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Jeff Loucks & Natasha Nagel

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Temporal perception is enhanced for goal-directed biological actions

Jeff Loucks and Natasha Nagel

Department of Psychology, University of Regina, Regina, SK, Canada

ABSTRACT

Research into the visual perception of goal-directed human action indicates that human action perception makes use of specialized processing systems, similar to those that operate in visual expertise. Against this background, the current research investigated whether perception of temporal information in goal-directed human action is enhanced relative to similar motion stimuli. Experiment 1 compared observers' sensitivity to speed changes in upright human action to a kinematic control (an animation yoked to the motion of the human hand), and also to inverted human action. Experiment 2 compared human action to a non-human motion control (a tool moved the object). In both experiments observers' sensitivity to detecting the speed changes was higher for the human stimuli relative to the control stimuli, and inversion in Experiment 1 did not alter observers' sensitivity. Experiment 3 compared observers' sensitivity to speed changes in goal-directed human and dog actions, in order to determine if enhanced temporal perception is unique to human actions. Results revealed no difference between human and dog stimuli, indicating that enhanced speed perception may exist for any biological motion. Results are discussed with reference to theories of biological motion perception and perception in visual expertise.

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Humans are immersed in a highly social environment, and as such require efficient and accurate mechanisms for perceiving the actions of others. Perceiving the actions of others is critical in interpersonal interactions, be they affiliative, cooperative, or informational in nature (e.g., Baldwin & Baird, 2001; Sebanz, Bekkering, & Knoblich, 2006; Woodward, 2009). While there is a long history of research on the processing of intransitive movements (e.g., walking) that can be perceived in impoverished visual conditions (Johansson, 1973), it is only in recent decades that research has focused on the perception of goal-directed actions in ecologically valid contexts (e.g., picking up a water bottle). This body of research has largely focused on motor representations of the observer that are shared in the processing of similar actions performed by others (Brass, Bekkering, & Prinz, 2001; Marshall & Meltzoff, 2014; Rizzolatti & Craighero, 2004). Less is known about the visual mechanisms that support the processing of goal-directed actions.

Research indicates that observers of human action attend to at least two distinct sources of perceptual information while they view others (Loucks & Baldwin, 2009). One source is hand information,

concerning how the hand interacts with objects as the action unfolds, and the other is configural information, concerning the spatial relationships among body parts and objects across time and space. These sources are distinct in that (1) observers often selectively attend to hand information over configural information, and (2) processing of configural information is significantly disrupted by inversion of action while processing of hand information is not (Loucks & Baldwin, 2009). The inversion effect for action is similar to the body inversion effect for static images (Reed, Stone, Bozova, & Tanaka, 2003), but manifests in dynamic stimuli. Although hand information is typically prioritized by observers, processing of configural information in action is enhanced in human action relative to processing of identical configural relationships in control motion stimuli (Loucks, 2011; Loucks & Pechey, 2016). This processing distinction may arise in development as observers become experts at processing the actions of others, as there are striking similarities between these findings and the hallmarks of processing with visual expertise (Gauthier & Tarr, 1997; Richler, Wong, & Gauthier, 2011; Rossion & Curran, 2010).

However, there is another critical source of perceptual information in action that has yet to be systematically explored: temporal information, or information concerning action speed. Because action is a dynamic stimulus, accurate perception of the timing with which an action is executed has critical relevance in a great many situations, for predicting upcoming events and planning one's own actions. In life-threatening situations, detecting how quickly a dangerous action is unfolding (e.g., someone reaching for a gun) allows one to plan a fight or flight response appropriately. In less life-threatening situations, one needs to accurately perceive the speed of hand motion in order to know whether one is receiving a slap or a caress from a social partner. Processing of action speed is also informative for detection of another person's mood – imagine the differential readings one obtains from viewing someone slamming a book onto a table vs. placing it softly. Although such ready examples indicate that observers are sensitive to temporal information in human action, there have been few explorations into the nature of this processing, and no research to date has investigated whether temporal perception differs for goal-directed human action in comparison to similar dynamic stimuli. An investigation of this nature would allow for a novel aspect of visual perception to be examined in regards to theories of perceptual expertise, as research on visual expertise has so far only focused on static stimuli.

The only studies to date which have explored the perception of temporal information in goal-directed human action are those of Loucks and Sommerville (2012, 2018). Loucks and Sommerville (2012) found that 4-month-old infants are equally sensitive to changes in hand, configural, and temporal information in action (action speed), but that by 10 months of age infants have lost sensitivity to configural and temporal changes but retain high sensitivity to hand changes. However, Loucks and Sommerville (2018) found 6-month-old infants may sometimes be similarly sensitive to temporal changes as they are for hand changes (for live action compared to video). However, these infant studies only provide data on infants' sensitivity to temporal information relative to other sources of perceptual information in action, and tell us nothing about observers' processing of temporal information in action relative to other dynamic stimuli.

There are also a handful of studies which have investigated temporal perception in observers' processing of cyclical, intransitive movements in biological motion. First, Jacobs, Pinto, and Shiffrar (2004) found that observers' sensitivity to the speed of biological walking movements was enhanced for biomechanically possible relative to impossible movements, but did not vary as a function of the familiarity of the walking movement. These results suggests that speed perception for human actions may be enhanced due to shared representations between self and other (Rizzolatti & Craighero, 2004). More recently Ueda, Yamamoto, and Watanabe (2018) compared observers' speed sensitivity for upright and inverted biological (intact) and scrambled point-light stimuli across three experiments, using a broad range of cyclical actions (walking, throwing, kicking, and two callisthenic exercises). In this research, speed discrimination for intact biological motion was enhanced relative to scrambled biological motion, and inversion reduced speed sensitivity. However, the inversion effect on speed sensitivity occurred for both intact and scrambled stimuli, indicating that enhanced speed perception is supported by both global and local signals in biological motion. This latter result was likely due to the inversion of the local motion of the feet, which may act as an invariant cue in the detection of animacy, which subsequently boosts perceptual performance (Troje & Westhoff, 2006). While both of these studies indicate that speed perception is enhanced for human actions relative to other motion stimuli, it is unknown whether such effects would be observed for singular goal-directed actions (involving no repetition) occurring in a rich, ecologically-valid context.

A related finding is that biological motion alters observers' subjective perception of time. Orgs, Bestmann, Schuur, and Haggard (2011) found that observers' subjective estimates of stimulus duration were biased according to the perceived velocity of biological movement (faster implied movements perceived as shorter duration). Inverting biological motion eliminated this time compression effect, suggesting that configural processing of the human form is key to this phenomenon (see also Orgs & Haggard, 2011; Orgs, Kirsch, & Haggard, 2013). Wang and Jiang (2012) found that both intact and scrambled biological motion of human walking (which both contain life signals) slows down the subjective perception of time, but that when inverted no slowdown

occurs for either stimulus. In contrast, Ueda et al. (2018) found a similar slowdown for upright and inverted biological motion, which was greater for intact than for scrambled biological motion. One possible explanation for this discrepancy is that Ueda et al. used a wider range of actions than Wang and Jiang (2012). Most importantly for the purposes of the current research, it does not directly follow from these findings that subjective time compression would necessarily impact the perceptual judgements of speed for goal-directed actions. That is, if an observers' subjective time is altered, does that entail they will be better at discriminating two different human action speeds relative to non-biological motion? Evidence from Ueda et al. indicates that this is unlikely, as there was independence between the slowdown effect and the enhancement to speed discrimination.

Against this background, in the current study our primary interest was in examining whether speed perception for goal-directed human actions is enhanced relative to control dynamic stimuli. Such a finding would be consistent with the hypothesis that human action is processed with visual expertise, but to our knowledge no research has ever explored whether improved temporal processing is a product of expertise in processing. In the present research we addressed this question by asking observers to discriminate between actions that differed only in speed and not in overall duration. In Experiment 1, short video clips of an actor intentionally moving an object with the hand were filmed. Alterations to these clips were made such that the translocation portion of the action was sped up or slowed down, and the remaining reach and withdraw portions of the action were slowed down or sped up in order to keep the overall duration constant. On each trial observers were shown two clips and asked to discriminate whether the pairs differed in motion speed. This first experiment compared speed perception for upright human action (described above) to inverted human action (rotated 180 degrees in the picture plane) as well as a control motion stimulus. Our control in Experiment 1 was an animated motion that was matched to the kinematic motion of the actor's hand. Our control in Experiment 2 was an inanimate motion stimulus that closely matched the human action. Two different controls were chosen a priori because they possessed different strengths and weaknesses.

Our hypotheses for these two studies were (1) that observers would be more sensitive to changes in speed for upright human action relative to both of these control motion stimuli, and (2) that inverting human action would result in a loss of sensitivity to speed changes. This latter hypothesis was based on the fact that configural processing of human action is impaired with inversion, and it is possible that temporal processing of the human body in action is supported by processing the canonical spatial relationships of the body in motion. It is also based on the inversion effect on speed discrimination observed for intransitive biological motion (Ueda et al., 2018).

Based on the results of the first two experiments, Experiment 3 was conducted in order to determine if enhanced temporal perception is specific to human action or would occur for any goal-directed biological motion. Previous studies on the visual perception of goal-directed human action have been unable to address the specificity of the hand/configural distinction in human action perception, as it is very difficult to obtain dynamic video stimuli of human and non-human animals that are matched on the perceptual changes of interest (i.e., hand/effector and configural changes in Loucks & Pechey, 2016). But because our speed manipulation was achieved artificially, we were able to match human and dog stimuli on equivalent speed changes. This allowed for a critical test that has implications for theories of both biological motion perception and visual expertise.

Experiment 1

In Experiment 1 we examined observers' perception of speed changes for human actions in comparison to a control stimulus which matched the exact kinematics of the human hand motion. A strength of this control lay in the matching of overall movement, but a weakness lay in the fact that it is significantly reduced in stimulus complexity (more on this in the methods). In addition we investigated whether inversion would alter speed perception for goal-directed human actions. We hypothesized that detection of speed changes for upright human action would be superior to the control stimulus. Because inversion disrupts configural processing of human action, we also hypothesized that detection would be superior in

the normal condition in comparison to the inverted condition.

Methods

Participants

Fifty-four University of Regina undergraduates (48 female) received partial course credit for their participation in the experiment. A power analysis with $\alpha = 0.05$ and power = .80 indicated that an $N = 42$ would allow us to detect a medium effect size ($f = 0.25$) for the interaction term. Equal numbers of participants were randomly assigned to the normal, inverted, and animation control conditions. Data from one additional participant was replaced because their same trial accuracy was three standard deviations below the mean for their respective condition.

Stimuli

The stimuli for the normal condition of Experiment 1 consisted of 32 videos generated from eight action scenarios; there were four videos with varying speed properties within each. In each scenario, the same male actor was seated at a table or desk and moved an object in a straight trajectory across a surface, moving to the pace of a metronome to keep the same timing of action elements across scenarios. Common everyday objects were used for each scenario (e.g., stapler, calculator, cup) and the actor held a neutral facial expression during filming. In the original video the actor grasped the object in 1 s, moved it across the table in 1 s, and retracted his hand in 1 s. From this video three new videos with speed transformations were created which altered the speed with which the object was moved: In one the duration of this movement was shortened to 0.5 s, in another it was lengthened to 1.5 s, and in another it was lengthened to 2 s. The remaining parts of the videos were sped up or slowed down in order to compensate for the increase or decrease in movement pacing, to keep video length (3 s) constant. See supplemental material to view example changes across all conditions in each experiment.

For the inverted condition, all of the normal videos were rotated in the picture plane 180 degrees. For the animation control condition, two-dimensional shapes were superimposed over the normal videos. In the first frame of each video, a circle representing the actor's hand and a rectangle representing the object

were superimposed over the hand and object. For each successive frame the circle moved yoked to the hand while the rectangle remained in the object's initial position, and thus the circle traced the exact path of the hand. A grey background was superimposed across the remainder of the scene. Different colour schemes were used in the eight different animation scenarios. Example still frames from one scenario in each condition can be found in Figure 1. All videos were recorded digitally at 30 frames per second. Video resolution was 860 (w) \times 484 (h) pixels. Sound on the videos was muted.

Objective movement change. These control animations matched the movement of the hand, but they did not match the normal videos on a number of other perceptual dimensions. The objects and backgrounds were simple in comparison. In addition, the amount of motion occurring on the screen was larger in the normal videos, as an articulated limb in motion holding an object alters more of the visual scene than does a single solid-colored object in motion. Any advantage we may observe for detecting human vs. control speed changes may be due to these perceptual differences in motion. We thus felt it would be best to analyze the objective differences in motion between these videos, and use this difference as a covariate in our analyses of sensitivity differences.

To this end we used a pixel change algorithm that was modified from a similar one used in Loucks and Baldwin (2009). This calculated the degree of pixel luminosity change across each frame of the video relative to the *first* frame of the video, using the following formula:

$$\sum_{i=1}^h \sum_{j=1}^w \sqrt{0.2126*(R_{Cij} - R_{Fij})^2 + 0.7152*(G_{Cij} - G_{Fij})^2 + 0.0722*(B_{Cij} - B_{Fij})^2}$$

where R , G and B represent the red, green, and blue colour values of a pixel, C denotes an individual frame beyond the first, F denotes the first frame, i and j represent the coordinate value of the pixel, and h and w represent the height and width of the frames in pixels. Each pixel colour value is multiplied by a specific proportion that reflects the relative luminance of those wavelengths in observers' perception. These values were computed for each frame beyond 1, and then the average was computed for the video. This average therefore reflects the amount of objective pixel change that transpired over the course of

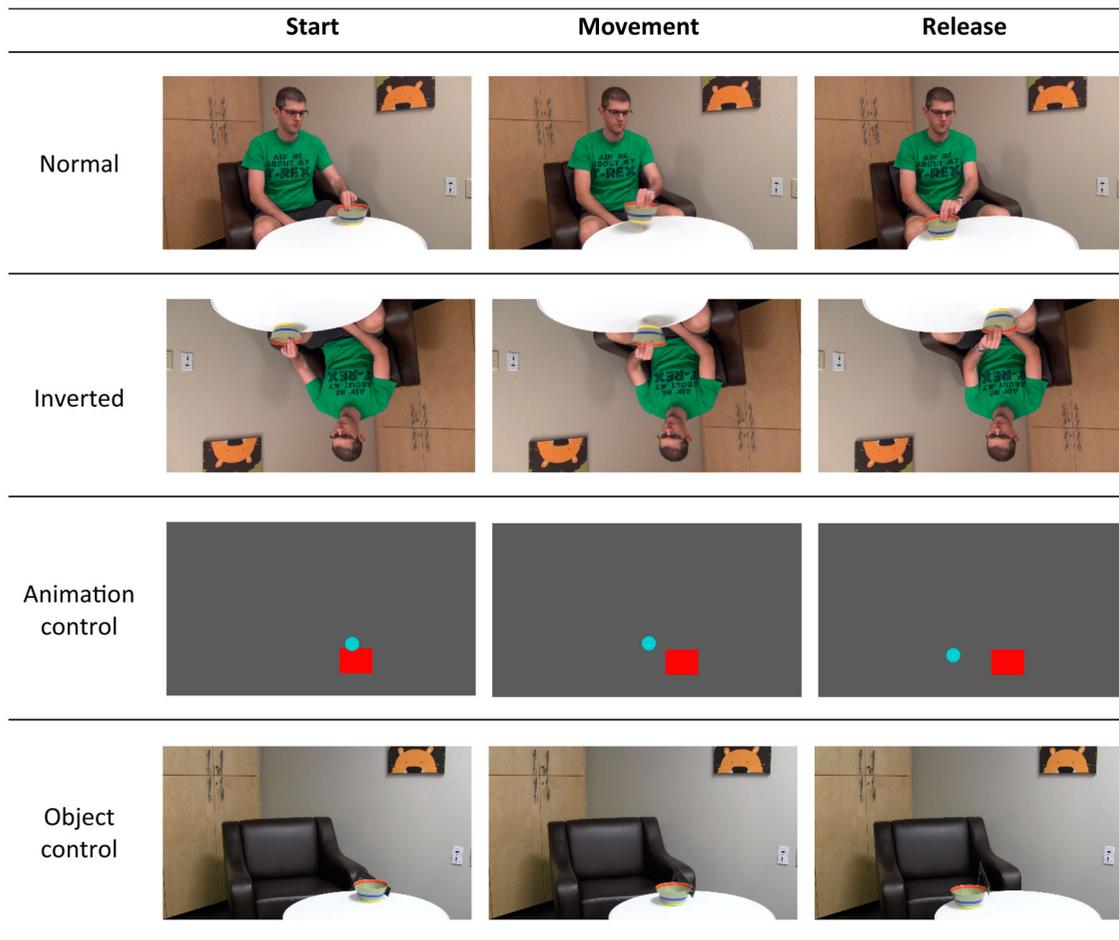


Figure 1. Example of the normal, inverted, and animate control conditions used in Experiment 1, and the object control condition used in Experiment 2.

the video that was a result of movement in the scene. This analysis was completed for each video in the normal condition and each video in the animation control condition.

For this measure the conditions clearly differed in the amount of objective movement change, with the normal videos possessing approximately twelve times the amount of movement change ($M = 2819711.92$, $SD = 696926.77$) than the animation control videos ($M = 225244.20$, $SD = 118222.52$), paired $t(7) = 11.87$, $p < .001$, Cohen's $d = 4.19$. To the extent that sensitivity differences could be explained by this objective difference, we treated this variable as a covariate in an item analysis (see Results).

Design and procedure

A mixed design was employed: condition (normal vs. inverted vs. animation control) varied between-subjects and time change (0.5 s vs. 1 s change) varied within-subjects. On different trials, two videos from a

scenario with temporal differences were paired. Specifically, there were three types of 0.5 s differences (i.e., 0.5 vs. 1, 1 vs. 1.5, 1.5 vs. 2) and two types of 1 s differences (i.e., 0.5 vs. 1.5, 1 vs. 2) which resulted in a total of 80 different trials. The order of the videos within each different trial was fully counterbalanced. On same trials, each video was paired with itself. There were a total of 64 same trials.

Stimuli presentation and data collection were administered using E-Prime on a PC with a 20 inch wide-screen monitor. From where participants were seated, stimuli subtended approximately 22×16 degrees 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 by pressing specially marked keys on a keyboard (same or different). Participants had an unlimited amount of time to make their response. The inter-trial interval was self-paced – the participant started the

subsequent trial by hitting the spacebar. Trial presentation order for a given participant was random.

After providing consent, participants in all conditions were told they would be seeing pairs of videos and would need to determine whether the videos in the pair were the same or different. They were explicitly told that the videos would only differ in the speed of motion, and that on the same trials identical videos would be played twice.

Results

Statistical analyses were performed on d' scores, converted from participants' accuracy scores, in order to assess sensitivity to the two time changes in each condition. Proportion of hits and false alarms, as well as response times, for all three experiments, can be found in Appendix A. Due to the low number of male participants, gender was not considered as a variable.

Mean d' scores for each of the time changes in the normal, inverted, and animated control conditions can be found in Figure 2. A 2 (time change) \times 3 (condition) mixed ANOVA revealed a significant effect of time change, $F(1,51) = 284.40$, $p < .001$, $\eta_p^2 = .85$, indicating that participants were more sensitive to the 1 s changes than the 0.5 s changes. As predicted, there was a significant main effect of condition, $F(2,51) = 24.49$, $p < .001$, $\eta_p^2 = .49$. Tukey post-hoc tests revealed that participants were less sensitive to changes in the animation condition compared to the normal and inverted conditions, $p < .001$, which were not significantly different from each other, $p = .95$. Finally, there was a significant interaction between change type and condition, $F(2,51) = 8.18$, $p < .001$, $\eta_p^2 = .24$. As can be seen in Figure 2, the improvement for

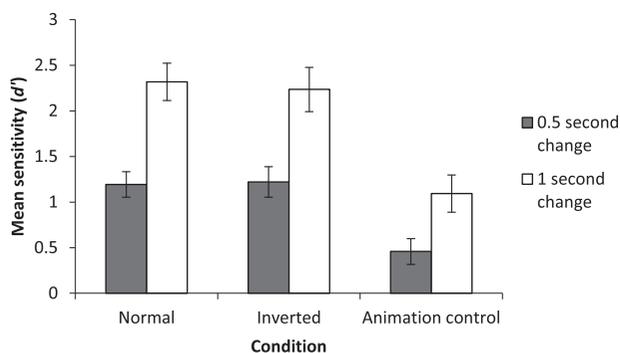


Figure 2. Mean d' scores as a function of time change and condition in Experiment 1.

0.5–1 s changes was larger for the human conditions than the animation control condition. However, planned comparisons within each condition indicated that in sensitivity to the 1 s change was superior to the 0.5 s change in all conditions, all p 's $< .001$.

We also performed an item analysis in which the individual videos served as the random variable (instead of participants) and the objective movement change measure served as a covariate. Adjusted means for this analysis can be found in Figure 3. A 2 (time change) \times 2 (condition: normal vs. animation) ANCOVA revealed significant main effects of time change, $F(1,13) = 8.27$, $p = .013$, $\eta_p^2 = .39$, and condition, $F(1,13) = 8.51$, $p = .012$, $\eta_p^2 = .40$. The interaction, however, was not significant, $F(1,13) < 1$. These results validate the main effects of the participant analysis, and indicate that despite the fact that videos differed on objective movement change, an effect of condition persisted after accounting for this substantial difference. The fact that the interaction was not significant in this analysis is somewhat difficult to interpret, but in any case reduces the reliability of this effect.

Discussion

The results of Experiment 1 clearly demonstrate that temporal perception is enhanced for human action relative to a kinematic control stimulus. Observers were equally skilled at detecting speed changes when human action was inverted, however, contrary to our prediction and deviating from findings with intransitive biological motion (Ueda et al., 2018).

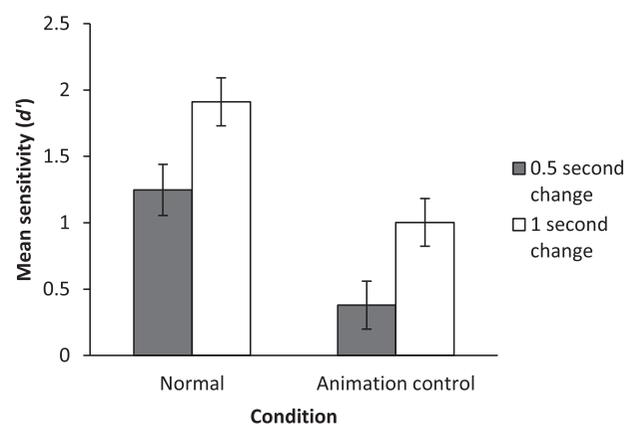


Figure 3. Adjusted mean d' scores from the item analysis with objective movement change as a covariate.

Although previous research has demonstrated that processing of configural information in goal-directed actions is disrupted with inversion (Loucks & Pechey, 2016), it appears that processing of temporal information survives inversion, similar to hand information. Serendipitously, however, the fact that the inverted condition was equally superior to the animation control condition served as an additional control for action familiarity. One could easily argue that the enhanced sensitivity for upright human actions was due to familiarity with processing this stimulus, but this explanation fails for the inverted action; very few individuals have experience with such a stimulus (i.e., astronauts).

The fact that the 1 s time change was easier to detect than the 0.5 s time change is certainly unsurprising, but it is important to note that no previous research has ever investigated adult observers' sensitivity to speed changes for a transitive event when the overall event length is kept constant. This experiment thus provides an important benchmark for investigations of temporal perception for complex motion events.

For this first experiment, using a kinematic control allowed us to tightly match the motion properties of the hand, but it did not serve as an ideal control in other ways. First, whereas the human action involved the motion of the hand, arm, and object, the animation control only involved the motion of one object, the circle. Second, the human action possessed a causal event structure that was lacking in the control. And third, this control was devoid of 3-dimensional structure and significantly reduced in stimulus complexity. Although our objective movement change measure captured some of these differences and the effect of condition was significant after accounting for this movement change, replicating this enhancement with a control that more closely matches the normal condition is preferable.

Thus, in Experiment 2 we aimed to replicate this superior speed perception against a different control stimulus which better controlled for the above features, even though it lacked identical kinematics. To this end, we filmed videos of non-human action that were matched to the human action in terms of the objects used and the context in which they occurred. We predicted that speed perception would still be enhanced for human action relative to this additional control.

Experiment 2

In Experiment 2 we compared speed perception of human actions to a different control stimulus. These control videos had the same causal event structure, used the identical objects, and occurred in the identical 3-dimensional environment that the human motion occurred in, but did not match the exact kinematics of the hand. We predicted that despite a closer match to the human action events, observers would still demonstrate higher sensitivity in detecting speed changes for the human action in comparison to this control.

Method

Participants

Thirty-six University of Regina undergraduates (30 female) received partial course credit for their participation in the experiment. A power analysis with $\alpha = 0.05$ and power = .80 indicated that an $N = 34$ would allow us to detect a medium effect size ($f = 0.25$) for the interaction term. Equal numbers of participants were randomly assigned to the normal and object condition.

Stimuli

The stimuli for the normal condition of Experiment 2 consisted of the same 32 videos used in Experiment 1. For the object condition, 32 videos were made that replicated as closely as possible the human motion videos used in the normal condition. The same eight scenarios were used, with the same objects, and filmed from the same camera angle (as close as possible). For each scenario a person (out of camera view) used a metre stick to move the object in a straight trajectory across a surface. The agent moved to the pace of a metronome such that the metre stick took 1 s to enter the scene and contact the object, 1 s to move the object, and 1 s to retract from the object. From these original videos three new videos with speed transformations were created for each scenario as in Experiment 1. Still frames of this condition can be found in Figure 1.

Objective movement change. We once again calculated the amount of objective change that was the result of movement in the videos in order to compare potential differences between conditions, using the same formula detailed in Experiment 1. Although

this analysis revealed that the videos were more closely matched on this measure, the human videos still possessed approximately two times more objective movement change ($M = 2819711.92$, $SD = 696926.77$) than the object control videos ($M = 1417368.60$, $SD = 428558.30$), paired $t(7) = 5.88$, $p = .001$, $d = 2.08$. We thus once again used this measure as a covariate in an item analysis.

Design and procedure

The same mixed design was used, with condition (normal vs. object control) varied between-subjects and time change (0.5 s change vs. 1 s) varied within-subjects. The structure and number of trials of the procedure remained identical.

Results

Mean d' scores for each of the time changes in the normal and object control conditions can be found in Figure 4. A 2 (time change) \times 2 (condition) mixed ANOVA replicated the significant effect of time change, $F(1,34) = 156.92$, $p < .001$, $\eta_p^2 = .82$, and also revealed a significant effect of condition, $F(1,34) = 5.00$, $p = .032$, $\eta_p^2 = .13$. In contrast to Experiment 1, the interaction between these variables was not significant, $F(1,34) = 1.67$, $p = .21$.

As in Experiment 1 we performed an item analysis with objective movement change entered as a covariate. The adjusted means for this analysis can be found in Figure 5. A 2 (time change) \times 2 (condition) ANCOVA revealed significant main effects of time change, $F(1,13) = 24.81$, $p < .001$, $\eta_p^2 = .66$, and condition,

$F(1,13) = 11.19$, $p = .005$, $\eta_p^2 = .46$, but no significant interaction, $F(1,13) < 1$. Thus, the objective movement differences between these conditions cannot explain the observed effects.

Discussion

The results of Experiment 2 are similar to Experiment 1, and further support the hypothesis that the perception of temporal information is enhanced for human actions. In this experiment the control stimulus was highly similar to the human stimulus, but did not involve a visible human. This indicates that the perception of identical object translocation events is enhanced when enacted by an on-screen actor in comparison to an inanimate tool operated distally by an off-screen actor. However, sensitivity was markedly better for these control events relative to the kinematic control in Experiment 1. Thus, speed perception for 3-dimensional events with causal structure is enhanced relative to 2-dimensional events that lack such structure.

An additional control provided by the object condition lies in the goal-directedness of the action. That is, it is clear when watching these videos that a human is operating the tool. As such, all of these events involve events motivated by a goal. We believe this result indicates that speed perception is enhanced due to the presence of an acting human and not due to the presence of a goal. One could argue, however, that this goal is more salient when enacted by a visible human, which then has a subsequent benefit to temporal discrimination of the actions executed in pursuit of that goal. From this

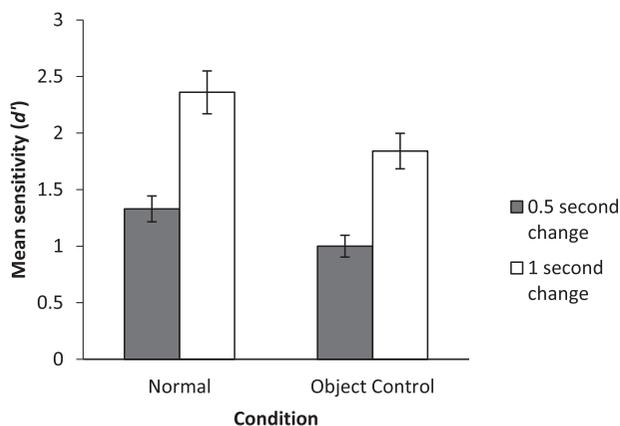


Figure 4. Mean d' scores as a function of time change and condition in Experiment 2.

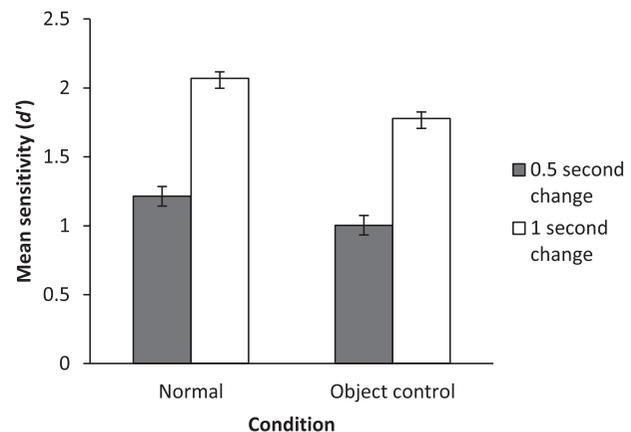


Figure 5. Adjusted mean d' scores from the item analysis with objective movement change as a covariate.

data alone we cannot definitively choose between these explanations.

In addition to the above ambiguity, we also cannot strongly conclude that the benefit to speed perception is specific to human action until we compare speed perception against another animate entity. Previous studies of action discrimination have never used a non-human animate control due to the significant rarity of animals who could vary their actions according to spatial trajectory or effector-object relationships as is critical in this line of research (e.g., Loucks & Baldwin, 2009). This stands in contrast to research that utilizes intransitive walking actions as stimuli, as many animals can be used in such research (e.g., Pavlova, Krägeloh-Mann, Sokolov, & Birbaumer, 2001). But because the way that we altered action speed in the current experiments was achieved artificially, this provided a unique opportunity to compare temporal perception for highly similar human vs. non-human actions. Thus, Experiment 3 was designed to compare observers' sensitivity to speed changes in human and dog goal-directed actions.

Experiment 3

In Experiment 3 we directly compared speed perception of human motion to another biological motion, that of a dog. Due to the unavailability of a highly-trained "Hollywood" dog who could move objects across a table with their paw in the same manner as a human actor, we instead settled for the motion of a fairly well-trained family pet who could "shake a paw" and "high-five". From these initial dog videos we could film human videos which were matched as closely as possible to the dog's actions.

If the superior speed perception for human motion that we observed in the first two experiments is specific to humans, then it should be observed in this experiment as well with a dog as the comparison stimulus. On the other hand, if this superiority is specific to any biological, goal-directed motion, then there should be no difference in speed perception between these two animals.

Participants

Thirty-six University of Regina undergraduates (29 female) received partial course credit for their participation the experiment. This sample size was chosen

based on the same power analysis used in Experiment 2. Equal numbers of participants were randomly assigned to the human and dog condition.

Stimuli

Stimuli consisted of 36 videos, generated from three dog and three human videos. Dog videos were filmed first and involved the same dog. In one video, the dog shook his owner's hand with his black paw, in another he shook with his white paw, and in a third he gave his owner a high-five with his black paw (the white paw high-five did not meet stimulus criteria). In all videos the dog was still for 1 s prior to moving, reached and engaged in the action for approximately 1 s, and released his paw in the remainder of the clip, such that the length of each video was 3 s. From these original clips the one second action portion was altered to be 0.5 s slower and 0.5 s faster. A 1 s slower transformation was not made due to the fact that it generated apparent unnaturalness in the dog's motion. Mirror image videos were then created for each of these nine videos (reflecting on the centre of the X axis), resulting in 18 dog videos. The human videos involved one actor mimicking the dog's actions in human form. The actor paced his movements to be on the same time line as the dog as closely as possible. A total of 18 human videos were created in the same fashion as the dog videos. Still frames of one dog video and its matched human video are presented in Figure 6.

Objective movement change. We once again analyzed the objective movement change in each video. For these stimuli there was no significant difference on this measure between the human videos ($M = 1589998.78$, $SD = 792818.79$) and the dog videos ($M = 2619827.36$, $SD = 1600129.46$), paired $t(2) = 0.82$, $p = .49$. We recognize that with only three pairs this t -test may be invalid, but if anything the mean difference favoured the dogs against our hypothesis of enhanced sensitivity for human perception. We therefore did not utilize this measure further as a covariate in an item analysis.

Design and procedure

We again employed the same mixed design, with condition (human vs. dog) varied between subjects and time change (0.5 s vs. 1 s) varied within subjects.

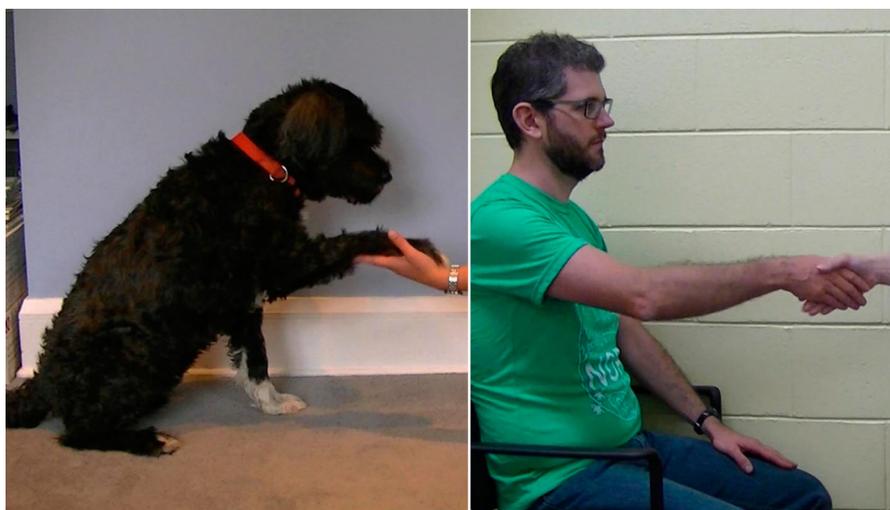


Figure 6. Stills of an example dog video and its matched human video used in Experiment 3.

However, because we filmed fewer videos for this experiment, and because we did not create 2 s movement alterations, the number and type of trials differed somewhat. Half second different trials involved pairings of 0.5 s and 1 s videos and 1 s and 1.5 s videos, while one second different trials involved pairings of the 0.5 s and 1.5 s videos. The order of the videos within each different trial was fully counterbalanced, resulting in 36 different trials. On same trials, each video was paired with itself, resulting in 36 same trials. There were thus a total of 72 trials.

Results

Mean d' scores for each of the time changes in the human and dog conditions can be found in Figure 7. A 2 (time change) \times 2 (condition) mixed ANOVA

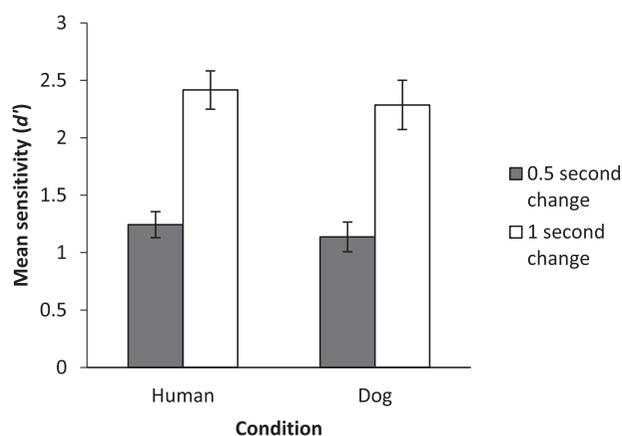


Figure 7. Mean d' scores as a function of time change and condition in Experiment 3.

revealed only a significant effect of time change, $F(1,34) = 112.42$, $p < .001$, partial $\eta^2 = .77$. The main effect of condition was not significant, $F(1,34) = 0.35$, $p = .55$, nor was the interaction between these variables, $F(1,34) = 0.01$, $p = .92$.

Discussion

The results of Experiment 3 provide strong evidence that the enhanced temporal perception observed in the first two experiments is not specific to humans. Observers were equally skilled at detecting speed changes for goal-directed actions enacted by a dog as they were for highly similar goal-directed actions enacted by a human. Although we recognize that these actions were not tightly controlled for in terms of low-level visual properties such as background and luminance, these factors would have had to specifically benefitted the dog videos only, elevating them from what they “should have been” if the dog had been filmed against a yellow background, for instance. We prefer a more parsimonious explanation that is consonant with broader theoretical claims regarding specialized processing for biological entities.

General discussion

Humans are adept at perceiving and understanding the actions of other humans. In the present research, we sought to discover whether one aspect of this proficiency is an enhanced ability to perceive the

temporal characteristics of human actions. We found that observers are indeed better at detecting speed changes for goal-directed human action in comparison to a kinematic control stimulus (Experiment 1) and a non-human motion stimulus (Experiment 2). However, we also observed that this benefit is not specific to humans and extends to other animate biological entities (Experiment 3). In the discussion that follows we will relate these results to previous research on the visual perception of human action, and consider the implications of these findings for theories of biological motion perception and visual expertise.

The most similar research to the present experiments is that of Ueda et al. (2018), who investigated speed perception for intransitive point-light biological motion. They found that observers were more sensitive to speed changes for intact biological motion compared to scrambled biological motion. They were unable to determine whether this benefit was due to the detection of biological motion or the detection of global form more generally (e.g., Hiris, 2007). The present results can address this issue and indicate that observers' sensitivity to the temporal characteristics of global coherent motion (as manifested in the object control condition of Experiment 2) is not on par with their sensitivity to the temporal characteristics of biological motion. They also found that inversion of biological motion – both intact and scrambled – impaired speed discrimination. In the present research, inversion did not affect observers' sensitivity to changes in action speed. This difference between studies is likely due to differences in stimuli, though the precise nature is unclear. Inversion may disrupt speed discrimination for intransitive actions but not goal-directed actions, or potentially for point-light biological motion but not full biological motion, or perhaps for repetitive actions but not for singular actions. Further studies are needed to shed light on this question.

The perception of biological motion has been shown to slow down observers' subjective perception of time (Orgs et al., 2013; Ueda et al., 2018; Wang & Jiang, 2012). The present results cannot be attributed to this slow down effect as presumably the time compression is constant and would compress two different speeds the same relative amount. The effects of inversion on this slow down effect are not entirely consistent either (compare Wang & Jiang, 2012, to Ueda et al.,

2018). Importantly, in the present research an enhancement to speed discrimination was observed in the inverted condition, even if observers were viewing those events as being generally slower. Overall, the present results indicate that temporal processing of biological motion is enhanced relative to non-biological motion. Thus, while enhanced speed perception cannot be explained by changes to subjective time, it is one more alteration to temporal processing that occurs as a result of the perception of biological motion.

The fact that speed perception was equivalent between human and dog action indicates that this benefit to temporal processing is not specific to humans and may apply to any biological motion (though future studies will need to explore whether this extends to non-mammalian motion). As animate biological entities, the actions of both the human and the dog may contain life signals. Troje and Westhoff (2006) proposed that the human visual system possess an evolutionarily-old life detection system that rapidly processes local motion signals from the feet as a cue to animacy, due to the relation of this motion to the downward force of gravity. For the intransitive walking movements of a human, cat, and pigeon, inversion of local feet motion disrupts direction discrimination similarly to inversion of the entire global form. While Troje and Westhoff demonstrated this novel inversion effect for local feet motion, Davila, Schouten, Verfaillie, and Longo (2014) provided compelling results that life detection may occur for any relevant articulatory point in contact with the ground (e.g., hands for handstand walking). In the present research we utilized goal-directed actions which did not involve motion of an entity against the ground, so it is not clear if the life detection system that has been proposed operates on this kind of motion (as gravity is largely unimportant for such motion).

Although we have framed these results according to a processing advantage for biological motion, it is possible that the processing advantage is for any goal-directed action, as the human and the dog were both executing actions toward a goal. We believe that the object control condition addresses this issue as it is apparent that an actor is operating the metre stick in those videos. Since the motion of even abstract shapes can be perceived as animate and goal-directed (Heider & Simmel, 1944), the fact

that observers were still better with the human motion suggests a special role for the identification of an animate entity. But one could also argue that there is some degradation in the perception of animacy when it does not involve a familiar stimulus such that the goal was less apparent in the control condition. Future work can potentially address this issue by comparing observers' speed perception for goal-directed actions to miming of those same actions (see Loucks & Pechey, 2016, for an example of this).

We consider our findings as demonstrating an enhancement to perception, but it is also possible that the enhancement is to visual working memory (VWM). The distinction in time scales between perception and working memory is by no means clear cut; however, the task involved comparing two 3-second videos, spaced by a 1-second inter-stimulus interval – a relatively long time frame. Wood (2007) demonstrated that VWM for actions has a lower capacity (2–3 actions) than VWM for objects (3–4 items). From this perspective, VWM for animate motion may be more robust than VWM for inanimate motion. Future research can explore these ideas more directly by comparing short-term recall of various types of motion in a standard VWM task.

What role might the motor system play in this temporal processing benefit? A number of studies indicate that the processing of object-directed human actions recruits the motor system (Brass et al., 2001; Prinz, 1997; Rizzolatti & Craighero, 2004). Importantly, this work has shown that recruitment of the motor system is increased when the observer possesses the same motor capacities (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005). Casile and Giese (2006), for instance, showed that training observers on executing a novel motor action improved their biological perception of that same motor action. On the surface motor resonance seems an unlikely explanation for the observed equivalence in temporal discrimination for human and dog stimuli – observers should have been better with the human with additional motor resonance for the more familiar human motor action. However, there is evidence that the processing of movements performed by non-conspecifics that are *similar* to those performed by conspecifics may recruit similar brain areas (Buccino et al., 2004). Provided the motions are similar they may also be constrained by fundamental kinematic laws of motion (e.g., Dayan et al., 2007;

Flash & Hogan, 1985), which may lead to equivalency in overall processing. Further research comparing the temporal perception of humans and other animates across a wider variety of actions can provide clarity on this issue.

Previous research on the visual perception of human action has shown that human action may be processed with expertise. Loucks and Pechey (2016) found that observers are more sensitive to configural changes in human action than for comparable dynamic stimuli – changes in the spatial relationships among body parts and objects (see also Loucks, 2011, for static stimuli). Configural information in goal-directed action is also uniquely disrupted with inversion, while the highly local motion of the hand is not (Loucks & Baldwin, 2009). Both of these properties are also present for the perception of configural information for objects processed with expertise (Gauthier & Tarr, 1997; Rossion & Curran, 2010). The present results do not support the hypothesis that enhanced processing of temporal information is a property of visual expertise for dynamic stimuli. However, it should be noted that no studies of visual expertise have examined processing of dynamic stimuli, so this is the first study to address this unique property of dynamic stimuli. In general, however, these results call into question whether the advantage for configural processing observed for human action is in fact specific to humans. While it may be possible to examine this issue in future research, it will be challenging to get two animals to enact the same configural changes (using animated stimuli may be one solution). More broadly, these results may indicate that certain properties of all biological entities are processed with a degree of expertise – not just humans. Perhaps a first target for research would be to evaluate whether the body inversion effect for static images (Reed et al., 2003) is unique to humans relative to other animals – an as of yet untested hypothesis.

Broader theoretical considerations need to also reflect the current state of knowledge regarding underlying neural systems. Research indicates that static and dynamic features of biological motion are processed in distinct neural pathways in the brain (Giese & Poggio, 2003; Vangeneugden, Peelen, Tadin, & Battelli, 2014). In the present task, it is natural to assume that dynamic information regarding speed would be processed along the dorsal motion pathway, via superior

temporal sulcus (Grossman & Blake, 2001). However, information regarding speed may also be processed along the ventral form pathway, as sequential snapshots of the animate entity across time, making use of the extrastriate body area (Downing, Jiang, Shuman, & Kanwisher, 2001). However, responses from the EBA to non-human mammals is intermediate – lower in comparison to human but higher in comparison to inanimate objects – so it is not clear if an enhancement in temporal perception for any animate could be carried out via the ventral route. In either case temporal information may be processed at a very early visual stage, as temporal anomalies in biological motion appear to be processed automatically in the temporo-occipital junction (Maffei, Giusti, Macaluso, Lacquaniti, & Viviani, 2015). However, the fact that Ueda et al. (2018) found inversion effects for speed discrimination for intransitive actions, and that we did not for transitive actions, suggests a potentially complex role for view-dependent processing of temporal action information. More research is certainly necessary to integrate these findings with respect to underlying neural systems.

Charting the development of these processing advantages – temporal and configural – will also be important for constraining these broader interpretations. There is considerable evidence to suggest that biological motion perception is an innate, evolutionarily-old system. For instance, both newborn human infants (Simion, Regolin, & Bulf, 2008) and newborn chicks (Vallortigara, Regolin, Marconato, & Burr, 2005) discriminate biological from non-biological motion. Human infants have also been shown to prefer biological motion displays that preserve the local upright motion of the feet regardless of global form (Bardi, Regolin, & Simion, 2014). However, a preference for biological motion does not necessarily entail that infants possess *enhanced processing* of biological motion. Nonetheless, if this processing advantage is a property of biological motion perception, it should be present relatively early in development. If this processing advantage is instead a result of relative expertise in processing the motions of animate entities (e.g., Diamond & Carey, 1986), it would likely develop later in life, and be variable with respect to infants' and children's experience classifying and categorizing these entities (Tanaka, Curran, & Sheinberg, 2005).

In summary, the present findings indicate that observers are highly sensitive to the temporal characteristics of animate entities acting in the world, and attend more to this information than for similar motion events that do not involve an animate entity. Such enhanced sensitivity serves observers well as they continually attempt to predict the actions of other animate entities around them, to avoid danger, glean information, make inferences, or coordinate their activities with other conspecifics. Further research on the relation between temporal and configural processing, in brain and behaviour, and on the developmental emergence of these enhanced sensitivities, can shed light on the efficient, high-level visual analysis that is undertaken to perceive the actions of other humans as well as the animate entities we live alongside.

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Appendix A

Mean percentage of hits, mean response times (RT, in ms), and mean percentage of false alarms (FA) as a function of experiment, condition, and time change. Standard deviations are presented in parentheses beside the means. For RT responses beyond 3 s were removed.

	0.5 s change		1 s change		FA
	Hits	RT	Hits	RT	
Experiment 1					
Normal	52 (17)	695 (227)	79 (22)	708 (248)	12 (6)
Inverted	51 (14)	621 (240)	84 (8)	564 (197)	12 (7)
Animation control	34 (15)	706 (257)	55 (17)	630 (208)	21 (12)
Experiment 2					
Normal	54 (14)	669 (269)	83 (16)	599 (228)	13 (9)
Object control	53 (9)	661 (191)	80 (14)	582 (173)	19 (9)
Experiment 3					
Human	64 (13)	634 (200)	91 (8)	668 (172)	21 (10)
Dog	56 (12)	627 (244)	85 (15)	573 (197)	19 (11)