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Human Action Perception is Consistent, Flexible, and Orientation Dependent

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Abstract
Previous research has found that observers of object-directed human action pay more attention to information regarding hand contact over information regarding spatial trajectories in action, and that processing of trajectory information is disrupted by inversion. However, observers can also flexibly modulate their attention to spatial trajectory depending on the goal or context of the actor. In Experiments 1(a) and 1b of the current research, we directly compared attention with hand and trajectory information across placing and dropping actions in order to determine whether the hand bias is always present or whether flexibility in action perception can attenuate this bias. Results demonstrated that observers attend more to hand information for placing, but attend equally to hand and trajectory information for dropping. Experiment 2 explored the role of the actor's goal in processing spatial trajectory for mimed dropping actions and non-human control stimuli, and the role of goals in the inversion effect. Results indicated that goal relevance increases processing of trajectory information, and that processing of all spatial trajectories in human action is disrupted by inversion, regardless of the actor's goal. The present findings highlight the role of prediction in action perception, and suggest that human action is processed with expertise.

Keywords
action perception, configural processing, intentions, attention, prediction, perceptual expertise

As a social species, we must evaluate the actions of others around us on a daily basis. Efficient and accurate perception of others' actions are crucial to interpersonal interactions, cooperative ventures, and human development (e.g., Baldwin & Baird, 2001; Sebanz, Bekkering, & Knoblich, 2006; Woodward, 2009). A ubiquitous class of actions that are relevant for humans in particular are intentional actions directed at objects (e.g., picking up a coffee mug). A wealth of cognitive and developmental research indicates that recruitment of one's own motor system plays a role in the processing of such actions in others (Brass, Bekkering, & Prinz, 2001; Marshall & Meltzoff, 2014; Rizzolatti & Craighero, 2004). However, considerably less research has investigated the role of visual perception in the processing of these actions. This was the focus of the current investigation.

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Research from two related literatures—human body perception and biological motion perception—suggests that configural processing plays a role in the perception of object-directed actions. Configural processing refers to the global perception of multiple features in relation to one another, rather than in isolation. Upright bodies appear to be processed configurally, as observers have difficulty in discriminating inverted bodies, which lack the typical relations between limbs and torso (Reed, Stone, Bozova, & Tanaka, 2003). Similar inversion effects have also been observed in the perception of biological motion, for both adults (Pavlova & Sokolov, 2003; Sumi, 1984; Thompson, Clarke, Stewart, & Puce, 2005) and infants (Bertenthal, Proffitt, & Cutting, 1984; Simion, Regolin, & Bulf, 2008). Configural processing of upright biological motion has also been shown to compress observers' subjective time, an effect that is diminished when the stimuli are inverted (Orgs, Bestmann, Schuur, & Haggard, 2011). At least for point-light walking stimuli, processing of highly local motion is also influenced by configural processing of the body (Bardi, Regolin, & Simion, 2014; Chang & Troje, 2009; Troje & Westhoff, 2006).

Perception of others' object-directed actions, however, may make use of additional processing mechanisms. For these actions, relatively local detail concerning the actor's grasp of on an object is highly relevant to (a) inferring the actor's intention and (b) predicting upcoming actions. For (a), attending to the type of hand contact can inform the observer about properties of the goal object and the actor's intention (e.g., reaching to press a button on the microwave or to open the microwave door). For (b), the type of hand contact used on certain objects constrains future actions (e.g., grasping a hammer with a precision grip precludes future hammering; Loucks & Sommerville, 2012b). Loucks and Baldwin (2009) thus theorized that observers process relatively local hand contact information separably from global spatial trajectory information for object-directed actions.[1] Trajectory information regarding the remainder of the body is also critical for processing intentions and predicting actions. For example, spatial trajectory of the arm cues the target of a reach (e.g., the remote control or the snack bowl), and the direction of head and torso motion allows anticipation of future actions with an object (e.g., changing the channel or just relocating the remote). They hypothesized that configural processing of trajectory information would be disrupted with inversion, but that processing of hand contact information would be unaffected by inversion.

Loucks and Baldwin (2009) tested observers' sensitivity to changes in hand contact (e.g., using a different grasp) and spatial trajectory (e.g., using a different reach path) for horizontal displacement (placing and pushing) actions, under upright and inverted conditions. Results demonstrated that detection of trajectory changes was significantly reduced with inversion, while detection of hand contact changes was equivalent across conditions. In addition, they found that observers were significantly more sensitive to hand contact changes for upright actions in comparison to trajectory changes. Thus, perception of others' object-directed actions involves two distinct processing systems: one which prioritizes the details of the hand and which is insensitive to inversion, and another which uses orientation-dependent mechanisms to process global spatial trajectory information. Increased sensitivity to hand contact is present by 10 months of age (Loucks & Sommerville, 2012a).

Additional research by Loucks (2011) replicated the trajectory inversion effect for static images of object-directed action. In this research, a wider variety of actions were used (e.g., opening a bottle, knocking on a door). In this case, while processing of hand contact information was still unaffected by inversion, evidence for a hand contact bias was more equivocal (present in one experiment but not another). This may indicate that the hand contact bias is stronger for dynamic actions, or that it is present only for object displacement actions. This research also demonstrated that observers process spatial trajectory information differently for human action compared with a control stimulus. Loucks created control images that directly mapped the hand contact and trajectory elements in the images of human action using abstract geometric shapes. Results indicated that inversion disrupted trajectory processing only for action images, and not for control images, despite being nearly identical spatial-relational changes. In addition, observers were more accurate at detecting trajectory changes for upright action images compared with control images, which suggests an advantage for processing spatial relations in human action.

While evidence seems to suggest that hand contact is more salient to observers than spatial trajectory for object-directed actions, research by Loucks and Sommerville (2013) provided evidence that observers can flexibly modulate their attention to spatial trajectory information, depending on the relevance of this information for predicting action outcomes. They examined this issue using targeted dropping actions: dropping an object into a container. They hypothesized that observers would vary their attention to drop height (trajectory information) when it was relevant to predicting the potential success of the drop (landing in the container). Specifically, they predicted heightened sensitivity to increases in drop height when the container was *narrow*, as such a change would impact the success of the drop (higher drop = increased chance of missing). However, they predicted no increased sensitivity when the container was *wide*, as an increase in drop height is less risky for such a container. These predictions were supported: adults were more sensitive to upward over downward changes for narrow containers only, as were 10-month-old infants. Thus, observers flexibly modulate their attention to trajectory information depending on context, and this may occur in the service of predicting action outcomes.

What is yet to be resolved from the extant research is whether the hand contact bias is pervasive for dynamic object-directed intentional actions—that is, whether individuals always attend more readily to hand contact over spatial trajectory for such actions. On the one hand, this seems to be the case for adults and 10-month-old infants for horizontal displacement actions (Loucks & Baldwin, 2009; Loucks & Sommerville, 2012a). But the work of Loucks and Sommerville (2013) did not directly compare the discrimination of hand contact and trajectory changes for dropping actions. Such an investigation can constrain theoretical conceptualizations of relatively focused, local processing within a framework of enhanced configural processing of human bodies and actions.

In Experiments 1(a) and (b) of the current research, this issue was examined directly by comparing detection of identical kinds of hand contact and trajectory changes in both targeted dropping and placing actions. In the current research, hand contact changes were changes in grasp type (whole-hand vs. precision) and trajectory changes were changes in drop height (high vs. low). If information regarding hand contact is especially critical to inferring goals and predicting upcoming actions (Loucks & Sommerville, 2012a), then grasp changes should be more salient than height changes for both dropping and placing actions. Alternatively, if attention is more flexible, such that whenever one perceptual dimension is more important for intentional inference or prediction it is attended to with higher fidelity, then grasp changes should be more salient than height changes for placing actions, but less salient than height changes for dropping actions, since drop height is relevant to prediction in this case. We hypothesized that elements of both possibilities would be observed: specifically, that grasp information would be highly salient for both dropping and placing actions, and that height information would be attended to more for dropping relative to placing actions, on par with grasp information, because of its increased relevance to predicting the outcome of dropping actions.

In Experiment 2, we explored several additional facets of the distinction between these two forms of processing. First, we sought to provide additional support for the hypothesis that sensitivity to trajectory information is enhanced for targeted dropping actions because observers utilize this information to evaluate the likelihood of a successful drop. Additional supportive evidence could come from observers' detection of the identical grasp and height changes when the action has no clear outcome or goal. For example, would observers still pay attention to changes in height when the actor is *miming* the action of dropping, without an object or a container present? We hypothesized that if observers are either implicitly or explicitly predicting the outcome of this action, then sensitivity to height information should be lessened in the case of miming the action. Exploring sensitivity to grasp and height information for miming actions also allowed us to test whether the hand contact or trajectory distinction extends beyond object-directed actions, and is a more general property of dynamic action perception, since miming actions involve no objects.

Alternative supportive evidence could also come from observer's detection of identical perceptual changes in non-human dynamic motion that retains the same spatial "goals" (i.e., making one object land in or on another object). Thus, in Experiment 2, we also probed observers' detection of local (grasp) and global (height) changes in the motion of geometric shapes yoked to the motions of the actors from the targeted dropping actions, which involved a replacement shape for the body, hand, dropped object, and container. This is similar to the control condition used for static actions in Loucks (2011), but to our knowledge is the first use of a *dynamic* control stimulus for investigating the processing of local and global information in action. This control allowed us to rule out the possibility that the hand contact or trajectory distinction in action is simply due to perceptual sensitivities that observers may have for any object interactions across space and time.

Second, we also wanted to replicate the unique deficit that inversion imposes on observers' processing of spatial trajectory relative to hand contact for targeted dropping actions. No previous research has examined whether inversion impacts processing of spatial trajectory for dropping actions, information that observers seem to attend to more readily. Thus, we also investigated the effect of inversion on targeted dropping actions, mimed dropping actions, and control motion animations. We hypothesized that inversion effects would be restricted to human actions.

A discrimination task was used for both experiments, in which participants judged whether pairs of videos were the same or different. On each trial, two videos were played, in a serial fashion, and after the second video, participants made their response. Our dependent variable was participants' accuracy at detecting the changes; response time was not evaluated as participants could detect the change well before they had an opportunity to respond. In Experiment 1, discrimination of upright videos of human motion was assessed, with change type (grasp vs. trajectory) manipulated within-subjects, and action category (placing vs. dropping) manipulated between-subjects. Experiment 2 assessed discrimination of various "dropping" actions, with orientation (upright vs. inverted) manipulated within-subjects, and stimulus category (real vs. mimed vs. animated) manipulated between subjects.

Experiment 1(a)

The purpose of Experiment 1(a) was to compare processing of identical kinds of grasp and spatial trajectory changes to action across two action categories: targeted placing and dropping. On the basis of the previous research that trajectory information is prioritized in the context of targeted dropping actions due to its potential impact on the outcome, we predicted that this information would be attended to at higher levels for dropping in comparison to placing. However, we also predicted that attention to trajectory information would not exceed attention to grasp information, due to evidence for a hand contact bias. As such, we predicted that grasp information would be attended to highly in both contexts, even though it had no impact on the outcome of either action.

Method

Participants. Sixty-eight University of Regina undergraduates (21 male) received partial course credit or 10 dollars for their participation in the experiment. Equal numbers of participants were randomly assigned to either the drop or place condition. Data from five additional participants were collected but omitted because their same trial accuracy was more than two standard deviations below the mean for their respective condition (two in the drop and three in the place condition).

Stimuli. Stimuli consisted of 32 videos, each representing a unique crossing of the following four factors: two action categories (drop vs. place), two grasp types (whole hand vs. precision), two drop heights (high vs. low), and four actors. In all videos, a female actor was seated at a table with a small beanbag to the actor's right and a small container to the actor's left. In the dropping videos, the actor grasped the beanbag, lifted it over the container, and successfully dropped it into the container. In the placing videos, the actor grasped the beanbag, moved it in an arcing trajectory to the container, and placed it inside. Actors moved in pace with a metronome, ensuring that all action elements (grasp, movement) were produced at the same rate and that each video was exactly four seconds long.[2] The actors also all held a neutral facial expression during the videos, and did not blink, ensuring that the grasp and height changes were the only identifiable differences between the videos. Sound on the videos was muted.

Still frames from one actor's videos can be found in Figure 1. Special care was taken during filming to ensure that the magnitude of change for featural and configural changes was equated between the action categories. For grasp changes, this was done by ensuring that the whole-hand and precision grasps looked identical with each deployment (e.g., same hand angle relative to camera). For height changes, this was done by ensuring that the low and high drop heights were identical to the low and high maxima of the two placing trajectories. Note that these heights for each category occurred in different horizontal positions on the screen. However, as can be seen in Figure 1, these were identical relative heights.

Design and procedure. A mixed design was employed: action category (drop vs. place) varied between-subjects, and change type (grasp vs. height) varied within-subjects. On different grasp trials, two videos with different grasp types but identical heights were paired, while on different height trials, two videos with different heights but identical grasps were paired. The temporal position of each video within a different trial was counterbalanced. Across all 4 actors, this resulted in 32 different trials. On same trials, a video was paired with itself. To balance the number of same and different trials, videos were paired with themselves twice. Thus, there were a total of 64 trials within each condition.

Stimuli presentation and data collection were administered using Psychtoolbox (Brainard, 1997), on a PC and 20 in. monitor. From where participants were seated, stimuli subtended approximately $22^\circ \times 16^\circ$ of visual angle. On a trial, the first video played, followed by a 1 s blank screen, then the second video played, and then participants were prompted to make their response (same or different). The inter-trial interval was self-paced. Trial presentation order for a given participant was random.

After providing consent, participants were told they would be seeing pairs of action videos, and they would need to determine whether the videos in the pair were the same or different. They were told that the videos would only differ in the action, and not in the background

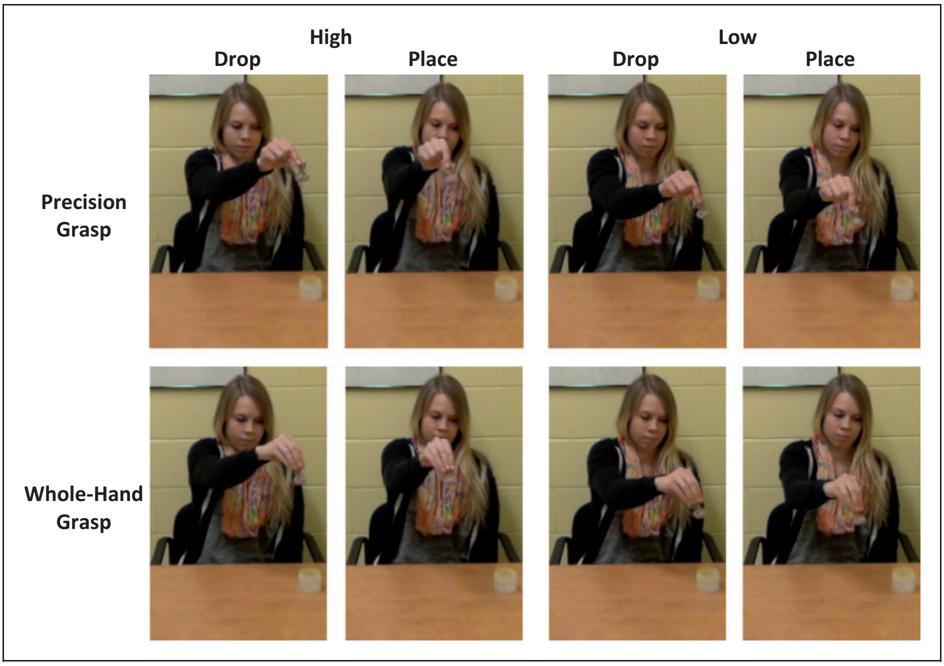

Figure 1. Still frames from one video set. Note that these stills are zoomed in to better show detail.

details, and that on same trials the identical video file would be played twice. Participants made their responses using specially marked buttons on a mouse.

Results

Preliminary analyses found no significant effects of gender on any of the variables, so further analyses collapsed across gender. Mean accuracy scores[3] for different trials can be found in Figure 2. A 2 (condition) $\times$ 2 (change type) mixed ANOVA revealed a significant main effect of condition, $F(1,66) = 5.58$, $p < .05$, $\eta^2 = .08$, change type, $F(1,66) = 8.17$, $p < .01$, $\eta^2 = .11$, and a significant interaction between change type and condition, $F(1,66) = 4.02$, $p < .05$, $\eta^2 = .06$. Planned paired samples *t*-tests were used to further probe the hypothesized interaction. While accuracy in the place condition was significantly lower for height changes relative to grasp changes, $t(33) = 3.06$, $p < .005$, Cohen's $d = 0.53$, no such difference was observed in the drop condition, $t(33) = 0.70$, $p > .45$. Planned independent samples t-tests were used to evaluate the hypothesis that only the height changes would be more salient in the drop relative to the place condition. This hypothesis was also supported: height changes $t(66) = 3.02$, $p < .005$, Cohen's $d = 0.70$, drop changes $t(66) = 0.06$, $p > .90$.

Experiment 1(b)

Although both hypotheses for Experiment 1(a) were supported, there existed an alternative explanation to the pattern of data. In the dropping videos, after the actor released the object to drop it into the container, the actor's hands remained static at the final position of the drop height until the end of the video. Thus, there was static perceptual information indicating the height of the action available for slightly longer (0.66 s) than the analogous information in

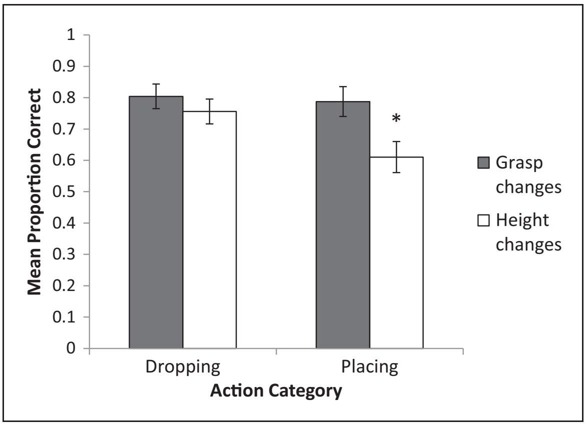

Figure 2. Mean accuracy for different trials as a function of action category and change type in Experiment 1(a). Asterisks indicate significant differences between conditions. Error bars indicate ±SE.

the placing videos (as the maximum height for the placing trajectory was only briefly available in transit). This may have made the height changes easier to detect in the drop condition. To rule out this alternative explanation, in Experiment 1(b), new dropping videos were created which removed this static perceptual information. If the duration that the height change was perceptually available was the cause of the increased sensitivity to height in the dropping condition, then observers should be less sensitive to height changes in dropping once this duration is equated to the duration it appeared in the placing videos.

Method

Participants. Thirty-four University of Regina undergraduates (five males) received partial course credit for their participation in the experiment. Data from one additional participant were collected but omitted because their same trial accuracy was more than two standard deviations below the mean.

Stimuli. The 16 dropping videos used in Experiment 1(a) were altered using Abode Premiere Pro. In each video, as soon as the actor's hand released the object, a black box was overlaid on the screen which covered the entire hand and arm of the actor, to the extent that all information about the drop height was unavailable. Thus information about the drop height was only available during object transit, similar to the placing videos of Experiment 1(a).

Design and procedure. The design was identical to the dropping condition in Experiment 1(a). Participants were additionally informed that black box would appear over the actor in every video, and that this would be consistent across videos.

Results

A paired-samples t-test on different trial accuracy revealed that participants had no advantage at detecting grasp changes ($M = 0.77$, $SD = 0.16$) compared with height changes ($M = 0.78$, $SD = 0.27$) for these new dropping videos, $t(33) = 0.18$, $p > .85$. In addition, a 2 (experiment) × 2 (change type) mixed ANOVA revealed no main effect of experiment, $F(1,66) = 0.04$, $p > .80$, change type, $F(1,66) = 0.13$, $p > .70$, or any significant interaction between the two, $F(1,66) = 0.38$, $p > .50$, indicating no differences between the dropping conditions of the two experiments. Thus, the increased saliency of height information for dropping actions is not due to a simple perceptual availability explanation.

Discussion of Experiments 1(a) and (b)

Taken together, the findings from Experiments 1(a) and (b) indicate that the saliency of perceptual information during action observation depends upon what action is being observed. Participants who viewed placing actions attended more heavily to local hand contact information over global spatial trajectory information, a result that replicates previous research (Loucks, 2011; Loucks & Baldwin, 2009). However, participants who viewed dropping actions attended to trajectory information to the same degree as they attended to grasp information. Importantly, participants in both conditions were noticing *identical* kinds of grasp and trajectory changes, and Experiment 1(b) ruled out the possibility that participants in the drop condition simply had more time to notice the trajectory changes. Thus, higher level selective constraints appear to be influencing observers' attention during perception; In this case, we believe that observers, predicting the potential outcome of the drop, increased their attention to drop height, and such information was not relevant to prediction in the case of placing.

On one hand, an alternative to prediction that might explain this differential attention is gravity. Because gravity moved the object downward in the dropping condition, but did not in the placing condition, perhaps observers' sensitivity to the effects of gravity made the height of the drop more salient in the dropping condition. We believe this is unlikely to account for this difference, given that Loucks and Sommerville (2013) found that observers were also differentially sensitive to drop height according to container width, where gravity's salience was held constant.

Although hand contact was only more salient in the placing condition, attention to hand contact was nonetheless high in the dropping condition, and attention to spatial trajectory did not exceed this level. This indicates that hand contact information may be habitually attended with relatively high fidelity, regardless of the action being performed. Attention to spatial trajectory information, on the other hand, seems to be more malleable, and may only be elevated in processing when it has more direct implications for action outcomes, as in the case of targeted dropping (Loucks & Sommerville, 2013). In this way, attention during action perception displays elements of both consistency and flexibility. We will revisit these properties of action perception in the General Discussion.

Experiment 2

Although we hypothesize that attention to spatial trajectory is higher for dropping actions because of its relevance to predicting the outcome of the action, more evidence that can support this point is warranted. Thus, in Experiment 2 we examined attention to these two dimensions when the same actions are mimed, without objects present. In this case, the motions of the actor all remain the same—the same type of grasp and the same spatial trajectories—but with no object that is being grasped or dropped into a container. In this case, the goal of the actor is much more ambiguous, and is certainly qualitatively different from the goal of the actor who is actually dropping an object into a container. Thus, we predicted that attention to the spatial trajectory of the "drop" would be lower in comparison to real dropping. To our knowledge, this is the first investigation of attention to local hand motion and global spatial trajectory for non-object-oriented human action. As such, it also allows us to further investigate the hypothesis that hand contact is consistently attended to at high levels, even when the goal of the actor is ambiguous and the action does not involve any objects.

In Experiment 2, we also manipulated the orientation of these dropping stimuli. This allowed us to investigate whether processing of trajectory information is uniquely disrupted by inversion in comparison with hand information even when these perceptual dimensions are attended to equally. It also allowed us to investigate whether inversion would similarly disrupt only trajectory information for mimed actions, when the goals of this action are less clear.

We also introduced a novel control condition with which to compare findings against, similar to the control condition used in Loucks (2011), which involved dynamic non-human motion that was highly similar to the human motion. To achieve this, we animated geometric shapes representing the focal visual elements of targeted dropping (e.g., the hand, the object, the container) along the identical spatial paths the actors used when executing their drops. We also varied the orientation of these stimuli. We hypothesized that the configural processing of human action differs from the configural processing of non-human dynamic stimuli, and thus predicted that there would be no disruption to processing trajectory information for these inverted control animations.

Method

Participants. Seventy-two University of Regina undergraduates (10 males) received partial course for their participation in the experiment. Equal numbers of participants were randomly assigned to either the normal, miming, or animation control condition. Data from two additional participants (one in the normal condition and one in the animation control condition) were collected but omitted as their same trial accuracy was more than two standard deviations below the mean for their condition.

Stimuli. Stimuli consisted of 96 videos—32 for each condition. A sample of one scenario across the three conditions can be found in Figure 3. The videos for the normal condition included the 16 upright dropping videos used in Experiment 1(a), 4 Actors $\times$ 2 Heights $\times$ 2 Grasps, and 16 inverted versions of those dropping videos. Video editing software was used to create the inverted videos by rotating the upright videos 180°.

The 16 upright videos for the miming condition matched the critical perceptual components of motion in the upright normal condition, as well as the background, but involved no beanbags and no containers. They also involved four actors crossed with the identical two drop heights and identical two grasps. Actors moved in pace with a metronome, and moved at the same pace as the actors in dropping videos. Extreme care was taken to ensure that the grasps, the drop heights, and the rate of motion were all identical between the normal and miming videos, and that a similar background was used. However, because the original dropping videos and the miming videos were filmed at different times, there were minor perceptual differences between the videos (e.g., two actors replaced with new actors, extremely small deviations in camera angle). Inverted miming videos were created through the same process of 180° rotation.

The 16 upright animation control videos were created using video editing software. For each upright normal condition video, geometric shapes representing the hand and the beanbag were first superimposed over the first video frame. The beanbag in each video was overlaid with an oval shape, and the hand was overlaid by one of the two complex polygonal shapes similar to a three-point crown. For whole hand grasp videos, the two edge points were taller than the middle point, and for precision grasp videos, the middle point was taller than the two edge points (see Figure 3 for an example of the latter).

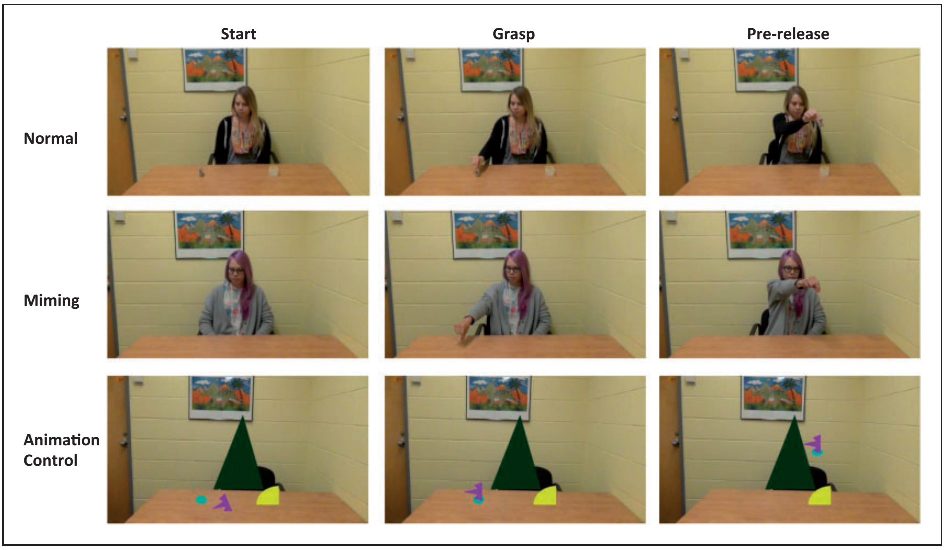

Figure 3. Still frames depicting the stimuli used in Experiment 2 across the three conditions. Depicted are high, precision grasps.

For each successive frame of the video, the crown shape moved yoked to the hand, and the oval shape moved yoked with the beanbag. Following this, the container was overlaid with a triangle with one arced edge, and the actor's body was overlaid with a large triangle. These shapes remained static throughout the videos. Different color schemes for all the shapes were used in the four different video scenarios. Finally, a similar background (filmed with no actor present) was superimposed on top of the original video layer but underneath the new animation layer. This was done to ensure that videos in all conditions contained a vertical reference, such that any effects that might be due to gravity could still manifest. Thus, while no part of the original video was visible, the shapes moved in identical spatial trajectories as the hand and the object in relation to the shapes representing the body and the container, and in the same context as the original dropping videos. Inverted versions of these animations were created by rotating the videos 180° following their completion.

Design and procedure. A mixed design was used, with condition (normal vs. miming vs. animation control) varied between-subjects, and change type (grasp vs. height) and orientation (upright vs. inverted) varied within-subjects. Different grasp, different height, and same trials were structured identically to Experiment 1(a), which again resulted in 32 different and 32 same trials per condition. However, two orders were used in each condition, such that participants in one order saw two of the actor's or scenario's videos upright and the other two inverted, while the other order saw the converse pairings of actors or scenarios and orientations.

Stimuli presentation and data collection were administered using E-Prime (Psychology Software Tools, Pittsburgh, PA), on the same PC with the same visual angles used in Experiment 1(a). All other aspects of trial structure were identical to Experiment 1.

After providing consent, participants were given the same instructions as Experiment 1. Participants made their responses using specially marked buttons on a keyboard. After debriefing, participants in the animation control condition were asked if the videos reminded them of anything, and then specifically asked if they reminded them of a person dropping something. No participants spontaneously identified a human dropping, but many noticed the similarity once explicitly asked.

Results

Preliminary analyses revealed no effects of gender or order on any of the variables, and thus those variables were collapsed in further analyses. Mean accuracy scores for different trials for each condition can be found in Figure 4. A 2 (Change type)×2 (Orientation)×3 (Condition) mixed ANOVA revealed a significant three-way interaction between change type, orientation, and condition, $F(2,69) = 5.36$, $p < .001$, $\eta_p^2 = 0.13$. Thus, individual ANOVAs were run for each condition in order to further decompose this interaction.

For the normal condition, a 2 (Change type)×2 (Orientation) repeated-measures ANOVA revealed a significant main effect for orientation, $F(1,23) = 7.92$, $p < .02$, $\eta_p^2 = 0.26$, with higher detection rates in the upright condition ($M = .77$, $SD = .16$) relative to the inverted condition ($M = .71$, $SD = .20$). There was no main effect for change type, $F(1,23) = 0.40$, $p > 0.50$. Also, there was a statistically significant interaction between change type and orientation, $F(1,23) = 4.51$, $p < .05$, $\eta_p^2 = 0.16$. This interaction can be explained by the significantly lower detection rates for height changes when presented inverted compared with upright, $t(23) = 2.89$, $p < .01$, $d = 0.55$, paired with no difference in detection rates for grasp changes based on orientation, $t(23) = .30$, $p > 0.75$.

For the miming condition, a 2 (Change type)×2 (Orientation) repeated-measures ANOVA revealed a statistically significant main effect for orientation, $F(1,23) = 18.97$, $p < .001$, $\eta_p^2 = 0.45$, with higher detection rates for upright changes ($M = 0.80$, $SD = 0.17$) compared with inverted changes ($M = 0.67$, $SD = 0.17$). There was also significant main effect for change type, $F(1,23) = 47.34$, $p < .001$, $\eta_p^2 = 0.67$. Grasp changes were detected more accurately ($M = 0.94$, $SD = .07$) than height changes ($M = 0.52$, $SD = 0.29$). Finally, there was a significant interaction between change type and orientation, $F(1,23) = 11.81$, $p < .003$, $\eta_p^2 = 0.34$. Similar to the normal condition, there was no effect of orientation for grasp changes, $t(23) = 1.32$, $p > 0.20$, but there was a significant reduction in accuracy for height changes when the orientation was inverted compared with upright, $t(23) = 4.11$, $p < .001$, $d = 0.72$.

For the animation control condition, a 2 (Change type)×2 (Orientation) repeated measures ANOVA revealed no main effect for orientation, $F(1,23) = 0.69$, $p > 0.40$, or change type, $F(1, 23) = 2.15$, $p > 0.15$, or any significant interaction between the change type and the orientation, $F(1,23) = 1.45$, $p > 0.20$.

We also investigated whether accuracy for grasp changes was significantly higher than accuracy for height changes for upright trials across the three conditions. The results of Experiment 1(a) were replicated in the normal condition, as participants again had no advantage at detecting grasp over height changes for targeted dropping actions, $t(23) = 0.35$, $p > 0.70$. However, in the miming condition participants were significantly better at detecting grasp changes over height changes, $t(23) = 4.35$, $p < .001$, $d = 1.26$. Finally, participants had a marginally significant advantage for detecting control grasp changes over control height changes in the animation condition, $t(23) = 2.01$, $p < .06$, $d = 0.49$.

We also were interested in direct comparisons of the two change types when they were upright across the conditions. For height changes, detection rates were significantly higher in the normal condition compared with the animation control condition, $t(46) = 2.44$, $p < .02$, $d = 0.69$, and marginally higher compared with the miming condition, $t(46) = 1.85$, $p < .08$, $d = 0.53$, but did not differ between the miming and animation control conditions, $t(46) = 0.51$, $p > 0.60$. For grasp changes, detection rates were significantly higher in the miming condition in comparison with the normal condition, $t(46) = 3.21$, $p < .003$, $d = 0.90$, and the animation control condition, $t(46) = 4.17$, $p < .001$, $d = 1.14$, but did not differ between the normal and animation control conditions, $t(46) = 0.34$, $p > .70$.

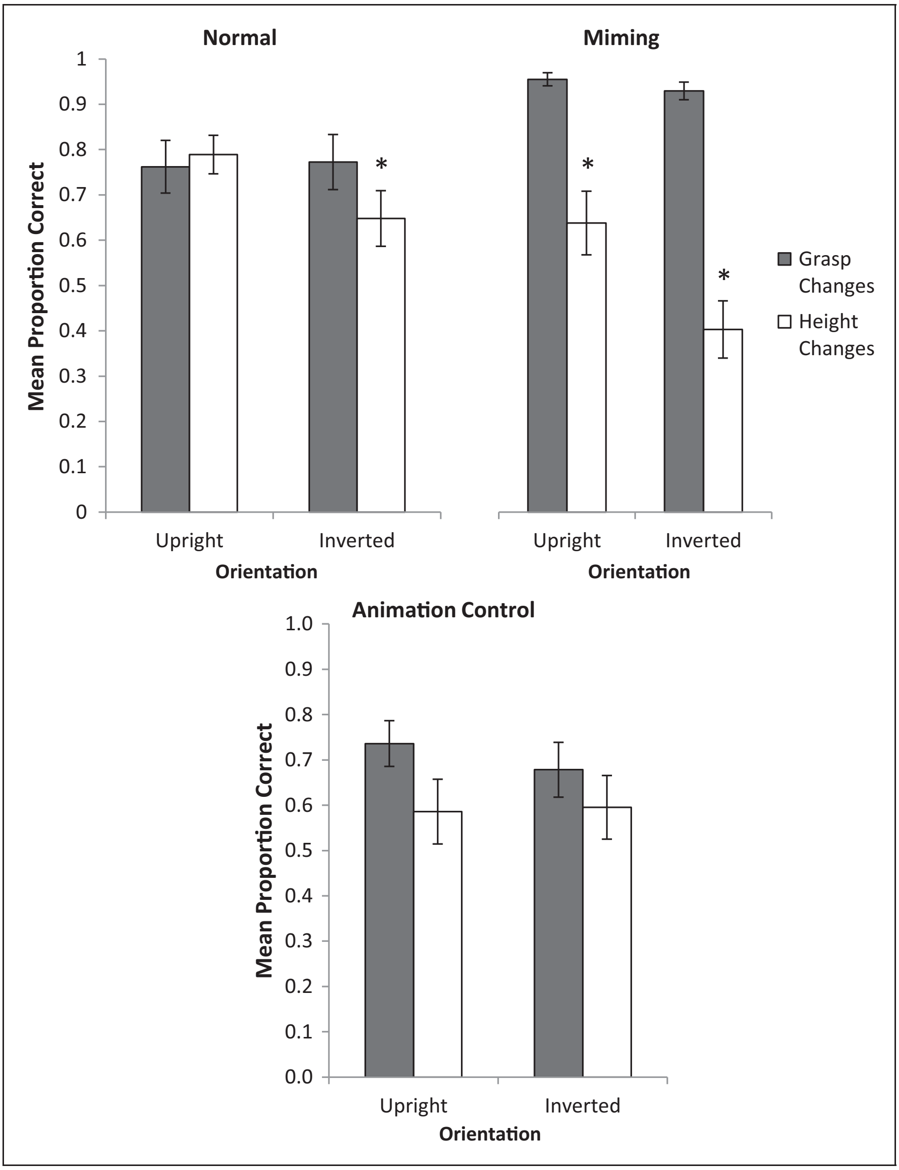

Figure 4. Mean accuracy for different trials as a function of change type, orientation, and condition in Experiment 2. Asterisks indicate significant differences between conditions. Error bars indicate ±SE.

Discussion

The results of Experiment 2 strongly indicate that processing of spatial trajectory in action involves orientation-dependent mechanisms. Observers have difficulty in noticing changes to such information when action is inverted, even when the saliency of this information is high, as in the case of targeted dropping. Observers also have difficulty noticing trajectory changes for mimed dropping actions with no clear goal, and inversion similarly disrupted processing of mimed trajectory changes. Finally, identical trajectory changes in the control condition showed no such disruption with inversion, indicating that the inversion effect for human trajectories is not due to more general difficulties processing inverted motion stimuli.

The high levels of attention to hand information in the miming condition also indicate that observers are consistently sensitive to hand information overall. Even when the goals of the action are ambiguous, observers pay more attention to the hands, and in the current research, do this at superior levels than for real dropping. What can explain this heightened attention to the hand? One possibility is that the lack of objects resulted in fewer visual distractors. Another possibility is that observers, struggling to understand the actor's goal, considered the hand shape the goal in and of itself. Future research can help to tease apart these possibilities by sampling a broader variety of mimed actions.

There was a tendency for observers to pay more attention to local information about geometric shape over global information about trajectory in the animation control condition, similar to what Loucks (2011) found for comparable static controls. This finding could suggest that consistently high sensitivity to the hand for manual actions is a broader phenomenon of visual event perception. However, such a conclusion is likely premature for two reasons. First, the result was relatively weak, in that it was not present for inverted control animations. Second, changes in action and geometric shapes, even when they are highly similar, are not equivalent in an absolute sense.

General Discussion

When viewing the actions of others, observers can extract only a sample of the complex visual information contained in the dynamic stimulus. Previous research has found that observers attend to at least two distinct sources of hand and trajectory information in action (Loucks, 2011; Loucks & Baldwin, 2009; Loucks & Sommerville, 2012a). The findings from Experiments 1(a) and (b) provide clear evidence that attention to the hand is high for both placing and dropping actions, but that attention to spatial trajectory is heightened for dropping actions relative to placing actions. The results of Experiment 2 indicate that processing of spatial trajectory in human action, regardless of the goal, is disrupted with inversion, and this differs from how observers process highly similar motion in a dynamic control stimulus. Thus, the current results indicate that attention during action observation is consistent in some ways, flexible in other ways, and relies on orientation-dependent processing mechanisms. We will discuss each of these properties in turn, followed by a discussion of alternative conceptualizations and broader implications.

Consistency

Observers appear to habitually pay attention to the hands for manual actions as a general rule. The results of the current research are consonant with previous research (Loucks & Baldwin, 2009; Loucks & Sommerville, 2012a). Importantly, however, these findings suggest that a hand *bias* is too strong a term, since spatial trajectory information can be attended to at equivalent levels for dropping actions. Perhaps a better term would be a hand *proclivity*.

Why do observers so readily key on hand information? There is seemingly no reason that hand contact information is especially critical for understanding placing or dropping. However, Loucks and Sommerville (2012b) argued that hand information is frequently relevant for predicting an actor's *upcoming actions*: for example, the type of grasp used on a pencil determines whether it can be used for writing. They demonstrated that 10-month-olds are sensitive to such functional consequences in other's actions, consistent with an emerging hand proclivity at this age (Loucks & Sommerville, 2012a). According to this hypothesis, participants in Experiment 1(a) attended to the grasp for placing and dropping with high fidelity as it constrained possible future actions (even though the actions never actually varied). Experiment 2 further suggests that because the hands are so often critical in inference and prediction, they are highly salient even for mimed actions involving no objects.

Flexibility

Observers also appear to be flexible in their attention to perceptual information in action, at least for spatial trajectory information. Loucks and Sommerville (2013) argued that observers target their attention on properties of actions that are relevant for predicting actions or goal outcomes. They demonstrated that observers are especially sensitive to increases in drop height over a narrow container, due to increased difficulty in targeting. In the current experiment the container was also narrow, and thus observers were likely highly sensitive to drop height as it was relevant to predicting the actor's success. The equivalent trajectory information is much less or not at all relevant to predicting success for placing or mimed dropping actions. Future research on this topic should more directly investigate predictive processes, for example, by utilizing eye tracking to find evidence of implicit prediction (e.g., Flanagan & Johansson, 2003). This work is currently underway in our lab.

The current results are likely only the tip of the iceberg of attentional flexibility in action perception. Additional actions that we have not examined here may demand greater attention to other perceptual dimensions (e.g., action speed). In addition, the goals of the observer himself or herself likely play a significant role in what information is attended to. We examined observers' sensitivity to perceptual information for actions that were largely irrelevant to the observers themselves, as stimuli in a perception experiment. It is easy to imagine that observers' attention may shift to different dimensions when they themselves may be the target of the actor's action (e.g., the actor reaching for a weapon; Parasuraman et al., 2009). This kind of contextual variable is a fascinating issue for future research in this domain.

Orientation Dependence

The present results very clearly show that processing of human action is dependent on processing mechanisms that operate on canonically oriented stimuli. Previous investigations into this phenomenon have been limited to using horizontal displacement actions (Loucks & Baldwin, 2009) or a wider variety of actions in a static form (Loucks, 2011). The current results are the first to demonstrate that an inversion effect occurs for a dynamic action in which attention to hand and trajectory information are equated in upright processing. Thus, the inversion effect is not the result of spatial trajectory information being more "fragile" information. They also demonstrate that inversion disrupts processing of global spatial relations for non-object-oriented actions.

These results are generally consonant with similar inversion effects observed in biological motion perception (Shipley, 2003; Thompson et al., 2005; Troje, 2003), and in human body perception (Reed et al., 2003). However, they extend this literature in two ways. First, they demonstrate that orientation impact processing of spatial relations of the body when it is in motion, displayed for a long period, and embedded in an ecologically valid context. Second, they demonstrate that the perception of some action information survives inversion—namely, hand information.

Characterizing the Processing Distinction

The fact that hand information is consistently attended to and is unaffected by inversion suggests that it is processed separably from the rest of the body in action. But this does not necessarily imply that hand information is not processed configurally. On the contrary, evidence indicates that observers indeed process configural relations of the hand (Candidi, Urgesi, Ionta, & Aglioti, 2008; Urgesi, Candidi, Ionta, & Aglioti, 2007). Configural processing of the hand may survive inversion because there is no canonical "upright" grasp: the human hand can grasp objects from above or below, and is only restricted from rotating freely in three dimensions by biomechanical constraints. Recent conceptualizations of biological motion detection also call into question whether inversion effects are meaningful for investigating local vs. global processing of a stimulus, as inversion of point-light walkers disrupts processing of the highly local motion of the feet (Hirai, Chang, Saunders, & Troje, 2011).

What role does gravity play in this processing distinction? Research indicates that visual processing areas are sensitive to normal gravity cues (Indovina et al., 2005), and that sensitivity to these cues may underlie biological motion perception (Maffei et al., 2015). Since gravitational acceleration is responsible for the dropped object's downward motion, one may wonder if abnormal gravity cues can explain the selective inversion effects for human action in Experiment 2. This explanation falls short, however. First, cues to abnormal gravity were also present in the control condition (upside-down room, inverted gravitational acceleration), yet there was no effect of inversion on trajectory in this condition. Second, inversion disrupted trajectory processing for mimed dropping, which had significantly weaker cues to abnormal gravity. Gravity no doubt plays a role in the processing of human action (e.g., Bardi et al., 2014; Hirai et al., 2011), but it cannot explain differential attention to these perceptual dimensions or selective inversion to spatial trajectory.

We believe that these inversion effects support the notion that upright human action is processed with expertise, in a holistic manner (Richler, Wong, & Gauthier, 2011; Rossion, 2008). Inversion is one hallmark of visual expertise (Diamond & Carey, 1986; Gauthier & Tarr, 1997). Another hallmark is more precise perception of stimuli. For instance, car experts are better at recognizing cars when they are upright, and inversion reduces recognition rates to novice upright levels (Rossion & Curran, 2010). This also occurred in the current research for processing of upright trajectory information for targeted dropping, and inversion reduced accuracy to upright control levels (see also Loucks, 2011). Thus holistic processing of human action may increase observers' sensitivity to spatial relations of the body. However, sensitivity may only be increased when it is relevant to the actor's goal (as there was no such improvement for upright miming).

A network of several brain areas underlies human action recognition. Processing of biological motion and the human body are associated with activation in temporal regions, while processing of grasp or hand information is associated with activation in parietal and frontal regions (see Thompson & Parasuraman, 2012, for a review). Importantly, the extant evidence indicates that only regions in temporal cortex, such as the superior temporal sulcus (STS), are sensitive to the orientation of biological motion (Grossman & Blake, 2001). The STS may be a good candidate for where processing of spatial trajectory information occurs for dynamic action, and may also be the region responsible for expertise in processing human action. The current results are thus in line with a neurological distinction between processing of the hand versus the rest of the body, which shows orientation sensitivity.

Action Prediction

Observers of action are typically are more concerned with understanding the goal of the action under execution rather than the surface characteristics of the action (Baldwin & Baird, 2001; Kurby & Zacks, 2008). As described above, we believe that the consistency and flexibility highlighted in the present experiments contribute to goal understanding by assisting in the prediction of others' actions (either new goals or goal outcomes). A large body of research suggests that action processing is predictive in nature (Falck-Ytter, Gredebäck, & von Hofsten, 2006; Flanagan & Johansson, 2003; Southgate, Johnson, El

Karoui, & Csibra, 2010). Prediction increases the efficiency of action processing, as observers can stay one step ahead of the action as it unfolds. Evidence for predictive processes have often been reported alongside evidence of shared relations between action production and perception (Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2012; Kanakogi & Itakura, 2011), leading some to suggest that one consequence of such shared relations is to improve the efficiency of prediction (Blakemore & Frith, 2005; Paulus, 2011).

Conclusion

In sum, the current results are the first of their kind to show that attention during action perception is consistent, flexible, and orientation-dependent. On the one hand, observers readily key on relatively local information concerning the hand, regardless of the goal or the orientation of the action stimulus. On the other hand, observers flexibly modulate their attention to global spatial trajectory information according to the goal, but processing of this information is sensitive to orientation. These three aspects of action perception likely fuel observers' ability to predict upcoming goals and action outcomes.

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Notes

1. Previous research by Loucks and colleagues has used the term "featural" to refer to hand contact information, and "configural" to refer to spatial trajectory information, as an analogy with face processing.
2. Actors grasped the beanbag at 1 s, held it mid trajectory at 2 s, and either placed it in the container or dropped it at 3 s. For both actions, this meant that the rate of motion was slightly faster for the high trajectories. For dropping videos, the trajectory difference sometimes resulted in a 1 frame (33 ms) difference in fall time (for 2/4 actors).
3. We report accuracy scores instead of d prime scores as there is no sensible way to calculate separate false alarm rates for each change type, since this variable was manifested within-subjects and thus there was one shared set of same trials. Instead, we removed participants who had false alarm rates that exceeded 2 standard deviations from the mean, and thus report change detection scores from a more homogenous group of participants.

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