognition of self-generated actions from kinematic displays of drawing. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 456–465.
- Kourtzi, Z., & Shiffrar, M. (1999). Dynamic representations of human body movement. *Perception, 28*, 49–62.
- McArthur, L. Z., & Baron, R. M. (1983). Toward an ecological theory of social perception. *Psychological Review, 90*, 215–238.
- Mutti, D. O., Zadnik, K., & Adams, A. J. (1996). Myopia: The nature versus nurture debate goes on. *Investigative Ophthalmology and Visual Science, 37*, 952–957.
- Nilsson, J., & Thorstensson, A. (1987). Adaptability in frequency and amplitude of leg movements during human locomotion at different speeds. *Acta Physiologica Scandinavica, 129*, 107–114.
- Ott, L. (1984). *An introduction to statistical methods and data analysis*. Boston, MA: PWS.
- Pavlova, M., & Sokolov, A. (2000). Orientation specificity in biological motion perception. *Perception & Psychophysics, 62*, 889–899.
- Perry, J. (1992). *Gait analysis: Normal and pathological function*. Thorofare, NJ: SLACK.
- Poizner, H., Bellugi, U., & Lutes-Driscoll, V. (1981). Perception of American sign language in dynamic point-light displays. *Journal of Experimental Psychology: Human Perception and Performance, 7*, 430–440.
- Pollak, S. D., & Sinha, P. (2002). Effects of early experience on children's recognition of facial displays of emotion. *Developmental Psychology, 38*, 784–791.
- Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology, 9*, 129–154.
- Proffitt, D. R., Bhalla, M., Gossweiler, R., & Midgett, J. (1995). Perceiving geographical slant. *Psychonomic Bulletin & Review, 2*, 409–428.
- Reed, C. L., & Farah, M. J. (1995). A psychological reality of the body schema: A test with normal participants. *Journal of Experimental Psychology: Human Perception and Performance, 21*, 334–343.
- Reed, C. L., Stone, V. E., Bozova, S., & Tanaka, J. (2003). The body-inversion effect. *Psychological Science, 14*, 302–308.
- Runeson, S., & Frykholm, G. (1981). Visual perception of lifted weight. *Journal of Experimental Psychology: Human Perception and Performance, 7*, 733–740.
- 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.
- 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). Percepts of biological motion across apertures. *Perception & Psychophysics, 59*, 51–59.
- Shiffrar, M., & Pinto, J. (2002). The visual analysis of bodily motion. In W. Prinz & B. Hommel (Eds.), *Common mechanisms in perception and action: Attention and performance XIX* (pp. 381–399). New York: Oxford University Press.
- 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.
- Stoffregen, T. A., & Flynn, S. B. (1994). Visual perception of support-surface deformability from human body kinematics. *Ecological Psychology, 6*, 3–64.
- Sumi, S. (1984). Upside-down presentation of the Johansson moving light-spot pattern. *Perception, 13*, 283–286.
- Thornton, I., Pinto, J., & Shiffrar, M. (1998). The visual perception of human locomotion across space and time. *Cognitive Neuropsychology, 15*, 535–552.
- Viviani, P. (2002). Motor competence in the perception of dynamic events: A tutorial. In W. Prinz & B. Hommel (Eds.), *Common mechanisms in perception and action: Attention and performance XIX* (pp. 406–442). New York: Oxford University Press.
- Viviani, P., & Stucchi, N. (1992). Biological movements look constant: Evidence of motor-perceptual interactions. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 603–623.
- Wiesel, T. N., & Raviola, E. (1977, March 3). Myopia and eye enlargement after neonatal lid fusion in monkeys. *Nature, 266*, 66–68.
- Wilson, M. (2001). Perceiving imitable stimuli: Consequences of isomorphism between input and output. *Psychological Bulletin, 127*, 543–553.
- Winer, B. J. (1962). *Statistical principles in experimental design*. New York: McGraw-Hill.

Received July 2, 2002

Revision received October 20, 2003

Accepted March 8, 2004 ■

Wanted: Old APA Journals!

APA is continuing its efforts to digitize older journal issues for the PsycARTICLES database. Thanks to many generous donors, we have made great strides, but we still need many issues, particularly those published in the 1950s and earlier.

If you have a collection of older journals and are interested in making a donation, please e-mail journals@apa.org or visit <http://www.apa.org/journals/donations.html> for an up-to-date list of the issues we are seeking.