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Perception of Continuous Movements from Causal Actions

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Abstract

We see the world as continuous with smooth movements of objects and people, even though visual inputs can consist of stationary frames. The perceptual construction of smooth movements depends not only on low-level spatiotemporal features but also high-level knowledge. Here, we examined the role of causality in guiding perceptual interpolation of motion in the observation of human actions. We recorded videos of natural human-object interactions. Frame rate was manipulated to yield short and long stimulus-onset-asynchrony (SOA) displays for a short clip in which a catcher prepared to receive a ball. The facing direction of the catcher was either maintained intact to generate a meaningful interaction consistent with causality, or was transformed by a mirror reflection to create a non-causal situation lacking a meaningful interaction. Across three experiments, participants were asked to judge whether the catcher's action showed smooth movements or sudden changes. Participants were more likely to judge the catcher's actions to be continuous in the causal condition than in the non-causal condition, even with long SOA displays. This causal interpolation effect was robust to manipulations of body orientation (i.e. upright versus inverted). These findings indicate that causality in human actions guides interpolation of body movements, thereby completing the history of an observed action despite gaps in the sensory information. Hence, causal knowledge not only makes us see the future, but also fills in information about recent history.

Keywords: causality; causal action; motion interpolation; human action; human interaction

Introduction

In our daily life, we are constantly incorporating new visual information to form a continuous impression of the dynamic world. However, the perceptual construction of smooth movements is not a trivial task, since visual inputs are actually discrete frames or disjointed clips separated by constant eye movements. Flipbooks, for example, exploit our susceptibility to apparent motion (Wertheimer, 1912), where our visual system induces the perception of dynamic scenes from the presentation of static images in rapid succession. Apparent motion offers an illustrative case of the human visual system's tendency to interpolate the paths of perceptual objects over time, and to produce the perception of smooth motion across discrete samples of visual stimuli at different time points. It is well-known that the appearance of smooth motion is determined not only by low-level visual features, such as inter-frame spatial displacement and temporal sampling rate (Braddick, 1974; Burr, Ross & Morrone, 1986), but also by high-level visual knowledge about shapes, objects and events involved in the stimuli (Sigman & Rock, 1974; Braddick, 1980; Shiffrar & Freyd, 1990; 1993; Chen & Scholl, 2016).

In the present paper, we examine whether causal knowledge inherent in human actions influences the extent to which the visual system interpolates body motion. The sense of cause-effect relation can emerge from the irresistible perception of events involving causation, demonstrated by the well-known launching effect between two colliding objects (Michotte, 1946). However, such automatic perception arises not just for physical causation, but also for intentional causation in the social environment. Even as young as 9-month-old, infants perceive objects as "intentional agents" whose states can cause behavioral activities (Crisbra et. al., 1999). Both physical and social causal perceptions are susceptible to the change of spatiotemporal features in dynamic scenes. For example, the perceived causation in the launching event depends on relative speeds of objects in the scene, spatial gaps between those objects, temporal gaps between objects' motions, objects' path lengths (Scholl & Tremoulet, 2000). On the other hand, causal perception can also influence perceptual judgments and memory about spatiotemporal properties in dynamic events.

Previous research has shown that humans rely on their prior knowledge about the causal relation between limb movements and body motions in perceiving human actions (Peng, Thurman, & Lu, 2017), as actions are perceived more natural if visual stimuli are in accordance with causal expectation for human body movements. Causal knowledge has also been shown to elicit false memories of body movements. Strickland and Keil (2011) found that implicit causal connections between agents and objects led to false memories of action frames that were never presented. For example, adults watched videos in which an actor kicked a ball, but the videos omitted the moment in which the actor actually contacted the ball. In a later recall task, participants falsely reported seeing the physical contact when the subsequent footage implied a causal relation between the actor's movements and the motion of the ball. Similarly, Bechlivanidis and Lagnado (2013, 2016) demonstrated that causal knowledge can induce false memories about the temporal order of events. Having a belief that event type A causes event type B made participants more likely to misremember sequences of observed events that violated those causal beliefs (i.e., when an event of type B temporally preceded an event of type A) than sequences that coincided with their causal belief.

These findings present compelling cases in which causal knowledge plays an influential role in consolidating memories about actions and events. In addition, work on causal binding has shown that causal knowledge biases the perception of time and space (Humphreys & Buehner, 2009, 2010; Buehner, 2012). For example, Buehner and Humphreys (2009) demonstrated that when one event is represented as causing another, the perceived time lapse between the two events appears shorter than when the two events are not causally related. This finding indicates that two causally related events are more likely to trigger the perception of spatiotemporal contiguity.

In the present paper, we test the hypothesis that the perceptual system uses prior knowledge about causal relations in actions to fill in missing information between static frames, yielding the subjective experience of smooth motion in human actions. We recorded videos of human-object interactions in a natural environment (a thrower directing a ball to a catcher). For short clips in which the catcher prepared to receive the ball, the frame rate was manipulated to introduce short and long inter-frame durations, defined as stimulus-onset-asynchrony (SOA). The duration of short SOAs was 33.3 ms/frame; that of long SOAs was 100 ms/frame. For causal actions, the facing direction of the catcher was maintained to generate a meaningful interaction consistent with a causal interpretation. For non-causal actions, the facing direction of the catcher was inverted to disrupt any meaningful interaction and generate an action sequence inconsistent with a causal interpretation. Participants were asked to judge whether the catcher's action showed smooth body movements or sudden changes. If causal knowledge in actions creates a top-down influence on interpolation of discrete pieces of motion information, observers will be more likely to perceive smooth actions when observing causal than non-causal actions. In addition, the predicted effect is expected to be stronger for long-SOA displays in which the visual inputs are sparse, with fewer image frames.

Experiment 1

Experiment 1 was designed to assess how a causal action between an agent and a physical object influences interpolation in the perception of smooth human actions. Causal actions were generated with an agent interacting with a moving object. Non-causal actions were generated with the same agent facing away from the moving object. We hypothesized that in the causal action condition, discretized human actions would be more likely to be perceived as smooth motion sequences.

Method

Participants

Fifty undergraduate students at UCLA (mean age = 21.1; 40 female) participated in the experiment for course credit. All experimental procedures were approved by the UCLA Office for Protection of Human Subjects. All participants had normal or corrected-to-normal vision.

Stimuli

Action videos were filmed in a gym using a camera with a temporal resolution of 30 frames/s. Two pairs of actors (one male pair and one female pair) were filmed. Each pair performed three throwing-catching actions (bounce pass, overhead pass, and chest pass), with each actor being the thrower once and catcher once. Seven video clips were selected as experimental stimuli. Sample video stimuli can be viewed at https://yujiapeng.com/causal-illusion-real.

In Experiment 1, only the catcher and the ball appeared in the video; the thrower was not shown. For each video, a short critical period was selected during which the catcher's arms showed the largest rising momentum during preparation to catch the ball. Each video lasted for 567 ms. There were 10 frames before the critical period, and 1 frame after the critical period. The critical period began when the catcher's arms started to rise, and it ended right before the actor's hands touched the ball. The duration of the critical period was 200 ms. In the long-SOA condition, only the first and the last frame of the catcher's body movements were presented, all the middle frames were omitted. The presentation duration of the first and the last frames were lengthened to cover half of the critical period at 100 ms per frame. In the short-SOA condition, all six frames showing body movements of the catcher were displayed, with the frame duration at 33.3 ms/frame. Note that the duration of the critical period was the same (200 ms) for both long-SOA and short-SOA displays. The movements of the ball were also the same and were kept intact in both long-SOA and short-SOA displays (Figure 1).

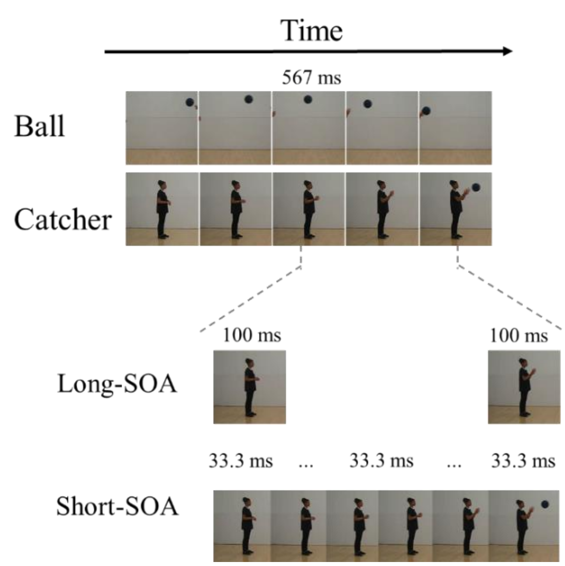

Figure 1. Illustrations of the critical clip in the long-SOA display with two frames (100 ms/frame) with a sudden posture change, and in the short-SOA display with six frames (33 ms/frame).

As shown in Figure 2, the causal condition showed the catcher facing toward the ball as the ball movement causes the catcher to move his or her body in preparation. To generate non-causal actions, image frames were processed using Matlab and Adobe Photoshop to horizontally reverse the facing direction of the catcher. The catcher was flipped horizontally to face away from the ball in the entire video, while keeping the background and the ball movement intact.

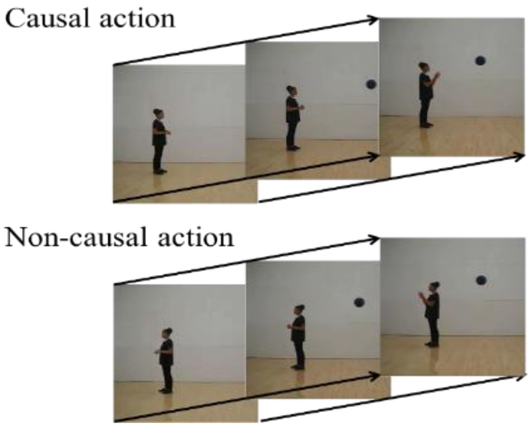

Figure 2. Sample frames of a causal action with the catcher facing towards the ball, and a non-causal action with the catcher facing away from the ball.

Procedure

Participants were seated 35 cm in front of a monitor with a 1024×768 resolution and 60 Hz refresh rate. All the stimuli were generated by MATLAB Psychtoolbox (Brainard, 1997). Participants were instructed, "You will view an actor playing sports (such as passing a basketball) with someone else who is occluded by a whiteboard. The task is to judge whether the catcher actor shows a smooth action or a non-smooth sudden posture change. For a smooth action, the actor smoothly moves from one posture to another. For a non-smooth action, the actor suddenly moves from one posture to another."

On each trial, a white fixation cross was presented at the center of the screen. Participants were asked to focus on the fixation cross throughout the experiment and to use their peripheral vision to see the video without making saccades. The center of the video was presented 13.7 degrees to the left or to the right of the fixation point with a height of 18 degrees. Showing the video in peripheral vision reduced the possibility that observers would track movements of the catcher without paying attention to other parts of the display. Half of the trials presented the video on the left of the fixation and the other half on the right. The catcher actor was always presented on the side relatively farther away from the fixation point. For example, if the video was presented on the right side, the ball flew from left to right and the catcher was located on the right side of the ball. After the video display, participants were asked to press one of two buttons to judge whether the video demonstrated actions with smooth body movements or sudden posture changes.

Participants were first presented with two blocks of practice trials to familiarize them with the task. In the practice blocks, participants saw "correct" on the screen plus a beep after each correct response, and saw "incorrect" without a beep after each incorrect response. Each practice block consisted of eight trials. A separate video was used as the stimulus for the practice block; this video was not presented in the test. In the first block of practice, videos were slowed down to show the entire video with the frame rate of 66.6 ms/frame and to display the critical period for 666 ms. This manipulation was intended to allow participants to become familiar with the experimental setting and to understand the difference between smooth motion and sudden posture changes in body movements. In the second block of practice trials, videos were presented at a frame rate of 33.3 ms/frames, and the duration of the critical period was 200 ms, as in the test session.

The test session followed the practice blocks. Test trials were identical to those in the second practice block with two exceptions: participants received no feedback on test trials, and test trials employed six new videos that were not used in practice blocks. A total of five test blocks were administered, each with 24 trials (causal/non-causal x long-/short SOA x 6 actions). In each block, the presentation order of videos was randomly shuffled. Proportions of responses in judging actions as smooth motion were recorded for each condition.

Results

We first examined the data in Block 1, as performance on subsequent blocks was likely to be affected by increased familiarity with the six videos used in the experiment. We conducted a 2 (SOA: short- vs. long-SOA) by 2 (causality: causal action vs. non-causal action) repeated-measures ANOVA on the proportion of responses judging the catcher's action as smooth motion. As shown in Figure 3a, results revealed a significant main effect of causal action, $F(1,49) = 4.742$, $p = .034$. Specifically, the proportion of "smooth" responses was significantly higher in the causal action condition in the long-SOA condition, in which the catcher faced towards the flying ball than in the non-causal action condition in which the catcher faced away from the ball ($t(49) = 2.243$, $p = .029$). This contrast was not significant in the short-SOA condition ($t(49) = 1.193$, $p = .239$), probably due to much less room of interpolation given the nature of smoothness of short-SOA videos. Note that the smooth motion signal was much weaker in the long-SOA display, since the stimulus included only two static postures with the largest spatial displacements. However, the causal relation between the ball and the body movements of the catcher enhanced interpolation between the two distinct postures, resulting in more misperception of sudden posture changes as smooth body movements. These results indicate that the effect of causality on motion interpolation emerged at the very beginning of the experiment. Not surprisingly, the main effect of the SOA was significant, $F(1,49) = 124.803$, $p < .001$, as short-SOA displays provided stronger motion signals with short inter-frame spatial displacements than did long-SOA displays. The two-way interaction effect between causality and SOA was not significant, $F(1,49) = .662$, $p = .42$.

(a)

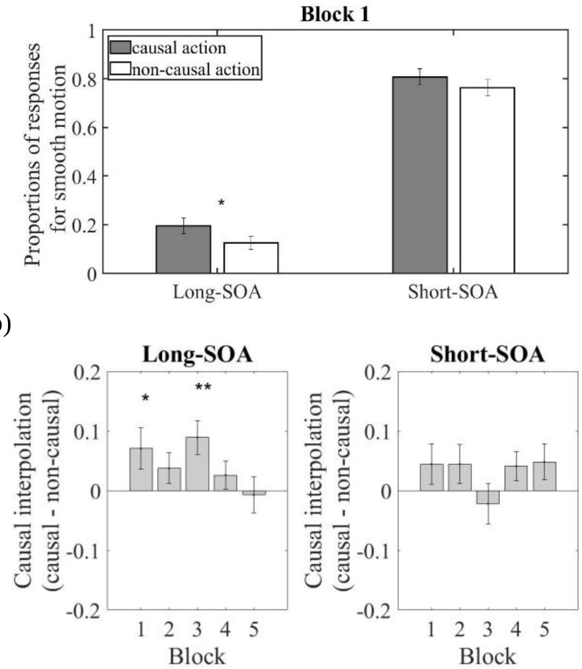

Figure 3. Results of Experiment 1. (a) Proportions of responses in block 1 judging the catcher's action as smooth motion. Asterisks indicate statistically significant differences between conditions (* $p < .05$, ** $p < .01$). (b) The difference between proportions of responses to causal and non-causal actions across 5 blocks in long- or short-SOA displays.

Results of the causal interpolation effect across 5 blocks were presented in Figure 3b. To investigate whether the impact of causal actions on motion interpolation was maintained across blocks despite increased familiarity with the six videos, we conducted a three-way repeated measures ANOVA with blocks as the third factor. We found a significant main effect of causal actions ($F(1,49) = 12.419$, $p = .001$), reflecting a larger proportion of "smooth" responses in the causal condition than non-causal condition. This result suggests that the facilitatory influence of causality on the perception of smooth movements was maintained, even with increased familiarity with the videos. However, this main effect was qualified by a significant three-way interaction ($F(4,196) = 2.815$, $p = .027$), reflecting a complex relation between familiarity and the influence of causal knowledge on the perceptual task. The block variable had a strong impact on responses in the long-SOA displays ($F(4,196) = 4.572$, $p = .001$), but a relatively weaker impact on short-SOA displays, for which the simple main effect of block was not reliable ($F(4,196) = 1.722$, $p = .15$). This pattern was likely the result of close-to-ceiling performance in perceiving smooth motion in the short-SOA displays.

Experiment 2

In Experiment 1, we found evidence that causal interactions between a catcher and the ball facilitated the perception of smooth movements. In Experiment 2, we investigated whether the effect could be generalized from human-object interactions to human-human interactivity. We predict that when the two agents show a causal relation connecting their movements (i.e. one agent throwing and one agent catching), observers will also be more likely to perceive smooth body movements.

Method

Participants

Forty-eight new UCLA students (mean age = 20.48; 33 female) participated in the experiment for course credit. All participants had normal or corrected-to-normal vision.

Stimuli and Procedure

The experiment employed the same basic videos as in Experiment 1, showing two actors pass balls. The stimuli included the body movements of the thrower and the catcher (Figure 4). A white occluder was presented at the center of the video to cover the movements of the ball. Depending on the actual duration of action sequences, the stimuli ranged from 633 ms to 1233 ms. There were 10 frames before the critical period, and 1 frame after the critical period. The duration of the critical period was 200 ms. In the instructions, participants were asked to respond to the movements of the catcher while paying attention to the entire video. The causal manipulation in Experiment 2 was the same as Experiment 1: the facing direction of the catcher was horizontally reversed to generate the non-causal condition. The procedure for Experiment 2 was the same as that for Experiment 1.

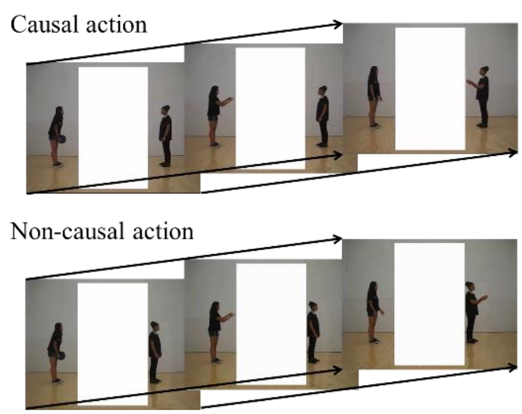

Figure 4. Sample frames of a causal action with the catcher facing towards the thrower, and a non-causal action with the catcher facing away from the thrower.

Results

As shown in Figure 5a, the proportion of smooth responses in Block 1 again revealed a significant main effect of causality ($F(1,47) = 9.874$, $p = .003$). Despite a longer temporal delay between the two actors' actions, the causal relation between the two actors' body movements impacted the visual experience of the catcher, as perceiving the catcher's movements elicited perception of more smooth and coherent motion. The proportion of smooth responses was significantly greater in the causal action condition compared to the non-causal action condition for the long-SOA condition (*t*(47) = 2.887, *p* = .006), but not for the short-SOA condition (*t*(47) = 1.681, *p* = .099). No interaction effect was found, *F*(1,47) = 0.407, *p* = .527. These results extended the pattern of causal effects observed in Experiment 1.

Results of the causal interpolation effect across 5 blocks were presented in Figure 5b. A three-way repeated measures ANOVA with blocks as the third factor showed a significant main effect of causal actions (*F*(1,47) = 6.508, *p* = .014), with a greater proportion of "smooth" responses in the causal condition than the non-causal condition. There was also a significant main effect of block (*F*(4,188) = 5.904, *p* < .001). Neither the two-way interactions nor the three-way interaction was reliable. In summary, the converging results from the two experiments indicate that the influence of causal action on motion interpolation persisted even with increased familiarity with the videos.

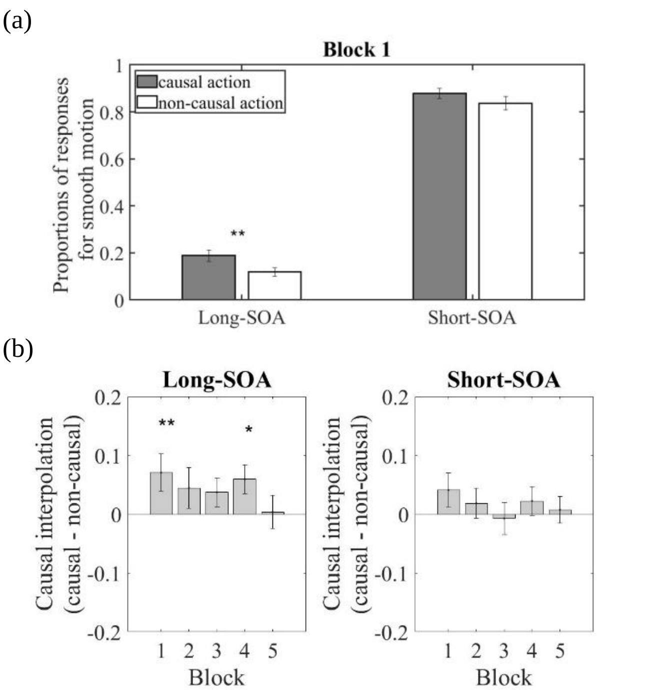

Figure 5. Results of Experiment 2. (a) Proportions of responses in block 1 judging the catcher's action as smooth motion (* *p* < .05, ** *p* < .01). (b) The difference between proportions of responses to causal and non-causal actions across 5 blocks in long- or short-SOA displays.

Experiment 3

Experiment 3 aimed to investigate whether the influence of causal actions on motion interpolation depends on other visual cues. Body orientation is a well-known cue for action recognition (Pavlova & Sokolov, 2000), as observers show worse recognition performance when actions are presented upside-down. If the interpolation effect revealed in the previous two experiments was induced by high-level causal knowledge, then inverting the video would *not* yield a significant difference between upright versus upside-down actions, since both cases preserve the temporal contingency and the causal relation between humans and objects.

Methods

Participants

Fifty-two new UCLA undergraduate students (mean age = 20.0; 43 female) participated in the experiment for course credit. All participants had a normal or corrected-to-normal vision.

Stimuli and Procedure

Experiment 3 used the same stimuli as the causal condition in Experiment 1. On half of the trials, the stimuli used inverted videos, and the other half used intact videos (Figure 6). The task and procedure of Experiment 3 were otherwise the same as in Experiment 1.

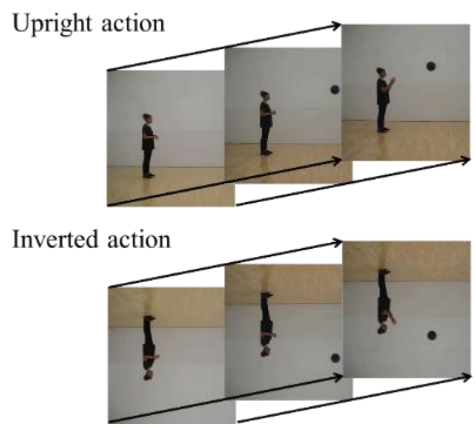

Figure 6. An illustration showing sample frames of an upright and an inverted action in Experiment 3.

Results

We first conducted a 2 (SOA: short- vs. long-SOA) by 2 (orientation: upright vs. inverted) repeated-measures ANOVA on the proportion of responses in Block 1 judging the catcher's action to be smooth motion. As shown in Figure 7a, the main effect of orientation was not significant (*F*(1,51) = 2.509, *p* = .119). The interaction between body orientation and SOA was also not significant (*F*(1,51) = 1.525, *p* = .222). The results from Block 1 suggest that as long as the causal relation is maintained in observed activities, body orientation does not affect the misperception of seeing smooth movements, even when the motion signals were weak (in the long-SOA displays).

Results of the causal interpolation effect across 5 blocks were presented in Figure 7b. To investigate whether the impact of body orientation on motion interpolation changed across blocks with increased familiarity with the six videos, we further conducted a three-way repeated measures ANOVA with blocks as the third factor. This analysis revealed a significant main effect of orientation (*F*(1,51) = 5.554, *p* =

.022). This main effect was largely driven by a significant difference between the upright and inverted conditions in later blocks. For example, in the final block (Block 5), a greater proportion of "smooth" responses was made in the upright conditions than the inverted conditions for the long-SOA condition ($t(51) = 2.139$, $p = .037$). This pattern suggests that the impact of body orientation on visual analysis of actions increased with familiarity of the stimuli.

(a)

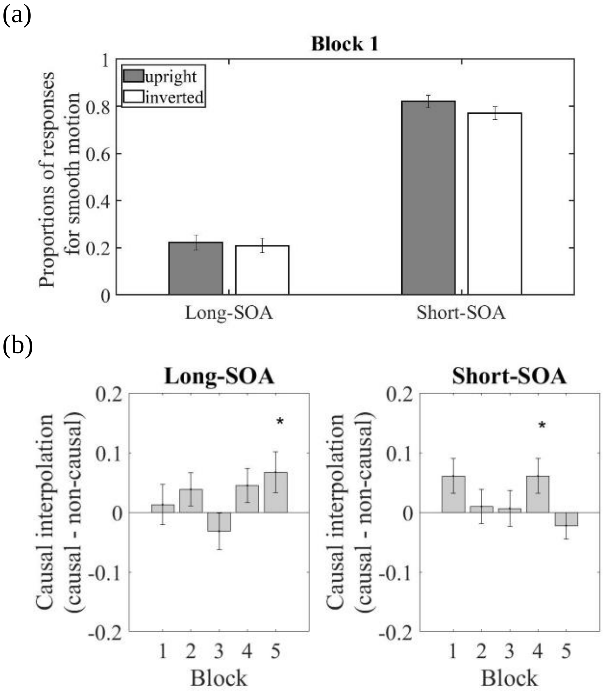

Figure 7: Results of Experiment 3. (a) Proportions of videos in block 1 judged as smooth actions (* $p < .05$, ** $p < .01$). (b) The difference between proportions of responses to causal and non-causal actions across 5 blocks in long- or short-SOA displays.

General Discussion

Apparent motion perception makes it possible to record movements of objects and humans by sampling the motion and displaying the samples as stationary pictures in sequence (e.g., videos, cinema). This study showed that a causal interaction between an agent and a physical object increased the likelihood that people would perceive smooth actions even when the stimuli showed a sudden change in long-SOA displays. This result suggests that causality acts as a temporal “glue” to fill in observers’ visual experience by interpolating discrete image frames to produce the perception of smooth, continuous motion. These results extended previous evidence that perception in physical causation helps to fill in important visual information left out from a sequence of events to social causal perception. The representation of an object’s implicit causal history has been shown to induce a transformational apparent motion (Tse, Cavanagh, & Nakayama, 1998) of simple objects (Chen & Scholl, 2016), akin to the “causal filling in” effect reported by Strickland and Keil (2011). A “causal filling in” mechanism could have benefitted from evolutionary selection pressure by aiding the continuous perception of animal motions despite occlusion by trees or other obstacles.

Causal knowledge about human body movements may not only help to connect discrete events in the perceptual process, but also may facilitate the process of making inferences and predictions about actions. A causal framework may help the visual system to infer the past. For example, human observers get a vivid feeling of seeing the immediate past of objects or human postures presented in static frames (Kourtzi, 2004). This phenomenon suggests that causal knowledge aids the visual system in inferring and reconstructing the causal history of objects and human actions. On the other hand, as earlier research on motion perception has suggested that the visual system anticipates the positions of simple objects based on their apparent motion trajectory (Freyd & Finke, 1984), more recent research has suggested that similar anticipatory visual processing is also affected by comparatively complex causal knowledge of human actions. For example, Su and Lu (2017) used skeletal biological motion displays and found a flash-lag effect, such that when a briefly-flashed dot was presented physically in perfect alignment with a continuously-moving limb, the flashed dot was perceived to lag behind the position of the moving joint. This finding suggests that the representation of human actions is anticipatory, due to a potential top-down action prediction mechanism. It has also been found that infants as young as five months are able to gaze toward the future direction implied by the static posture of a runner (Shirai & Imura, 2014, 2016), suggesting the early emergence in infancy of an ability to predict dynamic human actions from still pictures.

The present results demonstrated rapid effects of learning across blocks. Experiment 1 showed a significant three-way interaction between block, causality and SOA, suggesting an interaction between the top-down influence of causality and bottom-up perceptual processing of motion stimuli. The top-down influence of causality may be stronger in situations in which uncertainty about the visual input is high, such as when dynamic stimuli are presented in peripheral vision or embedded in noise. The effect may be weakened after repetitive exposures to the stimuli, as perceptual learning may enhance performance for visual tasks. These results are consistent with previous findings that causal perception can change upon repeated exposure of the same stimuli (Rolfs, Dambacher & Cavanagh, 2013).

In conclusion, the current study provides evidence of the important role played by causal knowledge in the perception of smooth motion. Causal relations involving human actions, and their interactions with objects and other agents, have a strong influence on motion perception for body movements. The causal relations involved in actions facilitate visual interpolation of discrete dynamic events to provide a continuous perception of human-involved activities. The top-down influence of knowledge about human actions interacts with bottom-up perceptual processes to enhance the robustness and efficiency in action perception (Lu, Tjan & Liu, 2006; Thurman & Lu, 2014) and intention inference (Shu et. al., 2018). Causal knowledge not only makes us see the future, but also fills in information about recent history.

Acknowledgments

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