Psychonomic Bulletin & Review (2022) 29:1803–1811
https://doi.org/10.3758/s13423-022-02106-z

BRIEF REPORT

Aesthetic preferences for causality in biological movements arise from visual processes

Yi-Chia Chen[1] · Frank Pollick[2] · Hongjing Lu[1]

Accepted: 13 April 2022 / Published online: 2 May 2022

Abstract
"People watching" is a ubiquitous component of human activities. An important aspect of such activities is the aesthetic experience that arises naturally from seeing how elegant people move their bodies in performing different actions. What makes some body movements look better than others? We examine how the human visual system gives rise to aesthetic experience from observing actions, using "creatures" generated by spatially scrambling locations of a point-light walker's joints. Observers rated how aesthetically pleasing and lifelike creatures were when the trajectories of joints were generated either from an upright walker (thus exhibiting gravitational acceleration) or an inverted walker (thus defying gravity), and were either congruent to the direction of global body displacements or incongruent (as in the moonwalk). Observers gave both higher aesthetic and animacy ratings for creatures with upright compared to inverted trajectories, and congruent compared to incongruent movements. Moreover, after controlling for animacy, aesthetic preferences for causally plausible movements (those in accord with gravity and body displacement) persisted. This systematicity in aesthetic impressions, even in the absence of explicit recognition of the moving agents, suggests an important role of automatic perceptual mechanisms in determining aesthetic experiences.

Keywords Aesthetics · Animacy · Causality · Action

Introduction

We see people every day, and many of us enjoy watching people. Whether through the internet, television, or in person, and whether it is a stranger or a friend, we frequently seek to view people. Previous research has often focused on the ability to recognize action and to identify the goals of these actions. However, the visual experience is often much richer: From observing others' movements, we form impressions about the person (e.g., smooth or awkward; Kadambi et al., 2020), and of the emotional states of the actors (Pollick et al., 2001). These impressions then influence how we interact with people we observe.

One aspect of such impressions, which is particularly powerful in influencing social interactions, concerns how attractive the potential interactive partner looks. Most research on attractiveness has focused on human faces and body shapes (Rhodes, 2006; Weeden & Sabini, 2005), examining the impact of basic facial features (Langlois & Roggman, 1990), waist-to-hip ratio (Singh, 1993), and modern modifications such as makeup (Etcoff et al., 2011) and plastic surgery (Singh & Randall, 2007). Yet it is unlikely that static appearances provide a complete picture of a person's attractiveness. Dynamic cues intuitively play an important role. For example, we may find a person to be attractive at first glance, only to later be disappointed by their awkward body movements; conversely, seeing someone move in an elegant manner may increase their attractiveness.

Aesthetic experience from human actions

What processes underlie aesthetic experiences with human body movements? The aesthetics of actions is often considered to be based on higher-level cognitive judgments (e.g., dance-style preferences and physical-health evaluations), or as fashions that differ across time and cultures (e.g., walking styles). Only a few studies have examined the role of perceptual

✉ Yi-Chia Chen
yichiachen@g.ucla.edu

1 Department of Psychology, University of California, Los Angeles, Los Angeles, CA, USA

2 School of Psychology and Neuroscience, University of Glasgow, Glasgow, UK

features in perceived attractiveness of actions, which focused on specialized art forms such as dances (Christensen & Calvo-Merino, 2013; Christensen et al., 2016), and sexual dimorphism in walking styles (Morris et al., 2013; Provost et al., 2008). These studies have begun to identify perceptual features linked to attractiveness; however, it remains unknown *how* these perceptual features influence aesthetic experiences. In the present study, we examined two alternative hypotheses: Do perceptual processes only serve to provide inputs to higher-level aesthetic judgments (which may evaluate perceptual features in conjunction with prior knowledge or experience; Orlandi et al., 2020)? Or do perceptual processes themselves play a role in giving rise to aesthetic experiences?

Aesthetic experiences arising from viewing specialized movements, such as dance performances, may differ not only quantitatively but also qualitatively from those that arise from watching other people's daily actions. Accordingly, rather than further investigating such specialized movements, the present study focused on aesthetic experiences that arise when viewing the most basic type of biological motion: walking. To assess whether such experiences arise from visual processing itself, rather than higher cognitive processes, we isolated the effect of visual processes involved in viewing body movements from the influences of prior knowledge and static appearances of the walkers. In particular, we created point-light "creatures" by spatially scrambling initial locations of joints in a point-light walker, while maintaining the same trajectories for each individual point-light (Fig. 1; demonstration videos can be viewed at https://ycc.vision/Demo/ani-aes/). Consistent with the previous literature (Chang & Troje 2008; Pyles et al., 2007; Thurman & Lu 2014; Troje & Westhoff, 2006), the use of these stimuli prevents observers from recognizing human walkers or any specific existing animals, and thus prevents them from accessing prior experience regarding specific body forms and human actions. The perceptual nature of point-light display processing was further supported by the lack of influences from instructions (Pavlova & Sokolov, 2003). It is also likely that these processes are innate, as they are evident in both human newborns and newly hatched chicks: Human newborns prefer to look at point-light biological movements (Simion et al., 2008), and newly hatched chicks exhibit a spontaneous preference toward biological movements of a predator (cat) (Vallortigara et al., 2005).

In the two experiments reported here, we tested the possible roles in forming aesthetic experiences played by two kinds of perceptual processes related to motion: general motion perception and the specialized processes of biological motion perception. To tease apart their respective contributions, we measured both people's aesthetic experiences and perception of animacy when viewing the point-light creatures, while manipulating a feature that has been shown to influence both kinds of motion perception — causality (Chen & Scholl, 2016; Thurman & Lu, 2013; Troje & Westhoff, 2006).

Experiment 1: Causal links with gravity

Living under the constant pull of gravity, humans are especially sensitive to visual features of biological movements that indicate their causal links with gravity. Previous

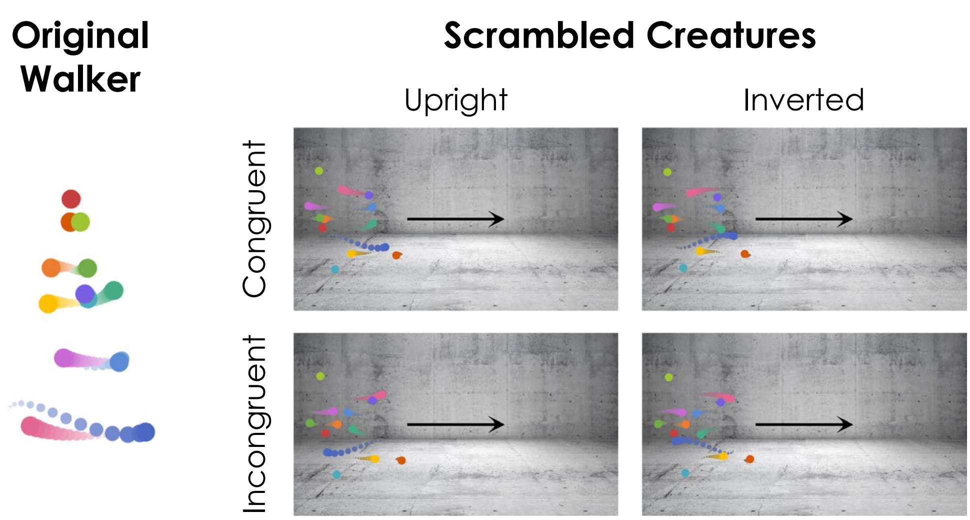

Fig. 1 Schematic illustrations of creature generation by spatial scrambling of initial positions of point-lights, and transformations introduced for different experimental conditions (all dots in the actual displays were presented in black and without trailing traces). To view the example videos, visit https://ycc.vision/Demo/ani-aes/

research suggests that humans use so-called "life detectors" to identify living creatures based on the specific profiles of feet movements caused by gravitational acceleration (e.g., feet accelerate faster downward than upward; Chang & Troje, 2008; Troje & Westhoff, 2006). Here, we tested whether this important perceptual feature informs aesthetic experience at the level of perceptual processing by inverting the joint trajectories of point-light creatures, thereby breaking their causal links with gravity.

Method

Participants

A convenience sample of 40 naive observers (28 females, 11 males, and one other gender; all with normal or corrected-to-normal vision) from the University of California, Los Angeles (UCLA) community completed an individual 20-min session online in exchange for course credit. An additional nine observers participated but were removed based on predetermined criteria (see details in Observer exclusions). The sample size was predetermined based on informal pilot experiments, and the replication in Experiment 2 confirmed that this sample size provided sufficient power to detect relevant effects. The study was approved by the UCLA Institutional Review Board.

Stimuli

Because the stimuli were rendered on observers' own web browsers, viewing distance, screen size, and display resolutions could vary dramatically; hence we report visual stimulus dimensions using pixel (px) values. Forty point-light creatures were made from a single point-light walker (walking toward the right of the viewer) taken from the CMU Motion Capture Database (http://mocap.cs.cmu.edu/). Using Biomotion Toolbox (van Boxtel & Lu, 2013), 13 joint trajectories were extracted (head, shoulders, hips, elbows, hands, knees, and ankles) from a 2-s walking clip. The global motion was removed (thus the walker appeared to be walking on a treadmill facing to the right of the viewer). For 20 creatures in the upright condition, we randomly scrambled the initial position of the joints within a square bounding box of the walker (250 px × 250 px), with the constraint that none of the joints ever moved out of the bounding box during their 2-s movements. The other 20 creatures in the inverted condition were made by inverting the trajectories of the upright creatures. We first identified the vertical center of each joint's bounding box by averaging the max and min y positions that the joint reached during the 2-s movements. We then locally flipped each trajectory upside-down by its vertical center. In this way, the inverted creatures followed inverted trajectories that defied gravity yet retained the same global shape as the corresponding upright creatures. Although this stimulus manipulation is subtle (as one can appreciate directly by looking at the stimuli here: https://yi-chia-chen.github.io/BM-aes-demo-expt/), previous studies have demonstrated that trajectory inversion in the spatially scrambled point-light display influences perceptual judgments such as animacy rating (Chang & Troje, 2008; Thurman & Lu, 2013) and facing direction discrimination (Troje & Westhoff, 2006). In addition, prior knowledge about stimulus orientation has no effect on processing inverted biological motion stimuli (Pavlova & Sokolov, 2003). Besides the evidence from the literature, the lack of influence from explicit knowledge can also be intuitively appreciated from looking at the stimuli: The inversion of trajectories is extremely hard to discern and thus is unlikely to engage higher-level cognitive processes. Thus, by using point-light creatures with inverted trajectories, we are probing perceptual effects of the gravitational acceleration cues, rather than effects of any prior knowledge of gravity.

Each of the 40 creatures were made into a 2-s video (800 px × 450 px) showing it move from left to right at a constant speed (250 px/s; Fig. 1). The joints appeared as black dots (12 px in diameter) against a realistic static background.

Procedure

Observers were directed to a website where stimulus presentation and data collection were controlled via custom software written in HTML, CSS, JavaScript, and PHP. Observers were not allowed to participate using phones or tablets. The experiment included two blocks with a fixed order of tasks, aesthetic rating block then animacy rating block. These blocks were followed by debriefing questions. In both rating blocks, the observers were shown 80 experimental trials after two practice trials. In each block all 40 videos were shown in random order, followed by a repeat of all videos in a different random order. On each trial, observers rated their impression of aesthetics or animacy, using a 6-point scale (certainly not pleasing/lifelike, probably not pleasing/lifelike, guess not pleasing/lifelike, guess pleasing/lifelike, probably pleasing/lifelike, certainly pleasing/lifelike). Observers were allowed to respond only after the video had finished playing. After completing both rating blocks, observers answered a series of debriefing questions to ensure they had completed the experiment without any issues. The experiment took about 15 min to complete. The data were recorded as text files and analyzed with both Microsoft Excel and customized Python code (using the pandas library).

Observer exclusions

Nine observers were excluded based on criteria decided before data collection began, with some observers triggering more than one criterion: Three observers reported that they did not understand the instructions or did not take the experiment seriously; one observer had a browser viewport smaller than 800 × 600 px; two observers gave the same rating to more than 15 consecutive trials; one observer hid the experiment browser tab more than three times during the trials; and three observers took too long to complete the experiment (two SDs longer from the mean duration from all observers before exclusions).

Analysis and results

Causality influences both aesthetic and animacy impressions

Observers' aesthetic and animacy ratings for creatures with upright and inverted trajectories were averaged, respectively. Gravitational acceleration cues were present in the upright creatures (consisting of joint trajectories from an upright walker), but absent in the inverted creatures (consisting of joint trajectories from an inverted walker). The results are depicted in Fig. 2a. Paired t-tests were used to compare the aesthetic ratings for upright and inverted creatures, as well as to compare animacy ratings for upright and inverted creatures. We found effects of gravitational acceleration on both aesthetic and animacy impressions: Upright creatures appeared both more aesthetically pleasing and more lifelike than inverted creatures (aesthetic: 3.6 ($SD = 1.3$) vs. 3.4 ($SD = 1.3$), $t(39) = 3.73$, $p = 0.001$, $d = 0.59$; animacy: 3.6 ($SD = 1.4$) vs. 3.4 ($SD = 1.4$), $t(39) = 3.83$, $p < 0.001$, $d = 0.61$; all instances of d stand for Cohen's d in this report).

Specialized biological motion perception plays a role in aesthetic impressions

Is relative positivity in aesthetic experience associated with increased engagement of specialized processes for biological movements? We calculated correlations between aesthetic and animacy ratings across videos for each observer (after averaging the two ratings from the two presentations of each video). The correlations were computed using ratings from upright or inverted creatures. One-sample t-tests were used to test whether these correlations between aesthetic and animacy ratings were significantly different from zero. We found significant positive correlations between aesthetic and animacy impressions for upright and inverted creatures (upright: $M_r = 0.27$ ($SD_r = 0.26$), $t(39) = 6.65$, $p < 0.001$, $d = 1.05$; inverted: $M_r = 0.18$ ($SD_r = 0.25$), $t(39) = 4.48$, $p < 0.001$, $d = 0.71$). Importantly, as shown in Fig. 2b, the correlations between aesthetic ratings and animacy ratings were stronger in upright than in inverted creatures, as demonstrated with a paired t-test (upright vs. inverted: $M_{diff} = 0.09$ ($SD_{diff} = 0.27$), $t(39) = 2.18$, $p = 0.035$, $d = 0.35$).

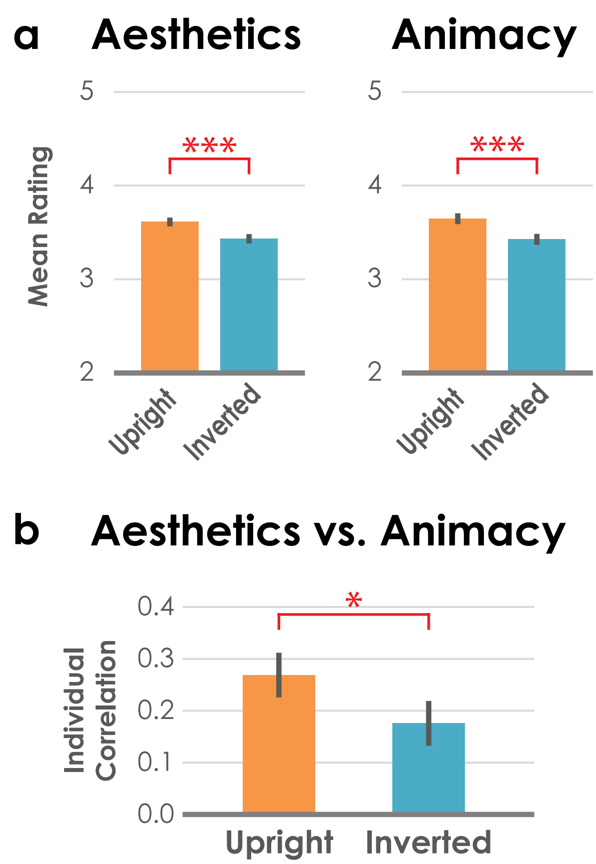

Fig. 2 Results of Experiment 1: (**a**) Mean aesthetic and animacy ratings for upright and inverted creatures (y-axis is cropped from the full rating scale of 1–6 to 2–5 for clarity); (**b**) Correlation between aesthetic and animacy ratings for upright and inverted conditions. All error bars are within-subject 95% confidence intervals (computed after subtracting individual overall means from the individual's means in both conditions)

Thus, a stronger impression of animacy for the creatures (suggesting higher engagement of biological motion perception) co-occurred with more positive aesthetic experiences, and this relationship was stronger when joints of the creatures moved in accord with gravity.

General motion perception plays a role as well

Are there independent effects of gravitational acceleration cues on aesthetic experiences beyond those associated with animacy perception? To answer this question, we regressed out the animacy z-scores from aesthetic z-scores for each observer and performed a paired t-test on the residuals between upright and inverted conditions. After removing the impact of animacy, upright creatures were still more aesthetically pleasing than inverted creatures ($t(39) = 3.25$, $p = 0.002$, $d = 0.51$), suggesting a general effect of gravitational cues on aesthetic impressions beyond cues rooted in specialized processes for detecting animacy.

Discussion

The results of Experiment 3 revealed that causal cues related to gravity can influence aesthetic impressions of movements through both specialized mechanisms that underlie perception of animate agents and general mechanisms that are sensitive to the physical regularities relating gravity to object motion. Moreover, given the subtlety of the gravitational cues and the novelty of the scrambled creatures, these effects appear to be driven by visual systems alone, rather than relying on higher-order knowledge about actions.

Experiment 2: Causal links with propelling forces

How agents move is jointly determined by multiple causal factors besides gravity. For example, humans move their limbs in certain ways to generate propelling forces through surface friction, which in turns leads to displacements of the body. This congruency between relative limb movements and global body displacements is another important causal cue to biological movements (Peng et al., 2017; Thurman & Lu, 2016). Does this causal aspect of biological motion also influence aesthetic experience?

Method

The method of Experiment 2 was identical to that of Experiment 1 except as noted below. In addition to the gravity factor, we manipulated congruency of the creatures' global motion. Forty creatures with trajectories congruent to their global horizontal motion were generated in the same way as in Experiment 1. Another 40 creatures were created to show incongruent trajectories to their global horizontal motions by locally flipping each joint trajectory horizontally along the horizontal center of its bounding box (the average of minimum and maximum x positions for each joint throughout the 2-s video). In this way, the global forms of the creatures were fixed across all four conditions, while gravitational cues and congruency to global motion varied independently (see Fig. 1). The experiment involved two sessions, which were done within one week of each other and took an average of 18 min per session. Observers rated the videos in terms of their aesthetic appeal in the first session, and animacy in the second session. In both sessions, the 80 videos were first shown in a random order after two practice trials, and then repeated in a different random order. A self-paced break was allowed halfway through each session.

A convenience sample of 80 naive observers (62 females, 17 males, and one undisclosed) from the UCLA community completed the experiment. The sample size was selected before data collection started and was doubled from Experiment 3 to allow enough power to detect interaction effects. An additional 65 observers participated and were removed based on predetermined criteria, with some observers triggering more than one criterion: Six observers did not complete the second session; three encountered a technical difficulty during the experiment; six observers failed the instructions quiz more than once; 26 observers reported that they did not follow the instructions or did not take the experiment seriously; six observers spent less than 0.5 s to read at least one page of the instructions; four observers had a browser viewport smaller than 800 × 600 px; 14 observers gave the same rating on more than 15 consecutive trials; four observers hid the experiment browser tab more than three times during the trials; two observers gave a nonsensical response to one of the debriefing questions; and four observers took too long to complete at least one session of the experiment (two standard deviations (SDs) longer than the mean duration across all observers before exclusions).

Analysis and results

Causality influences both aesthetic and animacy impressions

Observers' mean aesthetic and animacy ratings for the four conditions are depicted in Fig. 3a. Inspection of this figure reveals two clear patterns: First, upright creatures appeared more aesthetically pleasing and animate than those that

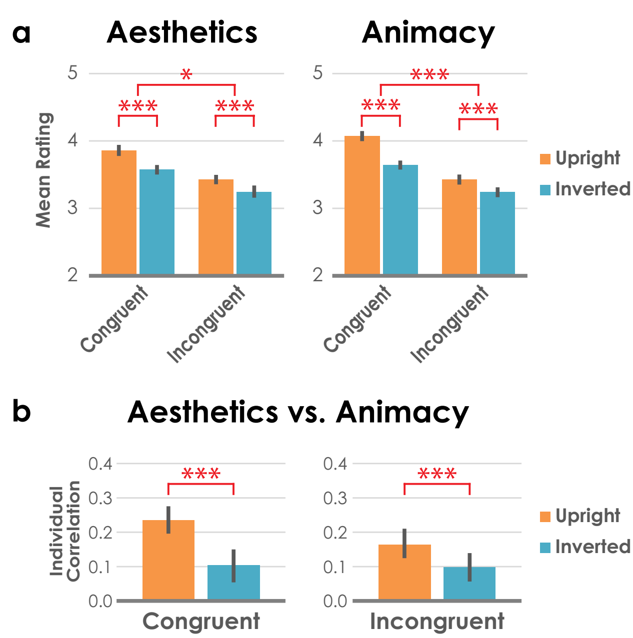

Fig. 3 Results of Experiment 2: (**a**) Mean aesthetic and animacy ratings (y-axis is cropped from the full rating scale of 1–6 to 2–5 for clarity); (**b**) Correlation between aesthetic and animacy ratings in four conditions

were inverted. Second, creatures with congruent motion appeared more aesthetically pleasing and animate than creatures with incongruent motion. Both of these observations were confirmed by significant main effects, in the context of significant interaction effects from two 2 (gravity) × 2 (congruency) repeated-measures ANOVAs for aesthetic and animacy ratings respectively: In aesthetic ratings, there was a main effect of gravity (3.6 ($SD = 0.5$) vs. 3.4 ($SD = 0.5$), $F(1,79) = 59.24$, $p < 0.001$, $\eta^2_p = 0.429$; all instances of η^2_p stand for partial eta squared in this report), replicating the result in Experiment 3 of higher aesthetics rating for creatures with upright trajectories than creatures with inverted trajectories. The result also revealed a main effect of congruency to global motion (3.7 ($SD = 0.5$) vs. 3.3 ($SD = 0.6$), $F(1,79) = 32.36$, $p < 0.001$, $\eta^2_p = 0.291$), showing higher aesthetic rating for congruent movements than for incongruent movements. In addition, we found a significant interaction effect ($F(1,79) = 5.40$, $p = 0.023$, $\eta^2_p = 0.064$) as well as significant simple main effects of both gravity and congruency to global motion (ts > 4.7, ps < 0.001, ds > 0.53), showing that the effects of these two causal factors are synergistic. Similarly, in animacy ratings, there was a main effect of gravity (3.7 ($SD = 0.4$) vs. 3.4 ($SD = 0.5$), $F(1,79) = 114.98$, $p < 0.001$, $\eta^2_p = 0.593$), a main effect of congruency to global motion (3.9 ($SD = 0.5$) vs. 3.3 ($SD = 0.5$), $F(1,79) = 73.06$, $p < 0.001$, $\eta^2_p = 0.480$). In addition, we found a significant interaction effect ($F(1,79) = 19.38$, $p < 0.001$, $\eta^2_p = 0.197$) as well as significant simple main effects of both gravity and congruency to global motion were significant (ts > 4.4, ps < 0.001, ds > 0.49), showing the synergy between the effects of causal cues associated with gravity and propelling forces on animacy perception.

Specialized biological motion perception plays a role in aesthetic impressions

To examine the role of animacy perception in aesthetic experience, we calculated correlations for individual videos between aesthetic and animacy ratings for each observer, in the same way as in Experiment 1. The results are depicted in Fig. 3b. Positive correlations were obtained between aesthetic and animacy impressions in all conditions (upright-congruent: $M_r = 0.23$ ($SD_r = 0.22$), $t(79) = 9.47$, $p < 0.001$, $d = 1.06$; upright-incongruent: $M_r = 0.17$ ($SD_r = 0.23$), $t(79) = 6.55$, $p < 0.001$, $d = 0.73$; inverted-congruent: $M_r = 0.10$ ($SD_r = 0.25$), $t(79) = 3.65$, $p < 0.001$, $d = 0.41$; inverted-incongruent: $M_r = 0.10$ ($SD_r = 0.24$), $t(79) = 3.54$, $p = 0.001$, $d = 0.40$). We found a main effect of gravity in a 2 (gravity) × 2 (congruency) repeated-measures ANOVA, as the correlation between aesthetics and animacy was stronger in the upright than the inverted condition ($F(1,79) = 16.39$, $p < 0.001$, $\eta^2_p = 0.172$), replicating the comparable finding in Experiment 1. Neither the main effect of motion congruency nor the interaction between the two factors were significant ($ps > 0.14$, $\eta^2_p < 0.030$). Thus, when the creatures looked more alive, aesthetic experiences became more positive, and this relationship was stronger when the creatures moved in accord with gravity (regardless of congruency with global motion). Again, this pattern suggests a role of specialized mechanisms for seeing biological motion in determining aesthetic experiences.

General motion perception plays a role as well

Do gravity and congruency information independently influence aesthetic experience beyond their effects on animacy perception? To answer this question, we regressed out the animacy z-scores from aesthetic z-scores for each observer and performed a 2 (gravity) × 2 (congruency) repeated-measures ANOVA on the residuals. Both main effects of gravity and congruency persisted (gravity: $F(1,79) = 39.42$, $p < 0.001$, $\eta^2_p = 0.333$; congruency: $F(1,79) = 18.39$, $p < 0.001$, $\eta^2_p = 0.189$). However, the interaction effect was diminished ($p = 0.345$, $\eta^2_p = 0.011$). The significant main effects of gravity and congruency after regressing out animacy ratings reveal a general influence of causality on aesthetic impressions that is not rooted in specialized processes for detecting animacy, but rather is based on general motion perception.

Discussion

The results of Experiment 2 thus replicated the effect of causal cues related to gravity identified in Experiment 1, and in addition identified an effect of causal cues related to propelling forces. These causal cues again influenced aesthetic impressions through both specialized biological motion processing and general motion processing.

General discussion

The present study used a paradigm to minimize the impact of high-level knowledge on aesthetic experience, and demonstrated that systematic aesthetic preferences based on causality can arise from perceptual mechanisms. Specifically, we investigated the role of perceptual processing in determining aesthetic experiences triggered by watching actions of animate creatures. Three major results were obtained using spatially scrambled "creatures". First, visual features indicating causal links based on gravity and propelling forces impact not only animacy perception but also aesthetic experiences. Creatures that move in a natural causal manner are perceived to be more aesthetically pleasing than creatures that do not conform to expectations based on physical causality. Second, creatures that look more alive appear more aesthetically pleasing. Third, specific processes tuned to biological motion and general perceptual processes both contribute to aesthetic preferences, and these effects emerge at the level of perceptual processing.

Aesthetic experience based on animacy perception

A simple explanation of a preference for animate and causal movements can be provided by fluency theory (Reber et al., 2004): Movements that look more animate may be processed more fluently (compare to those that look less animate) because the specialized processes for perceiving biological motion are highly efficient and have been optimized over either a long evolutionary history or lifelong visual experiences. Given that the causal cues for gravity and propelling forces are strongly associated with animacy perception (Chang & Troje, 2008; Thurman & Lu, 2013), causal movements may be processed more fluently as well. Greater perceptual fluency may lead to a positive aesthetic experience, either serving as an internal reward for successful recognition of the stimuli, or due to misinterpretations of the positive affect arising from fluent processing as positive evaluations of the stimuli.

An alternative explanation interprets the variations in aesthetic experience in the opposite direction, as aversion of non-causal movements. Such an aversion might be functional, as specialized processes for perceiving biological motion of animate agents are useful for detecting potentially dangerous animals or harmful conspecifics, finding suitable mates, and generating effective social interactions. Detecting animate agents that move in unusual ways may indicate that they are from an unknown species that could be aggressive, are unhealthy individuals that may spread diseases, or are devious social agents with ill intentions. Thus, a negative aesthetic experience triggered by seeing biological movements with deviant patterns may aid in avoidance of potential dangers.

Note that it is important to consider what seeing "non-causal" movements might mean in the real world. Unlike on computer screens, real agents relentlessly follow the laws of physical causality, so that non-causal movements cannot really exist. In response to events that seemingly do not follow physical rules, humans often infer unobservable causes (Little & Firestone, 2021). This may happen in the context of negative aesthetic experience based on "non-causal" movements. For an animal to be moving in seemingly non-causal ways, there must be unobserved external or internal forces that are influencing the movements, in addition to gravity and propelling forces. For example, a "sneaky" agent may exert extra forces to cancel out the expected effect of gravity. An aversion for "non-causal" movements might actually be an aversion for such inferred extra forces and their implications.

Aesthetic experience based on general motion perception

Besides perception of animacy, other perceptual processes are also sensitive to physical regularities, including causality (Chen & Scholl, 2016; Peng et al., 2017), gravity (Battaglia et al., 2013; Hubbard, 2020), and other physical forces (Little & Firestone, 2021). These processes are very effective in making predictions about physical environments based on dynamic information (even in infants; Baillargeon & Hanko-Summers, 1990), and thus support interaction with the physical world. In fact, in the predictive coding framework, the major function of perception is to enable accurate predictions by updating a perceiver's hypotheses about the world through prediction errors generated during actual experience (Rao & Ballard, 1999). Thus, in addition to the fluency effect, a positive aesthetic experience associated with causal expectations of dynamic movements may actually be functional, serving to strengthen correct hypotheses about the physical world.

The role of thinking

While the present study focuses on the impact of animacy and causal perception on aesthetic experiences, we would emphasize that by no means does our study rule out contributions from higher-level cognition. As suggested by previous studies, higher-level appraisals can modulate experiences in ways that would not have arisen solely from perceptual information (Reber et al., 2004). It is even possible that most aesthetic experiences are better explained by higher-level judgments. A salient example is the famous "moonwalk" dance move, in which the dancer performs walking movements that are incongruent with their body displacements (so that they appear to be magically sliding backward). This dance move is popular and interesting to watch, potentially because it challenges both our perceptual predictions and conscious expectations from knowledge of physics. Aesthetic pleasure from dance moves might also arise from a depth of explicit knowledge about how the movements are achieved, their biomechanics, the years of practice required to learn them, and their special place in history (Cross et al., 2011; Orlandi, Cross, & Orgs, 2020). Such high-level judgments might even override perceptual evaluations. Thus, in those cases, only when knowledge access is blocked (as with the spatially scrambled creatures used in the present study) will perceptual contributions be clearly revealed. These kinds of aesthetic experiences that are based on high-level judgments (e.g., in artistic contexts) may differ in intensity and nature from those triggered by scrambled creatures that simply "look good" (Brielmann & Pelli, 2017). By focusing on the role of *seeing*, the complementary approach introduced in the present study may contribute to identifying potential evolutionary functions of aesthetics, providing at least part of the answer to the question, "Why do we like what we like?".

Open Practices Statement All stimuli, raw data, and experiment and analysis code can be accessed via the Open Science Framework at: https://doi.org/10.17605/OSF.IO/WTSRF. A demonstration of the experiments can be viewed online at: https://yi-chia-chen.github.io/BM-aes-demo-expt/.

Acknowledgements For helpful conversations, we thank Felix Chang, Clara Colombatto, Christine Massey, Rebecca Smith, and the members of the UCLA Computational Vision and Learning Laboratory and Human Perception Laboratory. This project was funded by NSF BSC-1655300 awarded to HL.

Author contributions All authors designed the research and wrote the manuscript. Y.-C. Chen prepared the materials with inputs from H. Lu and F. Pollick. Y.-C. Chen conducted the experiments. Y.-C. Chen and H. Lu analyzed the data.

References

Baillargeon, R., & Hanko-Summers, S. (1990). Is the top object adequately supported by the bottom object? Young infants' understanding of support relations. *Cognitive Development, 5*, 29–53.

Bardi, L., Regolin, L., & Simion, F. (2014). The first time ever I saw your feet: Inversion effect in newborns' sensitivity to biological motion. *Developmental Psychology, 50*, 986–993.

Battaglia, P. W., Hamrick, J. B., & Tenenbaum, J. B. (2013). Simulation as an engine of physical scene understanding. *Proceedings of the National Academy of Sciences, 110*, 18327–18332.

Brielmann, A. A., & Pelli, D. G. (2017). Beauty requires thought. *Current Biology, 27*, 1506–1513.

Chang, D. H., & Troje, N. F. (2008). Perception of animacy and direction from local biological motion signals. *Journal of Vision, 8*(5):3, 1–10.

Chen, Y.-C., & Scholl, B. J. (2016). The perception of history: Seeing causal history in static shapes induces illusory motion perception. *Psychological Science, 27*, 923–930.

Christensen, J. F., & Calvo-Merino, B. (2013). Dance as a subject for empirical aesthetics. *Psychology of Aesthetics, Creativity, and the Arts, 7*, 76–88.

Christensen, J. F., Pollick, F. E., Lambrechts, A., & Gomila, A. (2016). Affective responses to dance. *Acta Psychologica, 168*, 91–105.

Cross, E. S., Kirsch, L., Ticini, L. F., & Schütz-Bosbach, S. (2011). The impact of aesthetic evaluation and physical ability on dance perception. *Frontiers in Human Neuroscience, 5*(102), 1–10.

Cutting, J. E. (2002). Representing motion in a static image: Constraints and parallels in art, science, and popular culture. *Perception, 31*, 1165–1193.

Etcoff, N. L., Stock, S., Haley, L. E., Vickery, S. A., & House, D. M. (2011). Cosmetics as a feature of the extended human phenotype: Modulation of the perception of biologically important facial signals. *PLoS ONE, 6*(e25656), 1–9.

Fink, B., Weege, B., Neave, N., Pham, M. N., & Shackelford, T. K. (2015). Integrating body movement into attractiveness research. *Frontiers in Psychology, 6*(220), 1–6.

Hubbard, T. L. (2020). Representational gravity: Empirical findings and theoretical implications. *Psychonomic Bulletin & Review, 27*, 36–55.

Kadambi, A., Ichien, N., Qiu, S., & Lu, H. (2020). Understanding the visual perception of awkward body movements: How interactions go awry. *Attention, Perception, & Psychophysics, 82*, 2544–2557.

Langlois, J. H., & Roggman, L. A. (1990). Attractive faces are only average. *Psychological Science, 1*, 115–121.

Little, P. C., & Firestone, C. (2021). Physically implied surfaces. *Psychological Science, 32*, 799–808.

Miura, N., Sugiura, M., Takahashi, M., Sassa, Y., Miyamoto, A., Sato, S., …, Kawashima, R. (2010). Effect of motion smoothness on brain activity while observing a dance: An fMRI study using a humanoid robot. *Social Neuroscience, 5*, 40–58.

Morris, P. H., White, J., Morrison, E. R., & Fisher, K. (2013). High heels as supernormal stimuli: How wearing high heels affects judgements of female attractiveness. *Evolution and Human Behavior, 34*, 176–181.

Muth, C., Raab, M. H., & Carbon, C. C. (2015). The stream of experience when watching artistic movies Dynamic aesthetic effects revealed by the Continuous Evaluation Procedure (CEP). *Frontiers in Psychology, 6*(365), 1–13.

Orlandi, A., Cross, E. S., & Orgs, G. (2020). Timing is everything: Dance aesthetics depend on the complexity of movement kinematics. *Cognition, 205*, 104446.

Palmer, S. E., & Langlois, T. A. (2017). Effects of implied motion and facing direction on positional preferences in single-object pictures. *Perception, 46*, 815–829.

Pathak, D., Agrawal, P., Efros, A. A., & Darrell, T. (2017). Curiosity-driven exploration by self-supervised prediction. In D. Precup & Y. W. Teh (Eds.), *Proceedings of the 34th International Conference on Machine Learning* (pp. 2778–2787). PMLR.

Pavlova, M., & Sokolov, A. (2003). Prior knowledge about display inversion in biological motion perception. *Perception, 32*, 937–946.

Peng, Y., Thurman, S., & Lu, H. (2017). Causal action: A fundamental constraint on perception and inference about body movements. *Psychological Science, 28*, 798–807.

Pollick, F. E., Paterson, H. M., Bruderlin, A., & Sanford, A. J. (2001). Perceiving affect from arm movement. *Cognition, 82*, B51–B61.

Provost, M. P., Troje, N. F., & Quinsey, V. L. (2008). Short-term mating strategies and attraction to masculinity in point-light walkers. *Evolution and Human Behavior, 29*, 65–69.

Pyles, J. A., Garcia, J. O., Hoffman, D. D., & Grossman, E. D. (2007). Visual perception and neural correlates of novel 'biological motion.' *Vision Research, 47*, 2786–2797.

Rao, R. P., & Ballard, D. H. (1999). Predictive coding in the visual cortex: A functional interpretation of some extra-classical receptive-field effects. *Nature Neuroscience, 2*, 79–87.

Reber, R., Schwarz, N., & Winkielman, P. (2004). Processing fluency and aesthetic pleasure: Is beauty in the perceiver's processing experience? *Personality and Social Psychology Review, 8*, 364–382.

Rhodes, G. (2006). The evolutionary psychology of facial beauty. *Annual Review of Psychology, 57*, 199–226.

Singh, D. (1993). Adaptive significance of female physical attractiveness: Role of waist-to-hip ratio. *Journal of Personality and Social Psychology, 65*, 293–307.

Singh, D., & Randall, P. K. (2007). Beauty is in the eye of the plastic surgeon: Waist–hip ratio (WHR) and women's attractiveness. *Personality and Individual Differences, 43*, 329–340.

Simion, F., Regolin, L., & Bulf, H. (2008). A predisposition for biological motion in the newborn baby. *Proceedings of the National Academy of Sciences, 105*, 809–813.

Thakral, P. P., Moo, L. R., & Slotnick, S. D. (2012). A neural mechanism for aesthetic experience. *NeuroReport, 23*, 310–313.

Thornton, I. M., & Vuong, Q. C. (2004). Incidental processing of biological motion. *Current Biology, 14*, 1084–1089.

Thurman, S. M., & Lu, H. (2013). Physical and biological constraints govern perceived animacy of scrambled human forms. *Psychological Science, 24*, 1133–1141.

Thurman, S., & Lu, H. (2014). Perception of social interactions for spatially scrambled biological motion. *PLoS ONE., 9*(e112539), 1–12.

Thurman, S. M., & Lu, H. (2016). Revisiting the importance of common body motion in human action perception. *Attention, Perception, & Psychophysics, 78*, 30–36.

Topolinski, S. (2010). Moving the eye of the beholder: Motor components in vision determine aesthetic preference. *Psychological Science, 21*, 1220–1224.

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

Vallortigara, G., Regolin, L., & Marconato, F. (2005). Visually inexperienced chicks exhibit spontaneous preference for biological motion patterns. *PLoS Biology, 3*(e208), 1312–1316.

van Boxtel, J. J., & Lu, H. (2012). Signature movements lead to efficient search for threatening actions. *PLoS ONE, 7*(e37085), 1–6.

van Boxtel, J. J., & Lu, H. (2013). A biological motion toolbox for reading, displaying, and manipulating motion capture data in research settings. *Journal of Vision, 13*(12):7, 1–16.

Van de Cruys, S., & Wagemans, J. (2011). Putting reward in art: A tentative prediction error account of visual art. *i-Perception, 2*, 1035–1062.

Weeden, J., & Sabini, J. (2005). Physical attractiveness and health in Western societies: A review. *Psychological Bulletin, 131*, 635–653.