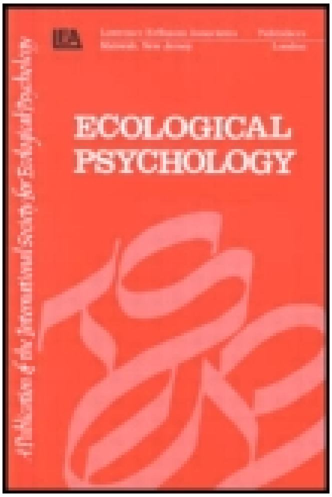

Ecological Psychology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/heco20

Seeing Where the Stone Is Thrown by Observing a Point-Light Thrower: Perceiving the Effect of Action Is Enabled by Information, Not Motor Experience

Qin Zhu[a] & Geoffrey P. Bingham[b]
[a] Division of Kinesiology and Health University of Wyoming
[b] Department of Psychological and Brain Sciences Indiana University
Published online: 28 Oct 2014.

Ecological Psychology, 26:229–261, 2014

ISSN: 1040-7413 print/1532-6969 online
DOI: 10.1080/10407413.2014.957969

Seeing Where the Stone Is Thrown by Observing a Point-Light Thrower: Perceiving the Effect of Action Is Enabled by Information, Not Motor Experience

Qin Zhu
Division of Kinesiology and Health
University of Wyoming

Geoffrey P. Bingham
Department of Psychological and Brain Sciences
Indiana University

People are very adept at perceiving biological motion (e.g., Johansson, 1973). This ability has been an essential life skill to members of this social species. The human niche during the ice age was socially coordinated hunting for big game. Being able to judge the location targeted by the throw of a conspecific would be a valuable perceptual ability that we now study to investigate 2 competing theories of biological motion perception: Common Coding (CC; Prinz, 1997) and Kinematic Specification of Dynamics (KSD; Runeson & Frykholm, 1983). The 2 theories diverge in attributing perceptual ability to either motor or visual experience, respectively. To test predictions of the CC theory, we performed 3 experiments to manipulate observers' specific motor experience while they judged the targeted location of throwing by watching point-light displays. In Experiment 1, we tested whether the identity of the thrower in the display mattered. In Experiment 2, we tested whether the motor expertise of the observer mattered. In Experiment

Correspondence should be addressed to Qin Zhu, Division of Kinesiology and Health, University of Wyoming, Department 3196, 1000 E. University Avenue, Laramie, WY 82071. E-mail: qzhu1@uwyo.edu

3, we tested whether the gender/style of throwing demonstrated by the point-light thrower mattered. The combined results failed to support CC theory, suggesting that motor experience is not required for the perception of action. Because all participants judged the target location of throwing quite well, KSD theory suggests that the kinematic information available in the displays may have enabled the perception. We performed Experiment 4 to analyze the information. We found that the judgment pattern exhibited by the observers in both Experiments 1 and 2 was well predicted by the KSD theory. Thus, we concluded that the perception of biological motion is enabled by visual information and improved by visual experience.

INTRODUCTION

People are quite adept at perceiving and judging biological motion (Johansson, 1973; Runeson & Frykholm, 1983) and then making appropriate responses to a perceived action or its intention. People use biological motion perception to support their social interactions (Pavlova, 2012; Yoon & Johnson, 2009), to facilitate performance of cooperative tasks from moving furniture to hunting game (Isenhower, Richardson, Carello, Baron, & Marsh, 2010; Runeson & Frykholm, 1983), and to enhance team sports performance (Bouquet, Gaurier, Shipley, Toussaint, & Blandin, 2007; Horn, Williams, Scott, & Hodges, 2005; Williams, Hodges, North, & Barton, 2006). Alternative theories have emerged to account for the human ability to perceive and judge biological motion so well. One theory hypothesizes that biological motion perception is a variety of visual event perception. According to this theory, exceptional sensitivity to the forms of biological motion events derives from extensive experience of perceiving those events. Another theory hypothesizes that the perception and the production of the actions that comprise biological motions are supported and enabled by the same representations. This symmetry of representation results in special skill at perceiving biological motion.

Visual Theories for Perception of Biological Motion

The visual theories for perception of biological motion adopt the concept of direct perception (Gibson, 1972), considering that information specifying the motion is readily available in the visual display of the motion. Using point-light displays (i.e., bright markers attached to the major joints of the actor viewed in darkness), Johansson (1973) first demonstrated that moving dots describing the motions of major joints were sufficient to evoke the impression of human walking, running, and dancing. Based on the belief that the recognition was determined by the spatiotemporal pattern of proximal stimuli, Johansson formulated a model of visual vector analysis in which the proximal stimuli were subject to geometric and kinematic analysis to yield correct perceptual responses. Cutting, Proffitt, and Kozlowski (1978) later established a single biomechanical invariant for identifying the gender of the walkers in point-light displays. In their study, three interrelated approximations (shoulder/hip ratio, torso torque, and center of moment) were evaluated for their effectiveness in determining the gender of the walkers, and it was concluded that the center of moment was the key.

These pioneering studies were followed by the formulation of a theory known as Kinematic Specification of Dynamics (KSD). According to Runeson and Frykholm (1983), events involving dynamical properties such as force, mass, expectation, emotion, and intention can be fully expressed by kinematics (spatiotemporal pattern of the motion) simply because kinematics resulted from dynamics. Observers could accurately judge the distance of underarm throwing viewed in a point-light display of the throwing motion without seeing the throwing object and target because object mass and reactive force used to propel the object were both specified by the kinematics of the point-light motion. Similarly, observers could judge whether the weight lifting in a point-light display was true or fake because the intended weight and the force used to lift that weight were both evident in the kinematics of the point-light motion. In the point-light display of a complex activity, the gender of the actor could be recognized because the observer could pick up the gender-specific information from the kinematics of the point-light motion, and this information remained invariant even when the actor in the display attempted to exaggerate and fake the movement to deceive the observer.

More recently, neuroimaging studies provided a neural basis for the KSD account of recognizing biological motion. Grossman and Blake (2002) showed that viewing of biological motion mainly activated the posterior superior temporal sulcus (STSp) in the dorsal pathway. However, several regions in the ventral pathway seemed to be also involved in the recognition of movements. Whereas the occipital and fusiform face areas (OFA and FFA) may participate in differentiating biological from nonbiological motion, the extrastriate body area (EBA) and lateral occipital complex (LOC) might be involved in perception of human form. Accordingly, a model of neural mechanisms for detection and recognition of biological motion was proposed (Giese & Poggio, 2003), which included two separate channels for form and motion perception. These two channels integrate to exhibit "sequence selectivity" when the "snapshots" are displayed in the correct temporal order.

In the original formulation of KSD, Runeson and Frykholm (1983) argued that the relative sensitivity to kinematic information about an event was determined by perceptual experience. Reviewers responded to their experiments in which point-light actors attempted to deceive observers with respect to the amounts of lifted weight by suggesting that expert mimes should be used because the expert mimes should succeed in fooling observers. Runeson and Frykholm responded that they should likewise be allowed to use expert perceivers who had extensive experience in detecting the deceptive efforts of expert mimes. They argued that no one could override the physical/biophysical constraints in performing an action, and extensive experience in perceiving particular events would lead to good sensitivity to the relevant kinematic information with good skill in perception as a result. Later, Mark (2007) demonstrated that kinematic information was well used for perceiving the actions and intentions of other people.

Motor Theories for Perception of Biological Motion

Instead of focusing on visual information, motor theorists attributed sensitivity to the biological motion to the observer's previous experience in performing the action being observed. Thus, the more experience in performing the viewed action (or similar actions), the better chance that the viewed action would be recognized. Therefore, if the observer was the one who generated the motion, viewing self-generated motion should be more meaningful than viewing other-generated motion, leading to a better recognition. Beardsworth and Buckner (1981) found that the recognition of one's own movements was better than those of friends in point-light displays. This finding was further confirmed by Loula, Prasad, Harber, and Shiffrar (2005), who reported that the ability to identify or discriminate the actor in point-light displays of various sports and social movements progressively decreased as displays changed from self-motion to friend-motion, and to a stranger's motion, at which the sensitivity was at chance level. Although recognizing others' motion showed an advantage for a frontal view over profile views, recognizing self-motion has been found to be viewpoint independent (Jokisch, Daum, & Troje, 2006). Furthermore, motor learning without visual feedback was found to enhance the subsequent visual recognition of the learned movement (Casile & Giese, 2006), suggesting that motor experience played an important role in determining sensitivity to biological motion. Common Coding (CC) theory was proposed to account for the influence of motor experience on the perception of biological motion (Prinz, 1997). According to the CC theory, perception and action share the same representation, so the perception of action resonates with action production. Using an interference paradigm, Prinz (1997) demonstrated that perceiving an ongoing event impaired the action planning for the same event and vice versa, suggesting that perception and action call upon the same codes, and when the codes are occupied by one system, the other system cannot access the codes. Since its appearance, the CC theory has been widely used to account for the ability to identify human actions. Knoblich and Prinz (2001) showed that people were accurate in recognizing their own previously unseen drawings. Even in the linguistic domain, lipreading accuracy was found to be higher when people were viewing a silent video clip of their own previous utterances (Tye-Murray, Spehar, Myerson, Hale, & Sommers, 2013).

Like KSD theory, there is evidence from neuroscience to support CC theory. The discovery of mirror neurons in the premotor cortex of the macaque monkey (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996) provided the neural basis for the notion of common coding between perception and action. These neurons fired when monkeys watched and performed the same action. Brain imaging studies have shown that similar brain areas (frontal, parietal, and temporal lobules) were activated when participants perceived and performed the same action (Decety & Grèzes, 1999; Iacoboni et al., 1999). Recently, Serino et al. (2010) demonstrated that patients with hemiplegia (a lesion of the motor system) recognized their own arm gestures less accurately than their normal counterparts, suggesting that the impairment of motor cortex decreases visual sensitivity to human action.

Judging the Target of Throwing in Point-Light Displays

Targeted throwing has been used to study the perception of biological motion for various reasons. First, targeted throwing is a gross motor skill that involves multijoint movements, thus allowing for the production of point-light displays. In previous studies (e.g., Runeson & Frykholm, 1983), a point-light display of throwing showed the movement of the limbs up to the moment of release, so that the object flight and the target would not appear in the display. Second, targeted throwing is a dynamical event because force has to be generated intentionally to propel an object through the air to hit an intended remote target.[1] Thus, it is suitable for testing the KSD theory. Runeson and Frykholm (1983) used point-light displays of the underarm throwing of sandbags to show that observers were able to judge the throwing distance successfully. Third, targeted throwing is a fundamental skill that people have rich experience in both performing and watching. Thus, it is suitable for testing the CC theory. Knoblich and Flach (2001) used overarm dart throwing to show that observers were more accurate in judging the landing position of the dart on a target board when they watched their own throws, especially when information about the thrower's identity (i.e., visible head and body) was available. Recently, the French bowling game of *boule* was used in point-light studies (Munzert, Hohmann, & Hossner, 2010). The observers viewed the displays with or without reduction of the amount of kinematic information to judge bowled distances, and their performance worsened when the point-light display was reduced to one point representing

[1]Note that intentions are part of the dynamics in KSD as formulated by Runeson and Frykholm (1983).

the hand or when the time course of the visible arm movement was reduced. The authors interpreted the results as supporting the CC theory, arguing that the observers would have had difficulty internally simulating the bowling event to judge its outcome. However, it was equally possible that the reduction of kinematic information in the displays disrupted the perception of the overall spatiotemporal pattern of bowling, preventing specification of the dynamics. Thus, the results might serve equally well to support the KSD theory.

Current Study

So far, targeted throwing has been used to test both KSD and CC theories but separately in different studies. We now used targeted throwing to contrast and test both theories in a single study. Specifically, we tested people's ability to judge the target of throwing observed in point-light displays. According to the CC theory, the perception of action requires motor representation of the action. Hence, judgments of the target of throwing should be better when the observer has had motor experience of the targeted throwing. An observer might gain motor experience of targeted throwing in three ways: (a) the observer actually performed the targeted throwing shown in a display (the effect of thrower's identity); (b) the observer is an expert thrower, and thus, has had extensive experience of throwing at the target before participation in the study (the effect of observer's motor expertise); and (c) the observer learned to perform the throwing with a particular preferred style that could be the same or different from the style exhibited by a thrower in a point-light display[2] (the effect of style/gender of throwing motion). We investigated whether having any of these types of motor experience would allow an observer to judge the target of throwing more accurately. Because different types of motor experience may combine to affect judgments of throwing, we designed three experiments to isolate and evaluate the effect of each type of motor experience on judgments of the target of throwing. In Experiment 1, the effect of the identity of the thrower in point-light displays was tested. Expert throwers watched expert throws (either self-throwing or throwing produced by another expert of the same gender) to judge the target of throwing. Thus, the expertise and style (gender) of the throwing were controlled. If the judgment accuracy was higher when viewing self-throwing than when viewing other-throwing, the CC theory would be supported. If the reverse effect occurs, then the KSD theory would be supported, given that people have substantial

[2]Zhu, Lu, and Wilson (2012) performed motion analysis of the throwing recorded in point-light displays and found a significant gender difference in release control. Whereas male experts released the ball faster with a flat angle, female expert throwers released the ball much less rapidly while exhibiting much larger angles. Thus, we use gender to define the style of throwing in the present study (i.e., male style of throwing vs. female style of throwing).

visual experience of watching others throwing. In Experiment 2, the throwing expertise of the observer was isolated for investigation. Both expert and novice throwers observed gender-matched expert throwing in point-light displays to judge the target of throwing. Neither experts nor novices actually performed the throwing displayed in the video. Thus, the identity of the thrower and the style (gender) of throwing were controlled. Novice throwers were tested to show inability to hit the targets in long distance. If the judgment accuracy was higher for expert throwers, and novice throwers were judging at or below chance level, the CC theory would be supported. However, if novice throwers were able to judge the targets of throwing reasonably well (even if less well than the experts), then the KSD theory would be supported because the intact kinematic information available in point-light displays would have enabled them to do so. Then, in Experiment 3, the style (gender) of throwing was isolated for investigation. Male and female competent throwers observed point-light displays of expert throwing (both same gender and different gender) to judge the target of throwing. The identity of the thrower and the observer's throwing expertise were controlled. If the judgment accuracy was higher when observers viewed the same-gender throwing than when they viewed the different-gender throwing, the CC theory would be supported. Conversely, if the gender or style of throwing had no effect on the judgments, then the KSD theory would provide a viable account, especially if supported by the results of Experiments 1 and 2. Finally, in Experiment 4, we explicitly tested predictions of KSD theory. The kinematic information available in the point-light displays of throwing was analyzed and used to predict the judgments in Experiments 1 and 2. A good agreement between the predicted judgment performance and the actual judgment performance would support the KSD theory.

EXPERIMENT 1: THE THROWER'S IDENTITY

Common coding theory predicts that perception of action is better if the observer has previous experience in performing the observed action. Many studies have shown the advantage of watching self-generated motion over other-generated motion in recognizing the human actions (Beardsworth & Buckner, 1981; Jokisch et al., 2006; Knoblich & Flach, 2001; Knoblich & Prinz, 2001; Loula et al., 2005). Thus, the actor's identity in the point-light displays seems to be important for perception. However, high sensitivity to the self-generated motion found in previous studies may be confounded by other motor experience. For instance, observers might have been more skilled at the action than the other actors observed, or observers might have been more familiar with the particular style of action exhibited by the point-light actor. Thus, the actor's identity should be isolated from other types of motor experience (motor expertise and motor style) to test whether observing oneself as the actor in a point-light display yields better perception of action. Accordingly, we videotaped targeted throwing of expert throwers and used their throws to generate point-light displays. A month after the recording, we invited them back to view the point-light displays of their own throwing as well as throwing produced by another expert of the same gender and then to judge the target of throwing. Because the observer's motor expertise and gender (style of throwing) were both matched to the thrower's characteristics in the point-light displays, the effect of the thrower's identity could be accessed alone.

Methods

Participants. Twelve expert throwers were recruited from the University of Wyoming varsity teams: 6 male pitchers from the baseball team and 6 female pitchers from the softball team. Six of these participants (3 males and 3 females) were recruited earlier and participated in the videotaping of the targeted throwing and the following video judgment task, and the other 6 participants were recruited a year later. They did not know the previous 6 participants and participated only in the video judgment task without actually performing the targeted throwing. All participants signed a consent form before their participation. Both the consent form and the procedures of the experiment were approved by the institutional review board (IRB) at the University of Wyoming.

Apparatus and display generation. A target board (see Figure 1) was constructed of Plexiglas (sides of length = 122 cm) fixed in a metal frame that allowed the target to be raised or lowered to achieve different target heights. A circle (diameter = 30 cm) was taped in yellow on the Plexiglas with its origin at the center of the board, where a small reflective marker (diameter = 1.5 cm) was attached. Plexiglas was used so that a video camera could be placed safely behind the target to record the trajectory of the projectiles including the location of target hits.

Two fast-speed cameras (SportsCam 500 by Fastec Imaging, San Diego, CA) each fixed on a portable tripod were used to record the targeted throwing. One camera was used to record the throwing event. It was positioned perpendicular to the plane of throwing, facing the throwing side of the thrower 8 m away from where the thrower stood. A spotlight was fixed next to the camera to illuminate the reflective marks in the video. The zoom of the camera was adjusted so that the complete throwing motion would be recorded, including a portion of the ball's trajectory after release. The other camera was used to record the ball approaching and hitting the target. It was positioned behind the target at a distance of 3 m, facing the Plexiglas. The height of camera was adjusted to be equal to the height of the center of Plexiglas. The camera zoom was adjusted

FIGURE 1 The target board.

to show the entire Plexiglas area so that the location of the thrown ball on the target board could be determined. The two cameras were manually synchronized using a trigger to record both events at the rate of 250 frames per second (fps).

Six participants (3 males and 3 females) performed the targeted throwing in a gymnasium. They were given a dark spandex suit to wear while they were videotaped throwing. Seven reflective marks (diameter = 3.5 cm) were attached to the body of the thrower on the throwing side at the head, shoulder, elbow, wrist, hip, knee, and ankle. A tennis ball was wrapped with reflective tape so that it would appear in video recordings with the reflective markers on the body. Participants were told to throw the tennis ball to hit the target inside of the circle. The target was positioned at one of three different distances (5 m, 10 m, and 15 m) from the thrower, and at each distance, the target was adjusted to one of three different heights: below eye level (the center of the Plexiglas was

1 m above the floor), eye level (the center was 1.5 m above the floor), and above eye level (the center was 2 m above the floor). Thus, there were nine target locations yielded by 3 (distance) by 3 (height) configurations. To each location, participants were required to make five valid throws. To be valid, the throw had to result in a hit within the target circle as shown by the camera behind the target. Invalid throws were deleted and not used in the following video editing.[3] The recorded video clip for each valid throw was named after its corresponding distance-height configuration as well as the trial number under each configuration.

With five valid throws in each distance-height configuration, a total of 45 video clips of successful targeted throwing were used for production of point-light displays for each thrower. To produce the point light displays, each video clip was edited, using Adobe Premiere Pro CS4 (Adobe Systems Inc., San Jose, CA), to achieve the following goals: (a) to show only the eight reflective markers (7 body markers and 1 ball marker) against a black backdrop, (b) to show only the throwing motion up to ball release (neither ball flight nor the target board appeared in the displays), (c) to scale the images so that each thrower had the same image size in the displays, (d) to down sample the video frame rate from 250 fps to 30 fps for smooth and accurate real-time playback of all point-light displays, and (e) to repeat the same throw three times so that the duration of the point-light display for every throw was 9.14 s. Figure 2 illustrates a resultant point-light display.

Using 45 point-light displays for each participant and E-Prime software (E-Prime Version 2.0 by Psychology Software Tools, Inc., Sharpsburg, PA), the experimental sessions were programmed.

Judgment procedure. A month after the recording of their throwing, the same participants were invited back and tested in two separate experimental sessions. The task in both sessions was to view point-light displays of throwing and judge both target distance and target height. In one session, they viewed point-light displays of their own throws, and in the other session, they viewed displays of throws made by another familiar thrower who was of the same gender as the observer. The order of the two sessions was counterbalanced across the participants (2 of 3 males judged self-throwing first, and 2 of 3 females judged other-familiar throwing first), and participants were not told when they were viewing displays of themselves. The other 6 participants who did not participate in the videotaping of the targeted throwing were recruited later for one experimental session in which they viewed and judged the point-light displays of throws made by an unfamiliar expert thrower who was of the same gender as the observer.

[3]All throwers were quite accurate in throwing. Each produced only one or two invalid throws.

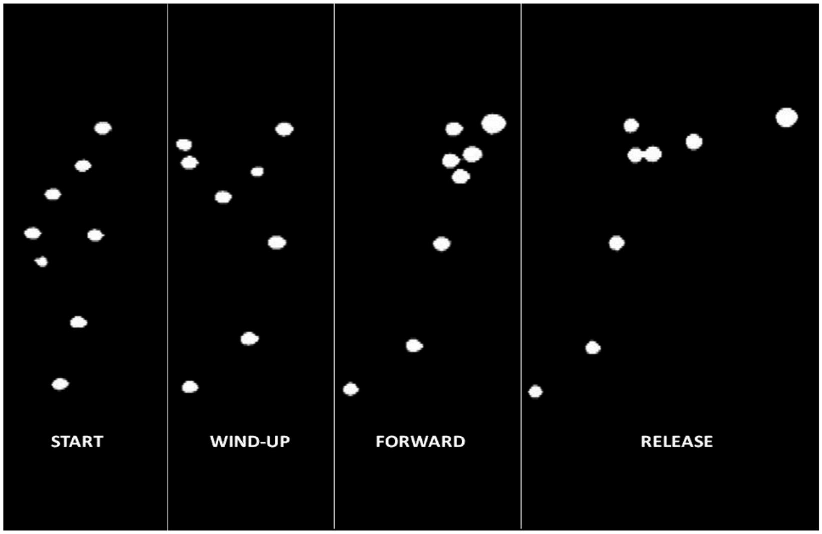

FIGURE 2 Snapshots of a throwing trial in a point-light display.

In each session, the participant was asked to sit in front of an LED computer screen (Dell 22-in. [55.88-cm] diagonal), keeping the distance from the nose to the center of the screen about 60 cm. A compatible keyboard with rest pad was provided on the table between the screen and the seat. Nine keys on the keyboard were labeled using color stickers, each representing a particular distance-height configuration (see Table 1). Participants were asked to rest their preferred hand on the rest pad of the keyboard. They were told to return to the rest pad every time after they had pressed the key in response to the video clip displayed on the screen.

Participants were then informed that the video clips of the previously recorded 45 successful throws in the targeted throwing were edited into 45 point-light displays of throws in which only the throwing motion prior to the ball release could be seen. Their task was to watch the point-light displays for a particular

TABLE 1
Labeled Keys to Be Pressed for Judgment

Height/Distance	*5 m*	*10 m*	*15 m*
Above eyeheight	Q	R	U
Eyeheight	A	F	J
Below eyeheight	Z	V	M

thrower and judge the destination of each throw (target distance and target height) as accurately as possible by pressing the corresponding key on the keyboard. They were also informed that the 45 displays were to be randomly called to play on the screen for judgment, and each display would repeat three times. Once the display started, they should pay close attention to the moving point-lights, and upon the end of the third repetition (when all point-lights stopped moving), make their best judgment of the target location by pressing the key on the keyboard. Upon the press of the key, the next trial was called up for the next judgment trial. To familiarize participants with the task before making judgments, each was shown a standard display. Participants were told that the standard display was a throw made to hit a target located at 10 m distance at eyeheight level and that a correct response would be to press the "F" key.

The dependent measure was the accuracy of the responses. Judgments were scored separately by E-Prime with respect to distance and height, assigning a "1" to each correct response in each case and a "0" otherwise. Thus, if the judgment was accurate in both distance and height, a value of "1" was assigned to both categories for that trial.

Results and Discussion

Judgment accuracy was evaluated by comparing the two sessions for the early 6 participants. First, we calculated the percentage of correct judgment for distance, height, and both height and weight. Participants were well above chance (33.3%) in judging distance (Mean = 52% [Self] & Mean = 62% [Other]) and height (Mean = 48% [Self] & Mean = 56% [Other]). Chance level when both judgments were combined was 11.1% and again, participants were well above chance (Mean = 25% [Self] & Mean = 38% [Other]) in both sessions. Nevertheless, judgments of self-throwing were consistently less accurate than judgments of other-throwing.

We computed d' to better evaluate the sensitivity of the judgments. Smith (1982) provided simple algorithms for calculating d' in M-Alternative-Forced-Choice (M-AFC) experiments. Accordingly, the judgment of distance and that of height were each 3-AFC task. Together, the judgments of both distance and height can be treated as a 9-AFC task. We used algorithm 1 in Smith's paper (see equation) to calculate the d's based on the percentage correct (P_c) obtained for each participant in each category of judgment.

$$d' = 0.86 - \frac{0.85 \ln(M-1) \ln((M-1)P_c)}{1 - P_c},$$

where $M = 3$ for judging distance and height separately and $M = 9$ for judging distance and height together. As can be seen in Figure 3, the d' values

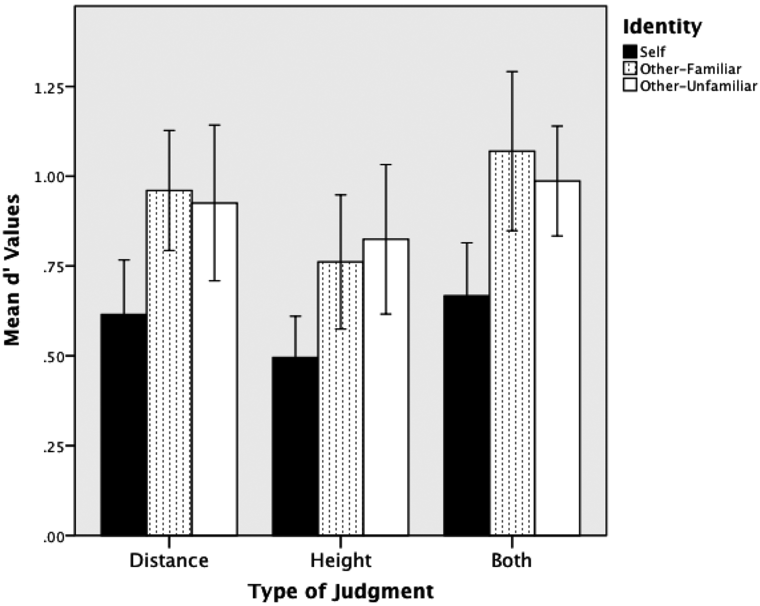

FIGURE 3 The mean d' values as a function of judgment type and thrower identity. The error bars represent the standard error of the mean.

were consistently higher for judging other-familiar throwing than for judging self-throwing in each category. This showed that viewing self-throwing did not improve the observer's sensitivity to the target location of throwing. We used a nonparametric Wilcoxon signed ranks test (treating session as a within-subject factor) to evaluate the effect of the thrower's identity. The judgments were significantly poorer when viewing self-throwing than viewing other-familiar throwing in each category of judgment: $Z = -1.992$, $p = .046 < .05$ for judging distance; $Z = -1.992$, $p = .046 < .05$ for judging height; and $Z = -2.023$, $p = .043 < .05$ for judging both distance and height.

Judgment accuracy was originally scored with dichotomous coding ("0" and "1"). To confirm the aforementioned findings, we performed a logistic regression in which the odds ratio (e^B) represented the probability that the dependent variable equaled 1 (correct judgment) when the independent variable increased by one unit (from viewing self-throwing to viewing other-throwing). Using session as the independent variable, the logistic regression was performed separately for judgments of distance, judgments of height, and judgments of both distance and height. The results yielded a significant odds ratio for judging distance ($e^B = 0.65$, $p < .02$), for judging height ($e^B = 0.72$, $p < .05$), and for judging both distance and height ($e^B = 0.55$, $p < .002$) when participants were viewing self-throwing. This suggested that when viewing point-light displays of self-throwing compared with other-familiar throwing, the probability for accurate judgment of distance was reduced by 35%, the probability for accurate judgment of height was reduced by 28%, and the probability for accurate judgment of both distance and height was reduced by 45%. In sum, viewing point-light displays of self-throwing significantly decreased the probability of being accurate in judging the location of the target compared with when viewing other-throwing.

We also analyzed the judgment accuracy from the additional 6 participants to test the reliability of the performance level when viewing other-throwing. As can be seen in Figure 3, the new calculated d' values for viewing other-throwing were quite similar to those found previously. We then used a nonparametric Mann-Whitney test (treating group as a between-subject factor) to examine the difference between the two conditions of viewing other-throwing (original vs. replication) as well as the difference between the replication of viewing other-throwing and the original viewing of self-throwing. The results showed no difference in the former comparison ($Z = -.222$, $p = .839 > .05$) but did in the latter. The judgments were significantly poorer when viewing self-throwing than viewing other-throwing ($Z = -3.679$, $p = .00001 < .001$).

In sum, the judgment accuracy was higher when viewing the point-light displays of the other-, rather than self-, throwing, suggesting that a thrower's identity in point-light displays is indeed a reliable determinant of the relative accuracy with which the distance and height of the targets of throwing can be judged from observation of only throwing motions. However, contrary to the predictions of CC theory, the advantage goes to judgment of a thrower other than the self, rather than the reverse. The judgment advantage for viewing the other-throwing may be simply that observers have had more experience viewing other people throwing (e.g., when playing or watching baseball or American football). Given that all observers were expert throwers and members of varsity baseball teams, it is likely that they had significant experience of viewing a model demonstrating the throwing motion in the Sagittal plane during skill acquisition (Al-abood, Davids, & Bennett, 2001; Horn, Williams, & Scott, 2002). In contrast, they would rarely have a chance to see their own throwing, at least from a third person perspective. The other possibility is that observers may have been distracted by self-motion during judgment. When they were presented with self-throwing motions and they wondered if they were the thrower, they might have attended more to how they as persons appeared in the movies, possible idiosyncrasies in their own motions, at the expense of attending to the target location. However, all observers were well above chance accuracy in both distance and height judgments, implying that there was sufficient information in the point-light displays for observers to perceive and judge both distance and height of the target.

EXPERIMENT 2: THE THROWING EXPERTISE OF THE OBSERVER

The results of Experiment 1 excluded one type of motor experience (thrower's identity) as an account for better judgments of throwing viewed in point-light displays. Now, we focus on a second type of motor experience, throwing expertise. Casile and Giese (2006) showed that people with nonvisual motor training on a novel skill improved in subsequent visual recognition of the trained skill. Likewise, basketball players were able to predict the success of free shots earlier and more accurately than did individuals with less motor experience (Aglioti, Cesari, Romani, & Urgesi, 2008). Thus, if our observers had some serious training and extensive experience of targeted throwing before the experiment, their judgments of the throwing should be better than those who did not have such training and experience. Accordingly, we recruited participants with or without serious training and experience of targeted throwing and tested their judgments of the targets of throwing when observing point-light displays. Again, to avoid confounding effects from other motor experience, we showed participants the displays of other-throwing and matched the observer's gender to the point-light thrower's gender. To be noted, the superior perception of action by skilled actors is also predicted by KSD theory because skilled actors concomitantly have had experience watching others perform throwing. Thus, the experts were experienced both as throwers and perceivers. Conversely, the novices were inexperienced both as throwers and perceivers of the action to be judged. There are abundant studies showing that skilled actors are able to pick up the essential kinematic information for anticipation of action (Abernethy & Zawi, 2007; Cañal-Bruland & Schmidt, 2009; Cañal-Bruland, van der Kamp, & van Kesteren, 2010; Williams et al., 2006). Because both CC and KSD predict that expert throwers should outperform the novice throwers in predicting the target of throwing, we are more interested to see how well the novice throwers are able to perform the task. If motor expertise is crucial to their ability to judge the target of throwing, as suggested by the CC theory, they would be unable to do the task because they had little or no motor experience of targeted throwing, especially in hitting a target at long distance. Whereas, the KSD theory predicts that novice throwers can still do the task, judging above the chance level, due to the availability of kinematic information in the point-light displays, although they may be not as good as their expert counterparts.

Methods

Participants. Twelve unskilled throwers were recruited from the University of Wyoming campus. They were matched in gender and age with the previous 12 expert throwers. All participants were tested with a throwing task in which they had to throw a tennis ball 15 times to hit within the circle on the target board positioned at eyeheight level at 10 m distance. If the participant threw short or missed the circled area more than 12 times (miss rate $\geq$ 80%), the participant was considered a novice thrower and recruited for the experiment. All participants signed a consent form before their participation. Both the consent form and the procedures of the experiment were approved by the IRB at the University of Wyoming.

Apparatus and display generation. The same point-light displays and E-Prime-based judgment task used in Experiment 1 were used for Experiment 2.

Procedure. Participants were scheduled for one experimental session. They were told the following: (a) a total of 45 throws were performed by a skilled thrower to hit a target positioned at each of three distances and at each of three heights at each distance yielding five successful hits in each distance-height configuration, (b) the throws were videotaped and then edited to show only point-light displays of throwing up to ball release, and (c) their task was to observe each point-light display and judge both the distance and height of the target as accurately as they could by pressing the labeled key on the keyboard. Unknown to the participants was the fact that the thrower they judged was always of the same gender as themselves.

Results and Discussion

Judgments made by experts viewing other-throwing in Experiment 1 were compared with the judgments made by novices in Experiment 2. Despite the difference between expert and novice throwers as observers, both groups were well above chance (33.3%) accuracy in judging distance (Mean = 62% [Experts] & Mean = 50% [Novices]) and height (Mean = 57% [Experts] & Mean = 51% [Novices]) and as well as when judging both distance and height (Mean = 36% [Experts] & Mean = 25% [Novices]) where the chance level was 11.1%. Once again, d's were calculated for each participant in each category of judgment. As shown in Figure 4, expert judgments were consistently greater than novice judgments. This observation was tested using a nonparametric Mann-Whitney test in which group was a between-subject factor. The results showed a significant difference for distance ($Z = -3.080, p = .001 < .01$) and for both distance and height ($Z = -3.439, p = .0001 < .001$) but not for height ($Z = -1.593, p = .114 > .05$).

This finding was further supported by a logistic regression with group as the independent variable. The analysis yielded a significant odds ratio for distance ($e^B = 1.5, p = .001 < .01$) and for both distance and height ($e^B = 1.7, p = .0001 < .001$) but not for height alone ($e^B = 1.3, p = .054 > .05$), suggesting

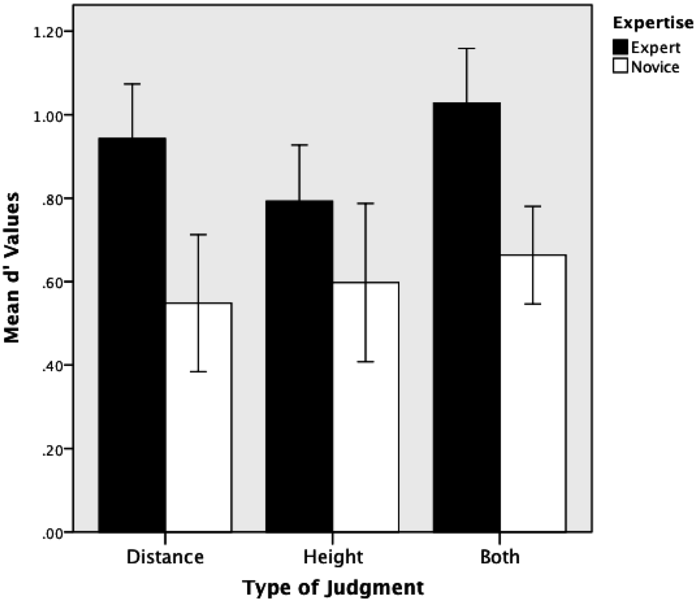

FIGURE 4 The mean d' values as a function of judgment type and motor expertise. The error bars represent the standard error of the mean.

that the expertise of the observer may affect judgment accuracy. The chance of being accurate was better for expert compared with novice throwers.

In general, judgments made by experts were more accurate than those made by novice throwers, suggesting that skill and experience improves the ability to perceive this action. This would lend support to the CC theory. However, the CC theory also predicts that novice throwers should not be able to perform the task at all because the task is more than identifying the type of action (throwing); it requires perceptually discriminating among the target locations. Because novice throwers had proven unable in the pretest to hit a target on purpose at all, they had absolutely no discriminative motor experience of the motor differences required to hit different targets. Hence, there was nothing that they could have relied on in performing the specific discriminative perceptual task. Contrary to this prediction, novice judgments were only slightly poorer than those of the experts. They were well above chance in all cases. Particularly in judging the height, novices were no different from experts. Thus, novices were able to pick up the information in the point-light displays to judge the locations of throwing targets. They were just not quite as good as the experts. Similar arguments have been made previously when young children and motor-disabled patients were asked to judge biological motion (Pavlova, Krägeloh-Mann, Sokolov, & Birbaumer, 2000; Pavlova, Staudt, Sokolov, Birbaumer, & Krägeloh-Mann, 2003). Both behavioral and neurological data suggest that perception of biological motion is not substantially affected by an observer's early restrictions on movement. On the other hand, KSD theory predicts that the judgments should be good as long as sufficient visual information about the target locations is available in the point-light display. KSD theory also predicts an advantage for experts because people with substantial skill and experience of targeted throwing would also have substantial visual experience of the action. Even if visual information is limited during skill acquisition, there is evidence supporting the possibility that kinesthetically learned movements can be recognized visually as well (Wilson, Bingham, & Craig, 2003). In this sense, motor expertise helped fine-tune the visual information for success of predicting the effects of throwing.

EXPERIMENT 3: THE THROWING STYLE (GENDER)

In Experiment 1, we found that the thrower's identity (self or other) did affect judgment accuracy but not as predicted by the CC theory; judgments of the other-throwing were more accurate than that of the self-throwing. In Experiment 2, we found that the observer's expertise in targeted throwing affected the accuracy of judgments of target distance but not judgments of target height. The former finding was consistent with the predictions of CC theory, although the latter were not. Furthermore, CC theory would predict that novice throwers should not be able to judge target locations at all because they lacked the ability to throw to hit targets. However, novice throwers were able to judge target locations, if not quite as accurately as the experts. Thus, the results of Experiments 1 and 2 failed to provide a good support for the CC theory. In Experiment 3, we tested a third aspect in judging skilled performance relevant to the CC theory, namely, the throwing style. We used the thrower's gender to manipulate the throwing style based on the finding that males throw quite different from females (Zhu et al., 2012). Calvo-Merino, Grèzes, Glaser, Passingham, and Haggard (2006) reported that greater premotor, parietal, and cerebellar activity was detected for expert dancers when they viewed same-gender dancing compared with opposite-gender dancing. However, it remained unclear whether greater activation in brain motor areas would lead to a more accurate prediction of action goals like the target of throwing. We recruited both male and female throwers who were competent in targeted throwing and asked them to judge the target of throwing by viewing point-light displays of either same-gender or different-gender throwers. If throwing style constitutes motor experience that determines effective perception of this action (as predicted by CC theory), then observers should be more sensitive to the point-light displays of the same-gender throwing than to those of the different-gender throwing, leading to more accurate judgments in the former compared with the latter case.

Methods

Participants. Twenty-four competent throwers were recruited from the University of Wyoming campus. Half were female. To be considered a competent thrower, the participant had to demonstrate the ability to throw a tennis ball to hit the circled area on our target more than 10 times in 15 attempts (hit rate = 67%) when the target was positioned at eyeheight level at 10 m distance. All participants signed a consent form before their participation. Both the consent form and the procedures of the experiment were approved by the IRB at the University of Wyoming.

Apparatus and display generation. The same point-light displays and E-Prime-based judgment task used in Experiment 1 were used in Experiment 3.

Procedure. The procedure was the same as in Experiment 1 except only two sets of point-light displays were used. One was selected from among those of the male expert throwers to represent the male-style throwing, and the other was selected from among the female expert throwers to represent the female-style throwing.[4] Participants were asked to view and judge the 45 point-light displays of throwing in two consecutive sessions with a break of 5 min between the sessions. Half of the participants started with the displays of the male thrower and the other half with the displays of the female thrower, although the gender of the actor in the displays was not explicitly identified. After each participant completed the judgments, he or she was asked to judge the gender of the throwers in the displays.

Results and Discussion

First, all participants were very sensitive to the gender of the point-light thrower seen in the displays. There were only 2 participants in each gender group who judged the gender of the point-light thrower incorrectly, which means more than 80% of the participants correctly recognized gender. As suggested by the mean percentages of correct judgment of the throw displays, all participants were well above chance accuracy in judging distance and height either separately

[4]They represented two extremes of throwing style: the male-like throwing demonstrated throws made with the fastest speed and the minimum angle at release, and the female-like throwing demonstrated throws made with the lowest speed and the maximum angle at release (Zhu et al., 2012).

(> 33.3%) or jointly (> 11.1%). The d's were calculated for each participant in each category of judgment and then evaluated with respect to gender in two ways: the gender of the observer and the gender difference between the observer and the point-light thrower. The former was a between-subject and the latter a within-subject manipulation. As shown in Figure 5, the judgments were similar between male and female judgers and for judging same or different gender throwing. We used a Mann-Whitney test to evaluate the effect of gender of the observer. The results showed no difference for any category of judgment ($p > .05$). Next, we performed a Wilcoxon Signed Ranks test separately for male and female observers testing the effect of gender difference. Again, no difference was detected in any category of judgment (all p values are greater than .05).

A logistic regression treating the two gender factors as independent variables did not yield a significant odds ratio in either case (see Table 2). The odds ratios were all close to 1, showing that gender did not affect judgment accuracy either with respect to the gender of the observer or the relation between the gender of the observer and that of the actor.

Because judgments were gender independent with reasonable accuracy, the gender-specific throwing style of point-light throwers does not serve to improve the ability to perceive the throwing action when styles agree between observer and actor. Considering that males would likely not have much experience in throwing like females, and vice versa to some extent, it was quite interesting

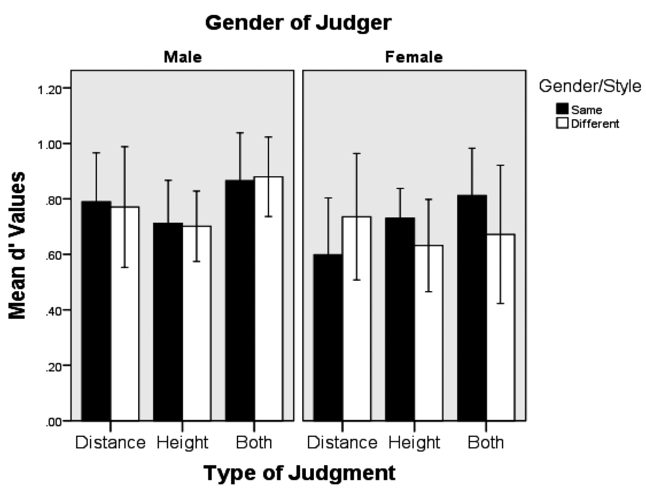

FIGURE 5 The mean d' values as a function of judgment type and gender. The error bars represent the standard error of the mean.

TABLE 2
Summary of Logistic Regressions for Gender Effect on Each Type of Judgment in Experiment 3

Gender Effect/Type of Judgment	*Distance*	*Height*	*Distance and Height*
Gender of the judger	$e^B = 1.15$ $p = .11$	$e^B = 1.03$ $p = .73$	$e^B = 1.17$ $p = .09$
Gender difference between the judger and the thrower	$e^B = .93$ $p = .41$	$e^B = 1.07$ $p = .44$	$e^B = 1.07$ $p = .45$

to see that participants performed equally well in judging both male-style and female-style throwing. Thus, there must be invariant information embedded in the point-light displays specifying the relative locations of throwing targets, which was obviously picked up by the observers. Participants also successfully recognized the gender of the point-light throwers in the displays, confirming previous findings of gender recognition in point-light displays (Cutting et al., 1978; Mather & Murdoch, 1994; Pollick, Kay, Heim, & Stringer, 2005; Runeson & Frykholm, 1983; Troje, Sadr, Geyer, & Nakayama, 2006). However, detecting the gender-specific information in the displays did not improve judgments of the target of throwing. This suggests that different information may have been used for judging the gender of the thrower and the destination of the throwing in the same point-light displays.

EXPERIMENT 4: ANALYSIS OF RESULTS IN RELATION TO THE KINEMATIC INFORMATION

In Experiments 1, 2, and 3, visual information about the kinematics of throwing was available in point-light displays, so the results from these experiments all could be anticipated, in principle, by the KSD theory, if not by the CC theory. This required that the observers should be sensitive to the kinematic information available in the point-light displays and were able to use it to make judgments of the target of throwing. The KSD theory predicts that judgments should be good when the information is good and poor otherwise. The remaining question is what information actually was available and what was the relative quality of the information used to make the different judgments (i.e., height and distance)? Because the throwing yields both ball speed and angle at release, which in turn determine the end location of the projectile motion in throwing, the kinematic information available in the point-light displays logically resided in the release of the ball. Thus, the analysis of the ball release parameters (speed and angle) as a function of target location was analyzed to investigate availability and resolution of kinematic information that could be used for predicting the target of throwing. Using the same set of point-light displays, Zhu et al. (2012) performed kinematic analysis of throwing and found that the release speeds increased only with the increasing target distance, independently of the variation in target height. In contrast, the release angles covaried with both the target distance and height, with a similar release angle used to throw at targets of varying heights in longer distances (see Figure 6).

So, the prediction of the KSD theory is that, if observers picked up the kinematic information about target location by attending to the release parameters in the point-light displays, we should expect their judgments to exhibit the patterns of ball release (speed and angle) as a function of target locations. Thus, we predict that the judgment performance should be relatively good if observers just rely on the ball release speed to judge the target distance. However, judging the target height would be difficult because observers would have to rely on the ball release angle that becomes similar when throwing at targets of varying heights in longer distances. Snippe and Koenderink (1994) investigated the sensitivity of human observers to 2-D frontal-parallel angles and reported that the threshold for discriminating a change in angle was about 7 degrees. Note in Figure 6 that throwing at a target below eyeheight compared with throwing at a target above eyeheight, the release angles changed about 9 degrees for targets at 5 m, about 6 degrees for targets at 10 m, and about 3 degrees for targets at 15 m. This suggests that the judgments of target height should progressively decrease in accuracy and precision as targets become progressively more distant to become

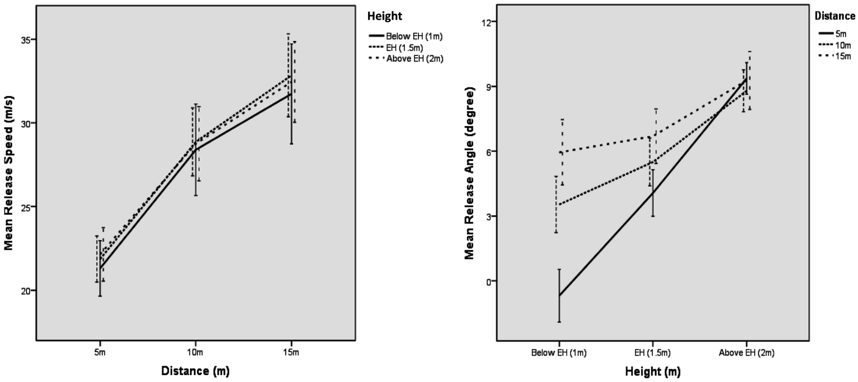

FIGURE 6 The ball release control as a function of target location in the point-light displays (adapted from Zhu, Lu, & Wilson, 2012). The left panel represents the mean release speed as a function of target distance and height, and the right panel represents the release angle as a function of target distance and height. The error bars represent the standard error of the mean.

close to chance level when the point-light thrower attempted to hit a target at 15 m. We now test if the judgment pattern predicted by the KSD theory was actually demonstrated by the observers in Experiment 1 and Experiment 2. If their judgment performance reflected what has been predicted by the KSD theory, then this theory is genuinely supported by the collected results of Experiments 1–4.

Methods

Participants. The judgments from the 6 participants who judged both self- and other-throwing in Experiment 1 and the judgments from the 24 participants who judged only other-throwing were used for analysis. Participants in Experiment 1 were all expert throwers, and half of the participants in Experiment 2 were expert and half novice throwers.

Procedure. For each participant, the judgment accuracy (percentage correct) for target distance was calculated at each level of target height, and the judgment accuracy for target height was calculated at each level of target distance. These percentages were then subject to an analysis of variance (ANOVA) to determine the respective effects of target distance and height as well as the effects of the experimental factors in Experiment 1 (identity) and Experiment 2 (motor experience).

Results and Discussion

As illustrated in Figure 7, in both experiments, the mean percentages of accurate judgment of target distance were well above the chance level (33.3%) and did not differ much among the different levels of target height, suggesting that observers in both experiments used release speed to judge target distance. A repeated measure ANOVA treating height and identity as the within-subject factors was performed for Experiment 1, and the results failed to show effects for height ($F_{2,10} = 1.72, p = .23 > .05$) or identity ($F_{1,5} = 2.99, p = .14 > .05$) or their interaction ($F_{2,10} = .72, p = .51 > .05$). A mixed-design ANOVA treating height as within-subjects and expertise as between-subjects was performed for Experiment 2, and the results showed a significant effect for expertise ($F_{1,22} = 10.02, F = .004 < .01$) but no effect for height ($F_{2,44} = .09, p = .91 > .05$) and a height by expertise interaction ($F_{2,44} = .40, F = .67 > .05$). The nonsignificant effect for identity in Experiment 1 suggested that the kinematic information about ball release speed was equally sufficient in point-light displays of both self- and other-throwing for observers to pick up and use for judgment of target distance. The significant effect for expertise in Experiment 2 suggested

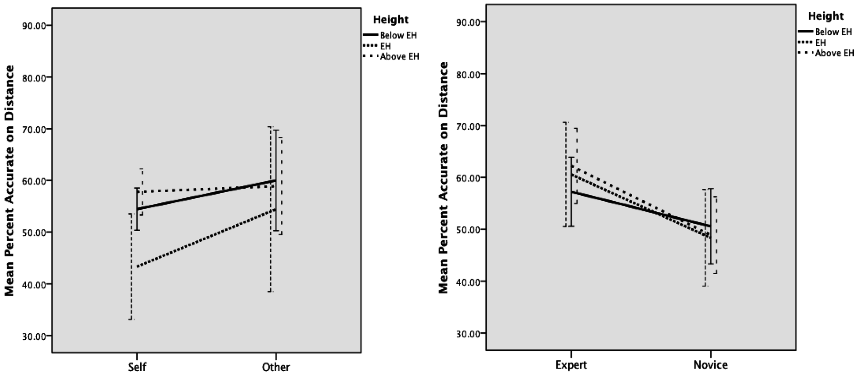

FIGURE 7 The mean percentage of judgment accuracy on distance separated by height in Experiment 1 (Left) and Experiment 2 (Right). The error bars represent the standard error of the mean.

that expert throwers were more sensitive and skilled than novice throwers at using the kinematic information (namely, ball release speed) for judgment of target distance.

As for the judgment accuracy for target height, there was, as predicted, an effect of distance in both experiments (see Figure 8). The lines representing accuracy for different levels of distance dropped, with the highest mean percentages of accuracy exhibited at 5 m and dropping at 10 and 15 m, suggesting that observers in both experiments used ball release angle for their judgment of target height. Judgments were more accurate when targets were at short distance

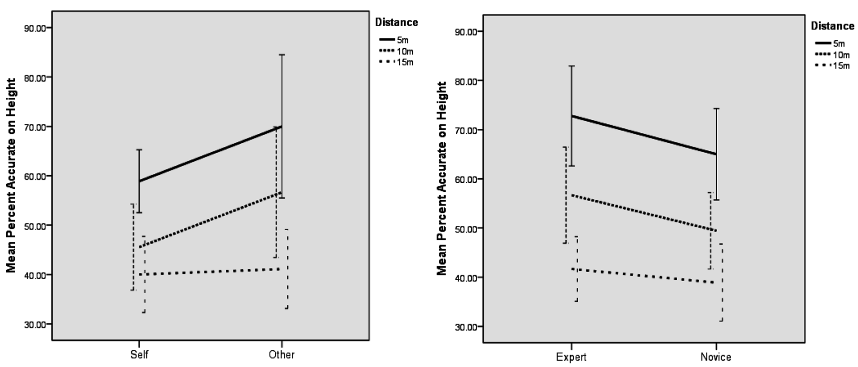

FIGURE 8 The mean percentage of judgment accuracy on height separated by distance in Experiment 1 (Left) and Experiment 2 (Right). The error bars represent the standard error of the mean.

than long distance. The judgment accuracy at the distance of 15 m was the lowest and close to chance in both experiments, implying that the use of release angle to judge target height was fairly unreliable, even for experts. A repeated measures ANOVA treating distance and identity as the within-subject factors was performed for Experiment 1, and the results showed significant effects for distance ($F_{2,10} = 7.40, p < .01$) and identity ($F_{1,5} = 8.08, p < .04$) but not for their interaction ($F_{2,10} = .77, p = .49 > .05$). Tukey post hoc tests were performed to examine the difference between different levels of distance, and it was revealed that the mean judgment accuracy was significantly better at 5 m than at 15 m ($p < .05$). A mixed-design ANOVA treating distance as the within-subject factor and expertise as a between-subject factor was performed for Experiment 2, and the results showed a significant effect only for distance ($F_{2,44} = 21.65, F < .001$). A Tukey post hoc test revealed a significant difference between each level of distance ($p < .05$) with the judgment accuracy highest at 5 m, then at 10 m, and finally at 15 m. The significant effect for identity in Experiment 1 suggested that the change of release angle was more salient in point-light displays of other- than self-throwing, yielding better judgments of target height. The nonsignificant effect for expertise in Experiment 2 suggested that expert and novice throwers were equally skilled at using release angle for judgment of target height.

In sum, there was a good agreement between the predicted judgment pattern based on the kinematic information in the point-light displays of throwing and the actual judgment pattern exhibited by observers in the both Experiment 1 and Experiment 2. Therefore, the kinematic information in the point-light displays of throwing must have been used by observers for judging the target of throwing. The results supported the KSD theory.

GENERAL DISCUSSION

Two theories have been developed to account for the perception of biological motion. The KSD theory, inspired by Gibson's ideas about direct perception (Gibson, 1979/1986), hypothesizes that kinematic information specifies the dynamics of action to allow the perception of action. The CC theory, inspired as a form of motor theory (Scheerer, 1984), hypothesizes that the observer's motor commands should serve as a representation used to allow the perception of relevant action. We sought to contrast these two theories by testing three predictions of the CC theory: (a) observers should be better at perceiving and judging their own actions than those of another person; (b) skilled performers of an action should be better at perceiving and judging it than unskilled performers, who, if they did not experience the success of action, should be unable to predict the success of action; and (c) an action performed using the same style as used by the observer should be better perceived and judged than an action performed using a different style. Using point-light display of overarm throwing, we tested these hypotheses in three corresponding experiments. In Experiment 1, we tested whether being the point-light thrower in the display could be a useful motor experience for the observer to judge the target of throwing correctly. We found, to the contrary, that judgments were more accurate when observers were viewing throws performed by another person rather than by oneself. This failed to support CC theory but did support KSD theory because expert throwers (tested as observers in our experiment) would have had lots of experience viewing other expert throwers performing the targeted throwing from the sagittal plane. In Experiment 2, we tested whether the judgment performance can be predicted by the observer's skill level in performing targeted throwing. Indeed, the judgments of expert throwers were generally good and better than those of novice throwers. However, the judgments of novice throwers were well above chance accurate and did not differ from experts' in judging the target height. These latter results were not consistent with the predictions of the CC theory. In contrast, throwers with little skill in targeted throwing still can have plenty of experience in observing targeted throwing when watching others throw, for instance, in professional sports (e.g., baseball or American football) on TV or in local stadiums. Thus, KSD theory would predict that novice throwers might nevertheless be able to perceive and judge targeted throws with some accuracy. In Experiment 3, we examined whether gender or style of throwing (a third aspect of motor experience relevant to CC theory) common to observer and thrower would yield better judgments. Although the gender of the point-light throwers was successfully recognized by the observers, male observers did not differ from female observers in judging either same-gender or different-gender throwing, and all observers were well above chance accurate in judging the target of throwing. This last set of results also failed to conform to the prediction of CC theory. Because none of the motor experience variables in our experiments affected the ability to judge the target of throwing observed in point-light displays as predicted by CC theory, we concluded that motor experience is not reliable or required for good ability to perceive and judge this action and by extension, perhaps other actions as well.

All observers in our experiments performed relatively well in the judgment tasks. The KSD theory provides a viable explanation. To be able to perform the judgment task reasonably well, the observers need only have experience in observing accurate targeted throwing and in detecting the kinematic information available in the point-light displays. They need not be experienced in actually producing accurate targeted throws. This hypothesis was confirmed in Experiment 4 in which we showed that the judgment pattern based on the invariant kinematic information in the point-light displays of throwing was actually exhibited by the observers in both Experiment 1 and Experiment 2.

Efficacy of Visual Information Over Motor Experience

This study demonstrated the efficacy of visual information over motor experience in accounting for the perception of biological motion. Perception was accurate given the availability of visual information in the point-light displays, regardless of the motor experience of the observer either alone or in relation to the thrower. Previous studies have shown the same with a different approach. Researchers have perturbed the kinematic information in point-light displays to see whether the perception of biological motion would be impaired. They found that turning the display upside down or scrambling the point-lights in the display significantly disrupted the recognition of human or animal actions (Shipley, 2003; Sumi, 1984; Troje & Westhoff, 2006). Using video rotation and normalization techniques (replacing the individual kinematic cues with the averaged kinematic values), Troje, Westhoff, and Lavrov (2005) investigated how identification of a point-light walker would be impacted by perturbation of structural and kinematic cues. They found that recognition performance dropped when shape or walking frequency was normalized or the walker was presented from novel viewpoints, although the overall performance was still higher than chance level. All these studies showed that whenever the visual information is perturbed to either violate physical laws or reduce the critical kinematic information, the perception of action is correspondingly impaired.

In fact, evidence collected to support the motor-experience-based account of the perception of biological motion is often confounded with the effect of visual information. People with extensive experience in performing certain actions also have significant experience in perceiving the same actions, and thus, the influence of motor and visual experience on the perception of human action are typically difficult to separate and control. Observers with more motor experience, in the current as well as previous studies, judged actions better than those with less motor experience because of their superior sensitivity to the visual information embedded in the displays rather than their distinctive motor experience. Sometimes, visual information was intentionally manipulated to evaluate the effect of motor experience on the perception of action (Knoblich & Flach, 2001; Munzert et al., 2010), removing visual information when the action was generated so that judgment had to be guided using kinesthetic information. In such studies, which purported to demonstrate that observers were more sensitive to the self-generated motion than to the other-generated motion (Beardsworth & Buckner, 1981; Knoblich & Prinz, 2001; Loula et al., 2005), it may only have been the more extensive perceptual experience that yielded superior judgments. If kinesthetic experience can be exchanged for visual experience and vice versa (Bingham & Wickelgren, 2008; Wilson et al., 2003), then it would only be the total perceptual experience that would matter. Judging a self-generated action would, by definition, entail a great amount of total perceptual experience. It is worth noting that judgments of the other-generated motion in these studies were reasonably good. The judgment accuracy was above chance level indicating that the visual information about the action in the displays of the other-generated motion was also effective.

Recently, Kilner, Paulignan, and Blakemore (2003) conducted an interesting study to look at how ongoing movement observation could interfere with movement execution. They showed human participants human or robotic arm movements while the participants were performing arm movements that were either congruent or incongruent to the observed movements. The interference effect (i.e., the extent to which movement execution was affected by the ongoing movement observation) occurred only when participants were observing incongruent human rather than robotic movements. Based on this finding, the researchers concluded that perception of human actions is unique and high sensitivity to the human actions should be attributed to substantial experience in performing human actions (and not robotic ones). However, in the following study, Kilner, Hamilton, and Blakemore (2007) replaced the robotic movements with ball movements. They perturbed the velocity of both human and ball movements so that the movements would look like biological (with minimum jerk) or nonbiological (with constant velocity) movements. The interference effect was evaluated when human participants were performing arm movements that were either congruent or incongruent to the observed movements. Surprisingly, the interference effect occurred not only with the incongruent human movements but also with the incongruent ball movements. This finding suggested that humans are sensitive to the visual information presented in both human and ball movements, especially when the information is relevant to the motor response required to interact with the observed event.

From Perception of Human Action to Perception of Events

The advantage of visual information over motor experience in explaining the perception of biological motion can be also seen in the generalizability of the Kilner et al. (2003) and Kilner et al. (2007) studies. Based on the idea that human actions are both produced and perceived using a common representation, the motor-based theory is limited in its accountability in that it can only explain the perception of events involving human actions. In contrast, the information-based theory is more general because the successful pickup of visual information will allow for perception of any action and any event. Relying on visual information, humans can perceive human actions (Johansson, 1973; Loula et al., 2005; Runeson & Frykholm, 1983), animal actions (Pinto & Shiffrar, 2009; Troje & Westhoff, 2006), and inanimate object motions (Jacobs, Runeson, & Michaels, 2001; Todd, 1981; Tremoulet & Feldman, 2000). With sensitivity to visual information, animals such as cats and birds can respond to observed biological motion (Blake, 1993; Troje & Aust, 2013; Vallortigara, Regolin, & Marconato, 2005). Even human actions involving interaction with inanimate objects can be recognized through detection of visual information. For instance, Bingham (1987) showed that observers could accurately judge the amount of weight lifted in a patch-light display because kinematic information (measured and described by Bingham) specified the weight being lifted. Similarly, Warren, Kim, and Husney (1987) showed that the elasticity of a bouncing ball could be judged correctly as long as visual information about the relative bouncing height was available, and the perception allowed for regulation of the impulse applied to the ball in a bounce pass.

So, what is the information that is available in all these studies that might allow perception and judgment of events and actions? Bingham (1995) proposed trajectory forms as a type of information. A trajectory form is defined as the variation in velocity along a path of motion. It remains invariant with changing viewing distance, perspective, and size of the event (Wickelgren & Bingham, 2004, 2008). Muchisky and Bingham (2002) investigated trajectory forms of a freely swinging pendulum (nonbiological motion) and a manually moved pendulum (biological motion) and tested whether people were able to discriminate these two events using the invariant trajectory form despite differences in the amplitude of the events compared. They found people were very sensitive to the symmetric feature of the trajectory form in these two events, attributing the asymmetrical form to the manually moved pendulum and the symmetrical form to the freely swinging pendulum (see also Bingham, Rosenblum, & Schmidt, 1995). Further investigation revealed that the curvature of the path in a trajectory form is also reliably used for discriminating different events (Wickelgren & Bingham, 2008). Trajectory forms in the point-light displays may well have served as information for judging the targets of throwing in the current study. Because targeted throwing is a biological motion that involves energy flow among the joints that is designed to peak at release of the ball, the overall trajectory form must exhibit an asymmetry with the peak velocity at the release point at the end of the throwing motion of the arm. The specific nature of this trajectory is likely to provide the information needed to judge the locations of the targets of throwing. Future efforts will be required to pursue this possibility.

ACKNOWLEDGMENTS

We thank graduate and undergraduate students (Ms. Rashmi Ravi and Mr. Todd Mirich) who have assisted with the data collection and video editing. We also thank Dr. Joe Lappin and Dr. Sverker Runeson for their intelligent and constructive comments on the early version of this article.

FUNDING

This research was supported by the Faculty Seed Grant from the University of Wyoming to Qin Zhu.

REFERENCES

Abernethy, B., & Zawi, K. (2007). Pickup of essential kinematics underpins expert perception of movement patterns. *Journal of Motor Behavior, 39*(5), 353–367.

Aglioti, S. M., Cesari, P., Romani, M., & Urgesi, C. (2008). Action anticipation and motor resonance in elite basketball players. *Nature Neuroscience, 11*(9), 1109–1116.

Al-abood, S. A., Davids, K., & Bennett, S. J. (2001). Specificity of task constraints and effects of visual demonstrations and verbal instructions in directing learners' search during skill acquisition. *Journal of Motor Behavior, 33*(3), 295–305.

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.

Bingham, G. P. (1987). Kinematic form and scaling: Further investigations on the visual perception of lifted weight. *Journal of Experimental Psychology: Human Perception and Performance, 13*(2), 155–177.

Bingham, G. P. (1995). Dynamics and the problem of visual event recognition. In T. R. Port & T. Van Gelder (Eds.), *Mind as motion: Dynamics, behavior and cognition* (pp. 403–448). Cambridge, MA: MIT Press.

Bingham, G. P., Rosenblum, L. D., & Schmidt, R. C. (1995). Dynamics and the orientation of kinematic forms in visual event recognition. *Journal of Experimental Psychology: Human Perception and Performance, 21*(6), 1473–1493.

Bingham, G. P., & Wickelgren, E. A. (2008). Events and actions as dynamically molded spatiotemporal objects: A critique of the motor theory of biological motion perception. In T. F. Shipley & J. M. Zacks (Eds.), *Understanding events: From perception to action* (pp. 266–279). Oxford, UK: Oxford University Press.

Blake, R. (1993). Cats perceive biological motion. *Psychological Science, 4*(1), 54–57.

Bouquet, C. A., Gaurier, V., Shipley, T., Toussaint, L., & Blandin, Y. (2007). Influence of the perception of biological or non-biological motion on movement execution. *Journal of Sports Sciences, 25*(5), 519–530.

Calvo-Merino, B., Grèzes, J., Glaser, D. E., Passingham, R. E., & Haggard, P. (2006). Seeing or doing? Influence of visual and motor familiarity in action observation. *Current Biology, 16*(19), 1905–1910.

Cañal-Bruland, R., & Schmidt, M. (2009). Response bias in judging deceptive movements. *Acta Psychologica, 130*(3), 235–240.

Cañal-Bruland, R., van der Kamp, J., & van Kesteren, J. (2010). An examination of motor and perceptual contributions to the recognition of deception from others' actions. *Human Movement Science, 29*(1), 94–102.

Casile, A., & Giese, M. A. (2006). Nonvisual motor training influences biological motion perception. *Current Biology, 16*(1), 69–74.

Cutting, J. E., Proffitt, D. R., & Kozlowski, L. T. (1978). A biomechanical invariant for gait perception. *Journal of Experimental Psychology: Human Perception and Performance, 4*(3), 357–372.

Decety, J., & Grèzes, J. (1999). Neural mechanisms subserving the perception of human actions. *Trends in Cognitive Sciences, 3*(5), 172–178.

Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain, 119*(2), 593–609.

Gibson, J. J. (1972). A theory of direct visual perception. In J. Royce & W. Rozenboom (Eds.), *The psychology of knowing* (pp. 77–89). New York, NY: Gordon & Breach.

Gibson, J. J. (1986). *The ecological approach to visual perception.* Hillsdale, NJ: Erlbaum. (Original work published 1979)

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

Grossman, E. D., & Blake, R. (2002). Brain areas active during visual perception of biological motion. *Neuron, 35*(6), 1167–1175.

Horn, R. R., Williams, A. M., & Scott, M. A. (2002). Learning from demonstrations: The role of visual search during observational learning from video and point-light models. *Journal of Sports Sciences, 20*(3), 253–269.

Horn, R. R., Williams, A. M., Scott, M. A., & Hodges, N. J. (2005). Visual search and coordination changes in response to video and point-light demonstrations without KR. *Journal of Motor Behavior, 37*(4), 265–274.

Iacoboni, M., Woods, R. P., Brass, M., Bekkering, H., Mazziotta, J. C., & Rizzolatti, G. (1999). Cortical mechanisms of human imitation. *Science, 286*(5449), 2526–2528.

Isenhower, R. W., Richardson, M. J., Carello, C., Baron, R. M., & Marsh, K. (2010). Affording cooperation: Embodied constraints, dynamics and action-scaled invariance in joint lifting. *Psychonomic Bulletin & Review, 17,* 342–347.

Jacobs, D. M., Runeson, S., & Michaels, C. F. (2001). Learning to visually perceive the relative mass of colliding balls in globally and locally constrained task ecologies. *Journal of Experimental Psychology: Human Perception and Performance, 27*(5), 1019–1038.

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception & Psychophysics, 14*(2), 201–211.

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

Kilner, J., Hamilton, A. F., & Blakemore, S. J. (2007). Interference effect of observed human movement on action is due to velocity profile of biological motion. *Social Neuroscience, 2*(3–4), 158–166.

Kilner, J., Paulignan, Y., & Blakemore, S. J. (2003). An interference effect of observed biological movement on action. *Current Biology, 13*(6), 522–525.

Knoblich, G., & Flach, R. (2001). Predicting the effects of actions: Interactions of perception and action. *Psychological Science, 12*(6), 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*(2), 456–465.

Loula, F., Prasad, S., Harber, K., & Shiffrar, M. (2005). Recognizing people from their movement. *Journal of Experimental Psychology: Human Perception and Performance, 31*(1), 210–220.

Mark, L. S. (2007). Perceiving the actions of other people. *Ecological Psychology, 19*(2), 107–136.

Mather, G., & Murdoch, L. (1994). Gender discrimination in biological motion displays based on dynamic cues. *Proceedings of the Royal Society of London: Series B. Biological Sciences, 258*(1353), 273–279.

Muchisky, M. M., & Bingham, G. P. (2002). Trajectory forms as a source of information about events. *Perception & Psychophysics, 64*(1), 15–31.

Munzert, J., Hohmann, T., & Hossner, E. J. (2010). Discriminating throwing distances from point-light displays with masked ball flight. *European Journal of Cognitive Psychology, 22*(2), 247–264.

Pavlova, M. A. (2012). Biological motion processing as a hallmark of social cognition. *Cerebral Cortex, 22*(5), 981–995.

Pavlova, M., Krägeloh-Mann, I., Sokolov, A., & Birbaumer, N. (2000). Recognition of point-light biological motion displays by young children. *Perception, 30*(8), 925–933.

Pavlova, M., Staudt, M., Sokolov, A., Birbaumer, N., & Krägeloh-Mann, I. (2003). Perception and production of biological movement in patients with early periventricular brain lesions. *Brain, 126*(3), 692–701.

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

Pollick, F. E., Kay, J. W., Heim, K., & Stringer, R. (2005). Gender recognition from point-light walkers. *Journal of Experimental Psychology: Human Perception and Performance, 31*(6), 1247–1265.

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology, 9*(2), 129–154.

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.

Scheerer, E. (1984). Motor theories of cognitive structure: Historical review. In W. Prinz & A. F. Sanders (Eds.), *Cognition and motor processes* (pp. 77–98). Berlin, Germany: Springer-Verlag.

Serino, A., De Filippo, L., Casavecchia, C., Coccia, M., Shiffrar, M., & Làdavas, E. (2010). Lesions to the motor system affect action perception. *Journal of Cognitive Neuroscience, 22*(3), 413–426.

Shipley, T. F. (2003). The effect of object and event orientation on perception of biological motion. *Psychological Science, 14*(4), 377–380.

Smith, J. E. K. (1982). Simple algorithms for M-alternative-forced-choice calculations. *Perception & Psychophysics, 31*(1), 95–96.

Snippe, H. P., & Koenderink, J. J. (1994). Discrimination of geometric angle in the fronto-parallel plane. *Spatial Vision, 8*(3), 309–328.

Sumi, S. (1984.) Upside-down presentation of the Johansson moving light-spot pattern. *Perception, 13*(3), 283–286.

Todd, J. T. (1981). Visual information about moving objects. *Journal of Experimental Psychology: Human Perception and Performance, 7*(4), 795–810.

Tremoulet, P. D., & Feldman, J. (2000). Perception of animacy from the motion of a single object. *Perception, 29*(8), 943–952.

Troje, N. F., & Aust, U. (2013). What do you mean with "direction"? Local and global cues to biological motion perception in pigeons. *Vision Research, 79,* 47–55.

Troje, N. F., Sadr, J., Geyer, H., & Nakayama, K. (2006). Adaptation aftereffects in the perception of gender from biological motion. *Journal of Vision, 6*(8), 850–857.

Troje, N. F., & Westhoff, C. (2006). The inversion effect in biological motion perception: Evidence for a "life detector"? *Current Biology, 16*(8), 821–824.

Troje, N. F., Westhoff, C., & Lavrov, M. (2005). Person identification from biological motion: Effects of structural and kinematic cues. *Perception & Psychophysics, 67*(4), 667–675.

Tye-Murray, N., Spehar, B. P., Myerson, J., Hale, S., & Sommers, M. S. (2013). Reading your own lips: Common-coding theory and visual speech perception. *Psychonomic Bulletin & Reviews, 20*(1), 115–119.

Vallortigara, G., Regolin, L., & Marconato, F. (2005). Visually inexperienced chicks exhibit spontaneous preference for biological motion patterns. *PLoS Biology, 3*(7), e208. doi:10.1371/journal.pbio.0030208

Warren, W. H., Kim, E. E., & Husney, R. (1987). The way the ball bounces: Visual and auditory perception of elasticity and control of the bounce pass. *Perception, 16,* 309–336.

Wickelgren, E. A., & Bingham, G. P. (2004). Perspective distortion of trajectory forms and perceptual constancy in visual event identification. *Perception & Psychophysics, 66,* 629–641.

Wickelgren, E. A., & Bingham, G. P. (2008). Trajectory forms as information for visual event recognition: 3D perspectives on path shape and speed profile. *Perception & Psychophysics, 70*(2), 266–278.

Williams, A. M., Hodges, N. J., North, J. S., & Barton, G. (2006). Perceiving patterns of play in dynamic sport tasks: Investigating the essential information underlying skilled performance. *Perception, 35*(3), 317–332.

Wilson, A. D., Bingham, G. P., & Craig, J. C. (2003). Proprioceptive perception of phase variability. *Journal of Experimental Psychology: Human Perception and Performance*, *29*(6), 1179.

Yoon, J., & Johnson, S. C. (2009). Biological motion displays elicit social behavior in 12-month-olds. *Child Development, 80*(4), 1069–1075.

Zhu, Q., Lu, J. D., & Wilson, A. D. (2012). Expert release control in response to changing spatial properties of a remote target. *Journal of Sport and Exercise Psychology, S34,* 149.