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Aesthetic experience is influenced by causality in biological movements

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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 examined how visual processing contributes to the aesthetics experience from seeing actions, using point-light "creatures" generated by spatially scrambling locations of a point-light walker's joints. Observers rated how aesthetically pleasing and lifelike each creature looked in a video of the creature moving from left to right. They viewed four kinds of creatures: The joints' trajectories were 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 versus inverted trajectories, and congruent versus incongruent movements. Moreover, after regressing out the influence of animacy, the creatures that move in a natural causal manner (in accordance with gravity and their body displacements) were still preferred. The subtle differences between different kinds of creatures suggest a role of automatic perceptual mechanisms in these preferences. Thus, while our thinking minds may enjoy watching the magical moonwalk, our automatic minds, with a taste for causality, may curtail the impression of its visual beauty.

Keywords: Action; Motion; Aesthetics; Animacy; Causality

Introduction

Most of us see people every day, and many of us enjoy such activities. Whether through internet, televisions, or in person, and whether it is a stranger or a friend, we frequently seek to see someone in daily life. Among the things we can learn from watching others, it is often what they are doing that capture our interests. What do we notice when we look at a person's actions? We can certainly recognize what they are trying to do with the particular movements they are making. The experience is however much richer: From those movements, we also form impressions about the person (e.g., friendly, elegant, or awkward; Kadambi, Ichien, Qiu, & Lu, 2020), which then influence how we interact with them.

One aspect of these impressions is particularly powerful in influencing social interactions, that is, how attractive the potential interactive partner appears. Most research on attractiveness focused on human faces and body shapes (Rhodes, 2006; Weeden & Sabini, 2005), spanning from basic facial features (e.g., Langlois & Roggman, 1990) and waist-to-hip ratio (e.g., Singh, 1993), to modern modifications such as makeups (e.g., Etcoff, Stock, Haley, Vickery, & House, 2011) and plastic surgeries (e.g., Singh & Randall, 2007). These static appearances, however, are not the full picture. Dynamic cues can play an important role: One may find an attractive person only to be disappointed later by their awkward body movements; conversely, seeing someone moves elegantly may make them look attractive.

What processes underlie aesthetic experiences with human body movements? The aesthetics of actions is often viewed as based upon higher-level judgments (e.g., dance style preferences and physical health evaluations), or as fashions that differ across time and cultures (e.g., walking styles; for an interesting piece, see Anonymous, 1904). That said, a few studies have examined the role of perceptual features in perceived attractiveness of actions, focusing on specialized art forms like dances (e.g., Calvo-Merino, Urgesi, Orgs, Aglioti, & Haggard, 2010; Christensen & Calvo-Merino, 2013; Christensen, Pollick, Lambrechts, & Gomila, 2016), and sexual dimorphism in walking styles (e.g., Morris, White, Morrison, & Fisher, 2013; Provost, Troje, & Quinsey, 2008). However, these explorations aimed to identify perceptual features linked to attractiveness, rather than to isolate perceptual processes from judgements based on knowledge or expertise in specialized artistic actions. It is important to note that aesthetic experiences from viewing dance performances may differ not only quantitatively but also qualitatively from what one experiences from watching other people move through their daily lives. This means that, instead of focusing on the heightened experience of aesthetics as previous studies did, we aimed to explore the breadth of aesthetic experiences in everyday life.

Another aspect we aimed to explore is the possibility that the aesthetic impressions of others' actions simply arise in part from some generic preferences for certain motion signals, such as those produced by inanimate objects. There has so far been little research on generic motion features associated with aesthetic experience (but see Topolinski, 2010). However, many artists, historians, and psychologists have speculated about the role of motion perception in appreciating (realistic or abstract) static art that are not depicting animate subjects (e.g., Cutting, 2002; Palmer & Langlois, 2017; Thakral, Moo, & Slotnick, 2012).

In two experiments reported here, we ask what kinds of processes underly the perceived beauty in body movements. In particular, we assessed whether such aesthetic experiences arise with novel stimuli from perceptual processing itself, without any prior visual experience, and whether the mechanisms are specialized for movements of animate agents or generalized for all kinds of motions. To isolate visual processes from the prior knowledge and from the static appearances, we created point-light "creatures" by spatially scrambling initial locations of joints in a point-light walker, while maintained the same trajectories for each individual point-light. These creatures created from spatially scrambled point-lights (Figure 1a) prevent the viewers from accessing prior knowledge and experience regarding human forms and actions. We measured both aesthetic experience and perception of animacy when viewing these novel creatures.

Experiment 1: Upright vs. Inverted Trajectories

There are abundant of converging sources of evidence that humans reveal innate ability in detecting biological movements (e.g., Bardi, Regolin, & Simion, 2014), and such sensitivity to the motion cues is a hallmark of biological motion perception (e.g., Troje & Westhoff, 2006). Here, we explored how a critical cue that signals biological motion—gravitational acceleration in joint trajectories (e.g., feet accelerate faster downward than upward)—can influence aesthetic experience. This characteristic profile of joint movements (due to the regularity from gravity) exists across animate agents (e.g., humans and dogs), but is relatively scarce in motions of inanimate objects. Our key question is whether this biological cue that is perceptually processed serves as a critical feature not only for animacy perception but also for aesthetic experience with human actions.

Method

Participants Forty-nine naive observers (28 females, 11 males, and 1 other gender; all with normal or corrected-to-normal vision) from the UCLA community completed an individual 20-min session online in exchange for a course credit. Nine observers were removed based on predetermined criteria (see details in Results and Discussion). Hence data from forty participants were included in the analysis.

Stimuli Since the experiment was rendered on observers' own web browsers, viewing distance, screen size, and display resolutions could vary dramatically, and so we report visual stimulus dimensions below using pixel (px) values.

Forty point-light creatures were made from the right-side view of a single point-light walker (walking toward the right of the viewer) picked 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-second walking clip. The global motion was removed (thus, the walker appeared to be walking on a treadmill facing the right of the viewers). 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 moves out of the bounding box in their 2-second movements. The other 20 creatures in the inverted condition were made by inverting the trajectories of the upright creatures: We first found the vertical center of each joint's bounding box by averaging the max and min y positions the joint reached during the 2-second movements. We then locally flipped each trajectory upside-down by its vertical center. In this way, the inverted creatures had inverted trajectories that defy gravity yet retain the same global shape from the corresponding upright creatures.

Each of the 40 creatures were made into a 2-second video (800 px × 450 px) of it moving from left to right in a constant speed (250 px/s; Figure 1b). The joints were illustrated with black dots (12 px in diameter) in 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 with phones or tablets. The experiment had 2 blocks in fixed order of tasks: aesthetic rating block and animacy rating block, which were followed by debriefing questions. In both rating blocks, the observers were shown 80 formal trials after 2 practice trials: All 40 videos were shown in random order, and then they were followed by a repeat of all videos in another random order. In each trial, the 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) [1]. They were allowed to respond only after the video was done playing.

After completing both rating blocks, observers answered a series of debriefing questions to ensure they had completed the experiment without any issues.

Results and Discussion

Observer exclusion Nine observers were excluded using criteria decided before data collection began, with some observers triggering more than one criterion: 3 observers who

[1] The instructions for the aesthetic rating task were explained with various terms, including "visually pleasing", "good/beautiful", and "preference", to ensure correct interpretations of the word "pleasing" in this context.

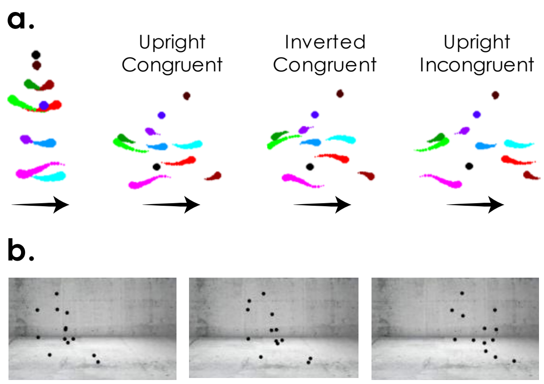

Figure 1. (a) Schematic illustrations of creature generation by spatial scrambling of initial positions of point-lights, and transformations introduced for different experimental conditions; (b) Three example frames in the video.

reported that they did not understand the instructions or did not take the experiment seriously, 1 observer who had a browser viewport smaller than 800 × 600 px, 2 observers who gave the same rating to more than 15 consecutive trials, 1 observer who hid the experiment browser tab more than 3 times during the trials, and 3 observers who took too long to complete the experiment (2 SDs longer from the mean duration from all observers before exclusions).

Aesthetic and animacy impressions Observers' aesthetic and animacy ratings from upright and inverted creatures were averaged respectively. The gravitational acceleration cues that signal biological movements were present in the upright creatures (consisting of joints trajectories from an upright walker), but were absent in the inverted creatures (consisting of joint trajectories from an inverted walker). The results, as depicted in Figure 2a, showed main 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), $t(39) = 3.73$, $p = .001$; animacy: 3.6 (SD = 1.4) vs. 3.4 (SD = 1.4), $t(39) = 3.83$, $p < .001$). The higher animacy ratings for upright than inverted conditions replicated previous findings of inversion effect on animacy perception (e.g., Chang & Troje, 2008; Thurman & Lu, 2013). Furthermore, the results extended such effect to aesthetic impressions of animate movements, showing creatures with movement trajectories complying gravity appear more visually pleasing than creatures moving in violation of gravity.

Relationship between aesthetic and animacy Is the relative positivity in aesthetic experience related to increased animacy perceived in the lifelike creatures? We calculated by-video correlations between aesthetic and animacy ratings for each observer after averaging the 2 ratings from the 2 repeats for each video. This was done using ratings from upright, inverted, and all creatures. We found positive correlations between aesthetic and

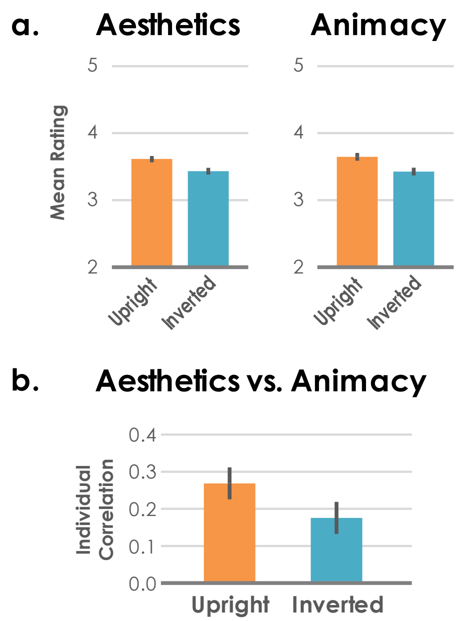

Figure 2. Results of Experiment 1: (a) Mean aesthetic and animacy ratings for upright and inverted creatures; (b) Correlation between aesthetic and animacy ratings for upright and inverted conditions. All error bars are within-subject 95% confidence intervals.

animacy impressions for the upright, inverted, and all creatures (upright: $r_M = 0.27$ ($r_{SD} = 0.26$), $t(39) = 6.65$, $p < .001$; inverted: $r_M = 0.18$ ($r_{SD} = 0.25$), $t(39) = 4.48$, $p < .001$; all: $r_M = 0.23$ ($r_{SD} = 0.21$), $t(39) = 6.74$, $p < .001$). Importantly, as shown in Figure 2b, the correlations between aesthetic ratings and animacy ratings were stronger in upright than in inverted creatures (upright vs. inverted: $Mean\ r_{diff} = 0.09$ ($SD_{diff} = 0.27$), $t(39) = 2.18$, $p = .035$). Thus, when the impressions of animacy from the creatures increase, the aesthetic experiences become more positive, and such a relationship was stronger when the creatures move in accordance with gravity in terms of their joint trajectories. These results suggested that gravitational acceleration influences aesthetic impressions partially through mechanisms that are specific to animate agents.

Independent effect on aesthetic 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-tests on the residuals between upright and inverted conditions. After removing the impact of animacy, the upright creatures were still more aesthetically pleasing than the inverted creatures ($t(39) = 3.25$, $p = .002$), suggesting a general effect of gravitational cues on aesthetic impressions that are not rooted in specialized processes for animate agents.

In summary, this experiment revealed that the critical cues of gravitational acceleration for perceiving biological motion can influence aesthetic impressions through both specialized mechanisms that underlie perception of animate agents, and general mechanisms that are sensitive to the physical regularity from gravity in object motion. Moreover, given the subtlety of gravitational cues and the novelty of the scrambled creatures, these mechanisms likely belong in perceptual processing, rather than relying on high-level knowledge about actions.

Experiment 2: Congruent vs. Incongruent Movements

How agents move in an environment are jointly determined by multiple causal factors besides gravity. For example, when humans move the limbs in certain ways to generate propelling forces, that leads to displacements of the body towards a goal position. This congruency between relative limb movements and global body displacements is another important causal phenomenon in biological movements (Peng, Thurman & Lu, 2017). Does this causal aspect of animacy perception also relate to aesthetic experience with actions?

Method

This experiment was identical to Experiment 1 except as noted here. In addition to the gravity factor, we manipulated congruency to the creatures' global motion: The 40 creatures with trajectories that are congruent to their global motion were generated in the same way as the 40 creatures in Experiment 1. Another 40 creatures were created to show incongruent trajectories to their global motions by locally flipping each joint trajectory *horizontally* along its bounding box's horizontal center (the average of min and max x positions for each joint throughout the 2-second video). This way, the global forms of the creatures were fixed across all 4 conditions, while the gravitational cues and congruency to global motion varied independently. The experiment included 2 sessions, which were done within 1 week of each other. 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 2 practice trials, and they repeated once again in another random order. A self-paced break was allowed halfway through each session.

Results and Discussion

Observer exclusion Sixty observers participated in this experiment. Twenty observers were excluded using criteria decided before data collection began, with some observers triggering more than one criterion: 1 observer who encountered a technical difficulty during the experiment, 14 observers who did not followed the instructions or did not take the experiment seriously, 3 observers who spent less than 0.5 second to read at least one page of the instructions, 1 observer who had a browser viewport smaller than 800 × 600 px, 6 observers who gave the same rating to more than 15 consecutive trials, 3 observers who hid the experiment browser tab more than 3 times during the trials, 1 observer

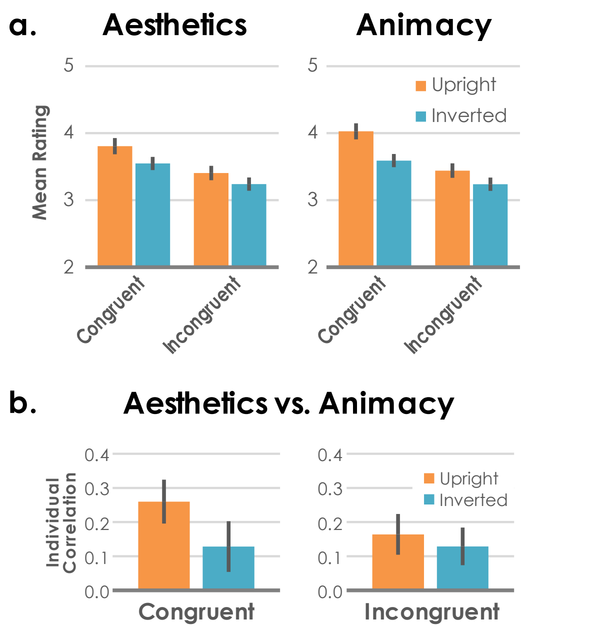

Figure 3. Results of Experiment 2: (a) Mean aesthetic and animacy ratings; (b) Correlation between aesthetic and animacy ratings in four conditions.

who gave a non-sensical response to one of the debriefing questions, and 4 observers who took too long to complete at least one session of the experiment (2 SDs longer from the mean duration from all observers before exclusions).

Aesthetic and animacy impressions Observers' aesthetic and animacy ratings from 4 conditions were averaged respectively. The results were depicted in Figure 3a. Inspection of this figure reveals 2 clear patterns: First, upright creatures appeared more aesthetically pleasing and animate. 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 aesthetic ratings, there was a main effect of gravity (3.6 (SD = 0.5) vs. 3.4 (SD = 0.5), $F(1,39) = 21.44$, $p < .001$) and a main effect of congruency to global motion (3.7 (SD = 0.5) vs. 3.3 (SD = 0.6), $F(1,39) = 15.87$, $p < .001$), without an interaction effect ($F(1,39) = 1.75$, $p = .193$). In animacy ratings, there was a main effect of gravity (3.7 (SD = 0.4) vs. 3.4 (SD = 0.5), $F(1,39) = 69.81$, $p < .001$), a main effect of congruency to global motion (3.8 (SD = 0.4) vs. 3.3 (SD = 0.5), $F(1,39) = 41.77$, $p < .001$), and a significant interaction effect ($F(1,39) = 7.77$, $p = .008$). The results again replicated the classic inversion effect on animacy perception in previous studies and the inversion effect on aesthetic judgement in Experiment 1. It also replicated the effect of motion congruency between relative limb movements and global body displacements on animacy perception (Thurman & Lu, 2013), and extended such effect to aesthetic impressions of animate movements.

Relationship between aesthetic and animacy To examine the relationship between the aesthetic experience and animacy perception, we calculated by-video correlations between aesthetic and animacy ratings for each observer in the same way as in Experiment 1. The results are depicted in Figure 3b. There were positive correlations between aesthetic and animacy impressions in all conditions (upright-congruent: $r_M = 0.26$ ($r_{SD} = 0.24$), $t(39) = 6.85$, $p < .001$; upright-incongruent: $r_M = 0.16$ ($r_{SD} = 0.19$), $t(39) = 5.43$, $p < .001$; inverted-congruent: $r_M = 0.13$ ($r_{SD} = 0.26$), $t(39) = 3.14$, $p = .003$; inverted-incongruent: $r_M = 0.13$ ($r_{SD} = 0.24$), $t(39) = 3.44$, $p = .001$). We found a main effect of gravity, where the correlation between aesthetics and animacy was stronger in upright than in inverted condition ($F(1,39) = 5.87$, $p = .020$), replicating the finding in Experiment 1. Neither the main effect of motion congruency nor the interaction between the two factors were significant (*ps* > .15). Thus, when the creatures look more alive, the aesthetic experiences become more positive, and such relationship were stronger when the creatures moved in ways that are in accordance with gravity, regardless of their congruency with the global motion. Again, this suggests a role of specialized mechanisms for aesthetic experiences from seeing biological motion.

Independent effect on aesthetic Does the gravity and congruency information independently influence aesthetic experience beyond effects through 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) ANOVA on the residuals. Both main effects of gravity and congruency persisted (gravity: $F(1,39) = 16.18$, $p < .001$; congruency: $F(1,39) = 9.11$, $p = .004$), and the interaction effect was still absent ($p > .9$). These indicate a general effect of gravitational cues on aesthetic impressions (as in Experiment 1), and potentially independently, a general effect of motion congruency between relative limb movements and global body displacements on aesthetic impressions, both in addition to specialized perceptual mechanisms for animate agents.

General Discussion

We investigated how aesthetic experiences arise from watching movements of animate agents. Four main results were revealed with spatially scrambled "creatures": First, gravitational cues and global-local movement congruency impact not only animacy perception but also aesthetic experiences. Second, creatures that look more alive appear to be more aesthetically pleasing. Third, most importantly, creatures that move naturally in a causal manner (in accordance with gravity and their body displacements) are perceived to be more aesthetically pleasing than creatures that do not conform to expectations based on physical causality. Fourth, both specific processes tuned to biological motion and general perceptual processes contribute to aesthetic preferences.

Aesthetic experience from animacy perception

The functional goals of specialized processes for perceiving biological motion of animate agents are often associated with detecting potentially dangerous animals or harmful conspecifics, finding suitable mates, or generating effective social interactions. Detecting animate agents that move in unfamiliar or unnatural ways may indicate that they are of unknown species that could be aggressive, unhealthy individuals that spread diseases, or sneaky social agents with ill intentions. Thus, a negative aesthetic experience from seeing biological movements with deviant patterns may trigger avoidance of potential dangers.

Alternatively, movements that look more animate may simply 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 a long evolutionary history. This perceptual fluency could 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 affects from fluency as positive evaluations of the stimuli (Reber, Schwarz, & Winkielman, 2004; Winkielman, Schwarz, Fazendeiro, & Reber, 2003).

Animacy may also influence aesthetics through its effect on attention, since biological movements is automatically processed (e.g., Thornton & Vuong, 2004) and attracts attention (e.g., Simion, Regolin, & Bulf, 2008; van Boxtel & Lu, 2012). However, whether such attention preferences to biological movements influence aesthetic experience requires future research.

Aesthetic experience from motion perception

Besides animacy perception, other perceptual processes are also sensitive to physical regularities, including causality (e.g., Chen & Scholl, 2016; Peng, Thurman, & Lu, 2017), gravity (e.g., Battaglia, Hamrick, & Tenenbaum, 2013; Hubbard, 2020), and other physical forces (e.g., Little & Firestone, in press). These processes are very effective in making predictions about the physical environments based on dynamic information (e.g., 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 our hypotheses about the world through prediction errors generated during actual experience (Rao & Ballard, 1999). A positive aesthetic experience associated with causal expectations of dynamic movements may thus strengthen the correct hypotheses about the physical world.

However, the relationship between aesthetics and predictions may be more nuanced. Efficient learning requires not only confirmation of correct hypotheses, but also curiosity to search for new information (Pathak, Agrawal, Efros, & Darrell, 2017). Some evidence suggests that this balance guides the appreciation of art (from perceptual to conceptual levels: Muth, Raab, & Carbon, 2015; Van de Cruys & Wagemans, 2011). Future research may examine whether this balance of confirmation and curiosity plays a role in aesthetics of biological motion.

A different kind of explanation on how general motion perception influences aesthetics centers around the low-level features themselves. For example, smooth movements are more aesthetically pleasing (e.g., Miura et al., 2010). While explorations in this direction have yielded fruitful findings in the past, the current study cannot be easily explained this way, due to the identical low-level motion features shared across conditions.

High-level and perceptual influences

While the present study focuses on the impact of animacy and causal perception on aesthetic experiences, we would like to emphasize that by no means does our study rule out contributions from higher-level. As pointed out by previous studies, higher-level appraisals can modulate the experiences that would have arisen solely from perceptual information (Reber et al., 2004), and it is even possible that most aesthetic experiences are better explained by higher-level judgments (e.g., Leder, Belke, Oeberst, & Augustin, 2004). A salient example is the famous dance move “moonwalk”, where the dancers perform walking movements that are incongruent with their global 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 (see Hagendoorn, 2005). Aesthetic pleasures from dance moves might also arise from a depth of explicit knowledge about how the movements are achieved, their biomechanics, years of practice required to learn, and their special place in history (e.g., Cross, Kirsch, Ticini, & Schütz-Bosbach, 2011). These high-level judgments might even override perceptual evaluations, and thus, in some cases, only if the knowledge access is blocked (e.g., with novel stimuli such as the spatially scrambled creatures in the current study), the perceptual contributions can be revealed. However, these kinds of aesthetic experiences from high-level judgments have been argued to differ in intensity and nature from the scrambled creatures that simply “looks good” here (e.g., Makin, 2017; Brielmann & Pelli, 2017), which is often what we experience in everyday life outside of artistic contexts.

This study used a paradigm to minimize the impact of high-level knowledge on aesthetic experiences, and demonstrated that consistent behavioral patterns in aesthetic preferences can be explained by perceptual mechanisms. This approach allows us to identify potential evolutionary functions of aesthetics, and, with hope, will lead us to part of the answer of why we like what we like.

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References

Anonymous. (1904, February 21). New walk comes with Spring. *The Arizona Republican*, pp. 7.

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.

Calvo-Merino, B., Urgesi, C., Orgs, G., Aglioti, S. M., & Haggard, P. (2010). Extrastriate body area underlies aesthetic evaluation of body stimuli. *Experimental Brain Research, 204,* 447–456.

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.

Hagendoorn, I. (2005). Dance perception and the brain. In R. Grove, C. Stevens, & S. McKechnie (Eds.), *Thinking in four dimensions: Creativity and cognition in contemporary dance* (pp. 137–148). Melbourne: Melbourne University Press.

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.

Leder, H., Belke, B., Oeberst, A., & Augustin, D. (2004). A model of aesthetic appreciation and aesthetic judgments. *British Journal of Psychology, 95,* 489–508.

Little, P. C., & Firestone, C. (in press). Physically implied surfaces. *Psychological Science.*

Makin, A. D. J. (2017). The gap between aesthetic science and aesthetic experience. *Journal of Consciousness Studies, 24,* 184–213.

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.

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.

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

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.

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.

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.

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.

Winkielman, P., Schwarz, N., Fazendeiro, T., & Reber, R. (2003). The hedonic marking of processing fluency: Implications for evaluative judgment. In J. Musch & K. C. Klauer (Eds.), *The psychology of evaluation: Affective processes in cognition and emotion* (pp. 189–217). Mahwah, NJ: Taylor & Francis.