Attention Capture by Animate Motion is Modulated by Physical and Subjectively Perceived Animacy

by

Nicole C. White

A thesis submitted in conformity with the requirements for the degree of Master of Arts

Department of Psychology

University of Toronto

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Abstract

Previous research on animate motion perception indicates that animacy detection may be an evolutionarily developed mechanism of the visual system, responsible for adaptive alerting to other organisms in the environment. The present study further examined previously described attention capture by animate motion, and explored whether capture may be modulated by type of animacy (e.g., human motion vs. other animacy). The link between subjective animacy experience and perceptual processing was also examined. Results suggested that attention capture by animacy extends to situations in which animate motion is self-relevant. Animate motion entering the observer’s visual field captured attention relative to motion leaving out of the visual field. Subjective ratings of animacy experience also reliably predict reaction time in perceptual/attention tasks. Implications for theories of social cognition and higher order processing of agency are discussed.
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1 Introduction

The human brain is highly efficient at processing information pertaining to other living organisms in the environment. We are able to perceive human actions from minimal displays of dots moving in specific trajectories (e.g., Johansson 1973), and in some cases even the motion of a single dot is sufficient to create the impression that the dot is ‘alive’ (e.g., when the motion of the dot appears self-generated and not completely subject to external forces; Tremoulet & Feldman, 2000; Heider & Simmel, 1944). The tendency to perceive biological entities in displays of moving objects is referred to as perceptual animacy, and was first demonstrated by Heider and Simmel (1944). Heider and Simmel showed that, using displays containing only simple geometric shapes such as triangles and circles, participants would spontaneously infer agency and intention from these shapes (e.g., “the triangle is angry”), and social context to the displays (e.g., “the circle is running away from the triangle”). Further investigating the nature of this perceptual phenomenon, Tremoulet and Feldman (2000) highlighted the importance of information contained within various motion cues by demonstrating that the degree of reported animacy can be modulated by specific changes in motion; in particular, greater changes in the speed of an object or its direction of travel are associated with higher ratings of animacy by observers. These findings demonstrate that relatively complex social inferences can be drawn from displays containing very little perceptual information, suggesting that such inferences, typically thought to be served by “higher cognitive processes”, may rely on or largely involve processing at the minimal perceptual level. With only motion cues, observers create rich descriptions of the “characters” within animate displays. The present study aims to further investigate the relationship between perceptual processing of animacy and such ‘higher order’ impressions of animate stimuli to determine the strength and directionality of the link between perception and inference.
1.1 Perceptual animacy – bottom-up or top-down?

In a review of the perceptual animacy literature, Scholl and Tremoulet (2000) note that recognition of animacy appears to be perceptually driven, and may thus may be an automatic process of the visual system that forms the basis for more complex forms of social cognition. This suggestion follows from findings that the perception of animate entities and inference of goal-directed behaviour in displays of simple geometric shapes appears to be rapid and irresistible (e.g., Heider & Simmel, 1944), and common across different cultures (Morris & Peng, 1994). The authors suggest that such ‘reflexive’ appraisals of not only the presence of living entities but also of relationships between them may be part of a perceptual process that underlies the ability to understand social interactions. Research on biological motion perception demonstrates that such rapid and irresistible recognition of animate motion may extend to social alerting. Human point-light stimuli, first introduced by Johansson (1973), depict human motion using only about a dozen points of light, placed on the major articulating joints of a human actor. As such, these stimuli provide extremely sparse information about human body forms (i.e., a static frame of a point-light animation is meaningless to naive observers) while simultaneously allowing for rapid perception of different actions (Vanrie & Verfaillie, 2004), gender (Barclay, Cutting & Kozloski, 1978), mood (Michalak, Troje, Fischer, Vollmar, Heidenreich, & Schulte, 2009), and even individual identity (Cutting & Kozloski, 1977) from motion cues alone. In other words, we are able to extract a wealth of information from motion cues that may influence our social behaviour; if we notice a human approaching us, we can instantly recognize that she is our friend Mary, and she appears to be depressed. These instant appraisals, made on the basis of motion information alone, may influence our social behaviours in engaging with Mary.

A potential rebuttal to this motion-as-social-information interpretation is the suggestion that recognition of individuals from gait and inference of social relationships between geometric shapes occurs in a top-down fashion after perceptual information has been processed. This argument stems from the classical view of cognition, in which sensory processes are thought to occur at a lower level than complex functions such as reasoning, inference, and abstract thought. In this view, sensory information about the
world is processed by lower-level structures, and knowledge is accrued via some transformation of sensory information into amodal symbols which are stored somewhere in the brain, independently of sensory cortices (e.g., Fodor, 1975). When we need to access information about social context, for instance, this view argues that we activate higher-level symbolic representations of social interaction that we can then use to give meaning and context to moving displays in which “the triangle is chasing the circle”.

More recent theories of ‘grounded’ cognition posit that all mental representation involves modal processes, and that perceptual and/or sensorimotor activity form part of all representation and cognitive processes, including traditionally “higher order” functions (e.g., Meyer & Damasio, 2009; Barsalou, 2008; Lakoff & Johnson, 1999). In other words, grounded cognition suggests that the areas involved in perceiving a given stimulus are also involved in knowing about it (e.g., Gallese & Lakoff, 2005; Martin & Weisberg, 2003); thus, structures responsible for processing animate motion are also involved in ‘knowing’ about animate entities. Importantly, this holds true for both ‘bottom-up’ and ‘top-down’ activations of an object concept; for example, thinking about ‘chasing’ would be predicted to activate neural structures involved in direct perception of chasing.

It is worth noting here that a vast literature on biological motion perception indicates that biological point-light stimuli activate the superior temporal sulcus (STS; e.g., Grossman Donnelly, Price, Pickens, Morgan, Neighbor & Blake, 2002; Vaina, Solomon, Chowdhury, Sinha & Belliveau, 2001), an area in the brain that is known to integrate information about form and motion from extrastriate structures comprising the ventral and dorsal visual streams, respectively, and which participates in a wide variety of tasks related to social cognition (e.g., theory of mind; for a review of STS function, see Hein & Knight, 2008). Neuroscientific findings are reviewed in more detail below, but it should be emphasized that evidence from attention research (also reviewed below) indicates that simple animacy detection (e.g., recognizing a living entity) may be a very early process, occurring before the processing of ‘biological motion’ (a term which traditionally refers to point-light human walkers). It is possible that simple animacy detection is served by a mechanism in early visual cortex that codes for salience, and is separable from biological form-from-motion. Regardless of theoretical arguments over
the bottom-up vs. top-down nature of social inference, simple animacy detection as a bottom-up mechanism is well-supported by a large body of research. The present set of experiments aims to further address the possible distinction between animacy detection (e.g., ‘that’s alive!’) and recognition of and inference about animate entities (e.g., ‘that’s Mary, walking towards me’).

1.2 Evidence from non-human species

The suggestion that perceptual animacy is a ‘reflexive’ property of the visual system (e.g., Scholl & Tremoulet, 2000) hints at an evolutionary explanation. Indeed, a mechanism within the visual system of an organism designed to detect and orient the organism towards other living entities in its environment would be highly adaptive. From the perspective of predation, an animacy detector could by turns aid an organism to find food sources and to avoid becoming one. Such a mechanism could also be exapted to aid in alerting the animal to important social cues such as gait patterns that signal affect (Scholl and Tremoulet, 2000).

A growing body of research on non-human primates and other animal species provides support for the evolutionary explanation of perceptual animacy. Mascalzoni, Regolin, and Vallortigara (2010) have shown evidence of perceptual animacy and causality detection in newborn chicks. Visually naive chicks were shown cause-and-effect displays (e.g., Heider & Simmel, 1944), with the hypothesis that an innate animacy detection mechanism may rely on motion cues such as self-propulsion (i.e., an object that appears to be generating its own movement appears more animate, see Tremoulet & Feldman, 2000). Displays depicted two ovals (A and B) in which either one or both ovals demonstrated a self-propelled motion. On some trials, oval A moved towards and contacted B, causing A to stop and B to begin moving along the same trajectory (A is self-propelled, B is subject to external forces). After viewing this, chicks showed spontaneous preference for oval A, as measured by approach behaviour. However, when both ovals demonstrated self-propelled changes in movement, chicks showed no preference, approaching both items equally frequently. Because preference was only demonstrated when one of the two shapes underwent a self-propelled motion, the authors concluded that self-propulsion may be a hallmark of identifying living entities in the
environment, and that this is an innate ability developed as a result of the evolutionary advantage conferred by rapid detection of animate agents (though there is some conflict in the literature regarding the importance of self-propulsion vs. goal-directed behaviour in producing percepts of animacy in human observers, with goal-direction implying a ‘higher order’ interpretation; e.g., Opfer, 2002).

Biological motion perception, in addition to simple animacy detection, has been demonstrated in a variety of non-human species. Oram and Perrett (1994) have demonstrated sensitivity to biological motion in the macaque brain, while Blake (1993) was the first to show that cats can be trained to reliably discriminate between biological and non-biological motion using point-light stimuli. Vallortigara, Regolin, and Marconato (2005) have shown that baby chicks hatched and reared in complete darkness (i.e., with no visual experience) have an innate preference for biological motion. Visually naive chicks were presented with pairs of point-light displays depicting various combinations of a point-light hen, a scrambled point-light hen (containing identical motion trajectories as the hen, but spatially randomized such that the global form is no longer hen-like), a rigid, rotating point-light shape, and random point-light motion. It was found that chicks preferred (i.e., approached) the point-light hen stimulus relative to random and rigid motions; no preference was shown between the point-light hen and the scrambled point-light hen, indicating that chicks’ preference for biologically patterned motion was likely based more on local kinematic cues than global form (because these stimuli contain identical motion trajectories overall). To further test this preference for biological motion patterns, a point-light cat (i.e., a non-conspecific entity) was added to the stimulus set. It was found that chicks preferred the cat to non-biological motions, and showed no difference in preference between the cat and the hen. Though, as suggested above, simple animacy detection may be separable from biological motion perception, there is evidence that both are innate mechanisms of the visual system.

1.3 Evidence from attention research

A large body of research on human subjects also provides support for the hypothesis that animacy detection may be a perceptually driven, innate ability that occurs rapidly and without conscious awareness in the human brain. Experiments with infants as young as
two days demonstrate inborn preference for biologically patterned motion relative to rigid, non-articulated form-from-motion displays (e.g., Simion, Regolin & Bulf, 2008), and nine-month-old infants have been shown to demonstrate sensitivity to animacy and social ‘cause-effect’ contingency (e.g., Poulin-Dubois, Lepage, & Ferland, 1996; Schlottman & Surian, 1999).

In healthy, typically developed adults, the irresistible ‘reflexive’ nature of orienting to animate entities has been demonstrated by a wealth of research employing attentional paradigms. New, Cosmides and Tooby (2007) have demonstrated an effect of attention capture by humans and animals in static images. Using a change detection paradigm (e.g., Rensink, O’Regan & Clark, 1997), the authors measured the accuracy of change detection by participants for a set of complex natural scenes, which contained either animate objects (i.e., people or animals) or inanimate objects (e.g., plants, manipulable artifacts, landmarks, etc.). The results showed that, across three experiments, changes to scenes containing animate objects were detected with higher frequency relative to scenes with inanimate objects, and change detection was significantly faster for animate relative to inanimate scenes, with no speed-accuracy tradeoff effects (in fact, the authors report that subjects were more accurate in detecting changes for animate scenes). Importantly, all attention capture effects remained significant after controlling for differences in low-level visual characteristics (e.g., luminance, size) between stimuli. Further, no distinction in magnitude of attention capture was demonstrated between human and non-human animals, leading the authors to suggest that this effect may be evolutionarily based (e.g., rather than based on expertise with certain categories of stimuli), and lending further support to the hypothesis of an evolutionarily developed animacy detector. These findings have also been supported by studies of eye movements in object processing, with saccade latency being significantly shorter to scenes containing animals (e.g., Kirchner & Thorpe, 2006; Chow & Pratt, in preparation). When simultaneously presented with two complex natural scenes (on in either visual hemifield), participants are able to initiate saccades to animal scenes in as little as 120 msec (about 60 msec faster than was predicted based on event-related potentials data).

Examining attention as it relates to animate motion, Guo, Abrams, Moscovitch
and Pratt (2010) have demonstrated that the onset of motion in a visual display captures visual attention relative to the offset of motion, even after eliminating other potentially salient cues such as luminance. In a target detection task, participants were asked to press a button indicating the appearance of a target in a display of objects, some of which were in motion and some of which were not. During each trial, one of the objects could either stop moving, begin moving, or undergo no change in motion; after this event occurred, a target appeared. Participants were significantly faster to respond to targets that appeared in a location preceded by an object undergoing motion onset. In other words, when something in the visual field begins moving suddenly (i.e., appears to generate its own motion, a hallmark of animacy; Tremoulet & Feldman, 2000), attention is drawn to that location.

These findings were corroborated by Pratt, Radulescu, Guo, and Abrams (2010). To further investigate whether the previously observed attention capture by motion onset was due to the animacy of objects, the authors directly compared responses to animate and inanimate changes in object motion. Participants were first presented with a display of inanimately moving objects (i.e., objects moving in trajectories determined by external forces, such as bouncing off of the border of the display or off of one another). After a varied interval, one of the items in the display exhibited an animate change in motion (i.e., a change in motion not due to collision with another object). Following this event, one of the objects in the display disappeared, and subjects were asked to respond via button press when they noticed the disappearance. Participants were significantly faster to respond when the disappearing object had previously undergone an animate movement relative to an inanimate change, suggesting that the attention capture observed was indeed due to the animacy of the object. Importantly, Pratt and colleagues (2010) also provide evidence that the magnitude of attention capture, as measured by decreased response time, is positively correlated with the degree of animacy in the stimulus. Using the same paradigm, the authors varied the either the speed or magnitude of direction change of both animate and inanimate motions across trials. No effect of speed or magnitude of direction change was found on responses to inanimate motion. However, participants responded significantly faster to animate changes in motion when the speed or magnitude of direction change was greater (indicating greater animacy; see Tremoulet
& Feldman, 2000); the more animated the object’s motion, the faster participants were to respond when the object disappeared from the display (i.e., the greater the capture of attention). Furthermore, participants reported in a post-experiment interview that they had been unaware that displays contained animate motion, indicating that the effect of animacy on attention is rapid and unconscious.

As previously mentioned, the rapid and irresistible nature of animacy detection and recognition suggests that these abilities occur very early on in visual processing and may serve an adaptive evolutionary function. It is also possible (and indeed probable, from the theoretical perspective of ‘grounded cognition’), that these mechanisms serve, or at least contribute to, more complex cognitive functions. Scholl and Tremoulet (2000) suggest in their review that perceptual animacy may have been exapted to aid in social cognitive processes, and there is evidence to show that perceptual animacy not only induces powerful impressions of social context, but may also implicitly influence interactive behaviours. Gao, McCarthy and Scholl (2010) have demonstrated what they call ‘the wolfpack effect’, in which an array of randomly moving geometric shapes (‘darts’) consistently point towards a single, randomly moving disc. Though motion is random, when darts consistently face the disc, participants report that the disc is being pursued or hunted by the ‘pack’ of darts. Gao and colleagues (2010) gave participants a task in which darts acted as irrelevant distractors; in this task, participants were instructed to keep the ‘sheep’ disc away from another randomly moving ‘wolf’ object. The authors found that performance suffered significantly when the task-irrelevant darts faced the sheep relative to when darts were oriented randomly. In other words, participants’ attempts to avoid the single ‘wolf’ shape changed when the darts created the ‘wolfpack’ impression, and as they moved the sheep to avoid task-irrelevant darts, they were less successful at avoiding the wolf. Importantly, the ‘social’ context created by the randomly moving darts changed participants’ interactive behaviours, even though they were told which objects were task-relevant in advance. The wolfpack effect provides compelling evidence that social behaviour can be influenced by motion information in sparse perceptual displays, suggesting that at least some aspects of social cognition may be based in perceptual processing.
1.4 Evidence from social neuroscience

1.4.1 Evidence from normal healthy controls

Perceptual animacy has also been widely studied in the context of social cognition and development, where a link between perception and more complex cognitive processes related to social interaction has also been suggested. Neuroimaging studies have implicated the social neural network (SNN) in the processing of animate motion in visual displays; this network comprises the posterior insula, the superior temporal sulcus/gyrus (STS/G), the fusiform gyrus (FG), temporal poles, amygdala, parahippocampal gyrus, and ventromedial prefrontal cortex (e.g., Castelli, Happe, Frith & Frith, 2000; Schultz, Friston, O’Doherty, Wolpert & Frith, 2005; Santos et al., 2010).

In addition to the involvement of this network during viewing of animate motion, a number of studies have correlated subjective ratings of animacy with the degree of activity observed in SNN structures, indicating that subjective experience of animacy is strongly related to activation in this network. These findings support the grounded cognition hypothesis. For instance, Santos and colleagues (2010) scanned participants using functional magnetic resonance imaging (fMRI) while they viewed displays containing two spheres that were varied parametrically both in terms of the amount of self-propelled motion exhibited by each, and the amount of ‘social’ interactivity between the spheres. By parametrically manipulating the amount of interaction between two geometric objects, the authors were able to create a stimulus set in which the animacy of stimuli varied in a linear fashion. This approach affords a more stringent degree of control over the comparison of subjective animacy experience with the actual amount of interactivity in the stimulus, as the interactivity can be exactly measured and changed. After the scans, participants were asked to rate the stimuli for perceived animacy and interactivity. These ratings were used to separate the stimulus set into groups scoring high and low on both animacy and interactivity, and an analysis was performed to determine whether specific areas of the brain showed differential activation for high versus low ratings on each scale. It was found that activity in both the posterior insula and STG were highly positively correlated with animacy experience and interactivity; the more animate and interactive stimuli were subjectively rated, the more active these two
areas of the SNN. The authors concluded that both the insula and STG may underlie the subjective experience of animacy. In other words, the STS is a region that appears to be involved in both processing biological motion and in generating a conscious impression that stimuli are social agents.

Tavares, Lawrence and Barnard (2007) have also shown that increasing the amount of interaction between two objects in a visual animation is correlated with both an increase in the subjectively rated experience of animacy as well as brain activity in perceptual-level structures comprising the SNN. Participants in this study were scanned using fMRI while they viewed three kinds of animation, which could contain either “indifference” between two moving shapes (i.e., no interaction), or affiliative or antagonistic interaction. After the experimental task, subjects were asked to rate the stimuli on emotional valence and animacy; participants spontaneously rated the interactive stimuli as significantly more animate than the indifferent stimuli, and this distinction was used in analyses of fMRI data. Regardless of whether interactions were positive or negative in emotional valence, area hMT, the fusiform gyrus, the STS and the amygdala were all significantly more active in response to stimuli rated as highly animate as compared to socially “indifferent” stimuli. The subjective experience of animacy, then, seems to be highly correlated with activity in various ‘lower-level’ sensory structures.

The positive correlation between interactivity in animate displays and STS/G activity has been replicated by Schultz, Friston, O’Doherty, Wolpert and Frith (2005). Schultz and colleagues (2005) wanted to assess the role of attention in modulating neural responses to animate motion. Participants were scanned in an fMRI machine while they viewed animate displays and performed one of two different tasks. In one task, intended to direct attention towards more mechanical aspects of the stimuli, participants were asked to rate the speed at which objects in the display were moving. The second task required attention to social interaction, as participants were required to rate how much “chasing” occurred within the animation. The results demonstrated a task-independent increase in activity in the posterior STS/STG, the fusiform gyrus and medial occipital cortices. Regardless of whether participants attended to social or mechanical contingencies, there was increased activity within these regions of the SNN for animate
(i.e., interactive) relative to inanimate displays. The authors concluded that SNN responses to animacy occur rapidly and independently of directed attention, and thus these processes may be underlie the ability to engage in all social interaction.

As mentioned above, the STS/STG region has been widely implicated in tasks related to social cognition, including biological motion perception (e.g., Grossman et al., 2000; Grossman, Batelli, & Pascual-Leone, 2005; Peelen, Wiggett & Downing, 2006), deriving social cues from gaze direction (for a review, see Allison, Puce & McCarthy, 2000), and attributing intentionality and/or mental states to other individuals (e.g., Saxe, Xiao, Kovacs, Perrett & Kanwisher, 2004), thus it is perhaps not surprising that it may also be involved in processing animate motion. The aforementioned studies, however, do not necessarily allow for the conclusion that the STS is necessary for perception of animacy. All of the studies cited have conflated simple animacy (e.g., aliveness) with other cues (e.g., interactivity). In these studies, the STS is reported to respond to increasing animacy experience, which is in effect inseparable from increased interactivity (indeed, interactivity is the defining characteristic of animacy experience in the literature reviewed). Because interactivity is inherently a social phenomenon occurring between animate agents, it is not surprising that the STS is involved. This is not to suggest that interactivity does not add to subjective experiences of animacy, but it is possible that simple animacy detection may occur independently of processing more complex aspects of animacy that give rise to social context. It may be that two processes occur during perception of these stimuli, with one involving salience detection very early in visual cortex (e.g., detection of and orienting to living entities), and the other involved in more socially relevant recognition processes (e.g., biological motion perception) that require later STS recruitment (though note, again, that both of these processes seem to be rapid, fairly low-level, and innate). Evidence for this hypothesis is reviewed in the next section.

1.4.2 Evidence from autism

As mentioned, in many experiments investigating animate motion processing, ‘animacy’ and ‘interactivity’ are treated more or less equivalently; the possibility remains that the STS/STG is sensitive not to animate motion per se, but to the socially relevant information in a stimulus. However, perception of simple animacy may be separable
from perception of intention or of interaction between animate agents, though both (as reviewed above) may be rapid low-level processes that contribute to more complex forms of cognitive functioning. Such a distinction would support the hypothesis that detection of animate agents occurs very early in the visual system, and modulates what visual information will be sent to structures further downstream (e.g., if motion is ‘flagged’ as animate very early, the STS will be more likely to become active; Zhang & Luck, 2008).

Research on autistic individuals suggests that there may be a reliable distinction between simple animacy and social contingency/relevance. Arguably, human biological motion represents visual information that is not only animate, but potentially socially relevant. There are a multitude of studies examining biological motion perception in autistic individuals (e.g., Murphy, Brady, Fitzgerald, & Troje, 2009; Parron, Da Fonseca, Santos, Moore, Monfardini, & Deruelle, 2008; Hubert, Wicker, Moore, Monfardini, Duverger, Da Fonseca & Deruelle, 2007; Blake, Turner, Smoski, Pozdol & Stone, 2003) with conflicting results. Findings of normal performance versus deficits in biological motion perception in autistic individuals seem to depend largely on the nature of the experimental task. When the paradigm requires judgments that bias perception towards local motion cues (e.g., “which direction is the stimulus moving?”; e.g. Murphy et al., 2009), performance tends not to differ from that of normal healthy controls, whereas when the task requires appraisal of global form-from-motion (e.g., “is it a person or not?”), many studies show decreased accuracy in autistic participants (e.g., Koldewyn, Whitey & Rivera, 2010; Blake et al., 2003). Further, differences exhibited between autistic and typically developed individuals on tasks requiring local motion information are eliminated when intelligence quotient is controlled for (Rutherford & Troje, in press), while differences in global motion tasks persist even when this variable is held constant (Koldewyn et al., 2010). Again, these findings point to a potential neural distinction between simpler forms of animacy detection, and more complex forms of recognition that inform social cognitive processes.

Further to this hypothesis, Castelli, Frith, Happe, and Frith (2002) have demonstrated that neural responses in early visual cortices and extrastriate regions to animate displays are similar for increasingly complex ‘social’ scenes in both typically
developed and autistic individuals, but that structural connectivity to the STS is altered in autistic individuals. The authors showed both typically developed and autistic adults three sets of animations, designed to elicit different experiences of animacy, and asked them to describe what was happening in each. The simplest animations contained random motions. The second set of animations contained simple interactions between shapes (e.g., “chasing”), while the third set contained displays of shapes interacting with one another in a more socially complex fashion (e.g., “coaxing”). Participants underwent positron emission tomography (PET) scans while viewing these animations to ascertain whether any differences in subjective reports of the stimuli could be associated with neuroanatomical differences. For random motion and simple interactions, there were no differences in the accuracy or length of descriptions given between controls and autistic participants. For the more socially complex animations, however, autistic individuals provided significantly less accurate and less detailed accounts than did normal participants, suggesting that autistic individuals have more difficulty processing complex social interactions. In normally developed participants, the STS was most strongly activated by the complex set of animations, an effect not observed in the autistic group. However, reduced structural connectivity was observed in autistic participants between the STS and a region of extrastriate cortex that was particularly active in both groups while viewing the third set animations. The authors thus concluded that a lack of connectivity from the extrastriate cortex to the STS may reduce one’s ability to accurately characterize complex social interactions. In autistic subjects, the extrastriate cortex responds robustly to animations depicting complex social interaction; this suggests that processes involved in simple animacy detection occur early in visual processing. Subsequently, the results of this processing feed forward to inform more complex processing of social context/relevance. As would be expected from a grounded cognition standpoint, if the mode of perceiving animacy is changed, access to knowledge about animate agents will be altered (e.g., Martin & Weisberg, 2003). This may also explain why deficits are seen in autistic individuals in biological motion tasks requiring global form perception (and arguably, perception of potential social relevance), as the STS is known to integrate visual information regarding motion and form cues. These findings provide support for the notion that early animacy detection may subserve some crucial aspect of social cognitive processing.
1.5 The current study

The literature reviewed above supports the notion of a strong link between perceptual-level processes and more complex subjective impressions of social context in animate motion processing. According to more recent theories of cognitive function (e.g., Barsalou, 2008), such ‘higher’ operations as subjective experience of animacy and social inference are largely a function of activity occurring in the visual processing stream; to have knowledge of and reason about animate agents, we rely on experience with directly perceiving them. This is not to imply that other brain areas, such as the frontal cortex, are uninvolved, simply that the modal cortices are much more involved than is traditionally thought. The evidence reviewed points to an evolutionary basis for animacy detection, and highlights the rapid and irresistible nature of subjective impressions of social context that may be created by animate displays. Attention capture effects suggest that animacy is an extremely salient cue, and that motion carries critical ‘social’ information that may influence interactive behaviours. The motivation for the current set of experiments is two-fold: first, in an extension of previous research related to attention capture by animate motion (e.g., Pratt et al., 2010), this study aims to investigate whether the magnitude of attention capture is modulated by the type of animacy in a display. Some animate agents are inherently more ‘socially relevant’ than others; for instance, when we see a human walking towards us, we are likely more prone to engage socially than we would be if we saw a pigeon. Experiments 1 through 3 investigate the possibility that different types of animacy may be ‘ranked’ in terms of attentional salience; it is hypothesized that human motion will be more attentionally salient than animate, but non-human motion. To examine this, participants will be presented with visual displays containing a moving stimulus in both visual hemifields (i.e., competing inputs, both in the visual periphery) in a paradigm where motion is task-irrelevant. It is expected that context will modulate attention capture effects; if two animate stimuli are presented together, for example, the more ‘socially’ relevant one is predicted to capture attention. If this is the case, it would provide support for the hypothesis that at least some aspects of social cognition may be observed at the level of visual attention, which would not be predicted by the classical view that such ‘higher functions’ are separate from the sensory modalities.
The second motivation for this set of experiments is to more closely examine the link between subjective animacy experience and perceptual processing. To do this, subjective ratings will be collected from each participant regarding stimulus animacy (i.e., aliveness), whether the stimulus appears human, and how fast the stimulus appears to be moving. As with any measure, normal variation indicates that some individuals will have a lower subjective threshold for animacy, and be more likely to report a moving stimulus as appearing alive, while other individuals may stare at a biological motion point-light walker for minutes before recognizing its global shape as human. Ratings data concerning subjective experience of animacy (i.e., aliveness) and humanness (i.e., social relevance), will be entered as predictors into a linear mixed-effects model analysis to determine whether attention capture effects (as measured by reaction time) can be reliably predicted by individuals’ subjective sensitivity to animacy experience. For instance, if an individual is very sensitive to perceiving the global shape of a biological motion stimulus, does this give us predictive power as to the nature of potential attention capture effects? Because attention capture is an early visual phenomenon, if subjective ratings can be used to predict capture effects, this would provide strong support for the notion that subjective experience and inference of social context are rooted in early perceptual processing.

2 Materials & Methods

2.1 Apparatus

The apparatus for all experiments was identical. In each experiment, the experimental task was carried out in a dimly-lit room using a PC with the Windows operating system. Stimuli were presented on CRT monitor set at 75 Hz refresh rate. Stimuli were first created using the Psychophysics Toolbox (Brainard, 1997) in MATLAB (The MathWorks, Inc., Natick, MA) using a coordinate set indicating Cartesian coordinates for each of 13 point-lights comprising a human walker provided by Vanrie and Verfaillie (2004). Coordinates were rendered to animations and exported from MATLAB as video files. During the task, stimuli were presented to participants using Experiment Builder version 1.6.121 software (SR Research Ltd, Mississauga, ON) and participants’ eye
movements were monitored with an EyeLink 1000 desk-mounted eye tracking device (SR Research Ltd, Mississauga, ON), while viewing distance was fixed at a distance of approximately 45 cm from the screen by use of a chin/forehead rest.

2.2 Procedure

The general procedure for all experiments was the same. Participants sat in front of the CRT monitor and viewed pairs of stimuli presented simultaneously on either side of a central fixation cross. Each stimulus was presented 12.5 degrees away from the central fixation cross on either side of the screen. Participants were instructed to maintain central fixation throughout the duration of the task and the eye tracker was used to ensure compliance; if participants’ gaze deviated more than 2.9 degrees from centre on any trial, the trial was immediately aborted and recycled for later presentation. Thus, each participant completed all trials. Fortuitously, the eye tracker proved inordinately sensitive to deviations in gaze due to lack of attention (e.g., when participants allowed themselves to lose focus during the task, the eye tracker detected deviations from central fixation); this technical ‘problem’ forced participants to maintain active, attentive fixation to the centre of the screen during the experiment.

On each trial, a black screen with a white central fixation cross was displayed for 500 msec before a pair of stimuli was presented simultaneously; after a variable interval, one stimulus disappeared. This stimulus offset interval was the only aspect of the procedure that differed across experiments; in Experiment 1, stimulus offset times were 100, 200, 500 or 900 msec, while in Experiments 2 and 3, only the 500 and 900 msec offset times were used (see results for details). Participants were instructed to respond to the disappearance of the stimulus as quickly and accurately as possible using the keyboard (‘z’ when the left stimulus disappeared and ‘/’ when the right stimulus disappeared).

After completing the reaction time task, participants were instructed to seat themselves comfortably at another Windows-based computer, not linked to the eye tracker. For this portion of the experiment, participants were shown videos of each stimulus, one at a time, and asked to provide ratings regarding stimulus animacy,
“humanness” and speed. For all ratings, participants were shown a 16 cm long line and asked to mark where along the line they felt the stimulus fit (i.e., a continuous rating scale). Animacy ratings ranged from “Definitely not alive” to “Definitely alive” (a similar scale is used by both Pyles et al., 2007 and Tavares et al., 2008). “Humanness” ratings could range from “Definitely not human” to “Definitely human”. The explicit distinction between animacy and humanness is of interest in assessing contributions of local and global motion cues to the subjective perception of animacy. Both human biological and scrambled biological animations contain identical motion trajectories, but differ in global shape. It is possible that local motion cues are sufficient to create perceptual animacy, thus rendering scrambled motion and biological motion equally animate (scrambled motions may appear to represent an animate non-human entity). It is also possible that recognizable global “animate” shapes (i.e., humans) inflate ratings of animacy relative to scrambled biological motion even though motion information is identical in the two animations. The final rating of speed ranged from “Not moving” to “Extremely fast”; this scale was used to control for the potential conflation of perceived animacy with increased speed (e.g., Tremoulet & Feldman, 2000). All biological and scrambled stimuli contain identical motion information (i.e., move at the same speed).

Figure 1. Typical trial structure across all three experiments. After a 500 msec fixation, two motion stimuli appeared simultaneously. After a variable interval, one stimulus disappeared. Participants responded to the disappearance.
2.3 Data Analysis

All data were analyzed using R (R Development Core, 2011), and the R packages \texttt{lme4} v.0.999375-41 (Bates, Maechler & Bolker, 2011), \texttt{languageR} v.1.2 (Baayen, 2011) and \texttt{LMERConvenienceFunctions} (Tremblay, 2011). In all experiments, data were analyzed using linear mixed-effects modeling with maximum-likelihood estimation (Baayen, Davidson & Bates, 2008; Faraway, 2006). This technique allows for richer random effects structures to be modeled and accounts for violations of sphericity assumptions by modeling heteroskedasticity in the data when necessary, improving statistical power over other methods commonly employed for analyzing repeated-measures data. Further, one factor of interest the present experiments is whether subjective ratings of stimuli can be used to predict changes in reaction time. Typical approaches to this type of question include aggregating ratings data and splitting subjects on the basis of “high” vs. “low” ratings for a mixed ANOVA, or performing multiple regression using ratings values as regressors. With the former technique, statistical power is lost when data are aggregated; using the latter technique, circuitous by-item and by-subjects regressions have to be computed to account for the non-independence of repeated-measures observations (e.g., Lorch & Meyers, 1990; Baayen et al., 2008; Baayen, 2008) to avoid violating the assumptions of multiple regression. Linear mixed effects modeling provides a method of implementing a regression-type analysis that accounts for by-subject variability and non-independent observations (Baayen et al., 2008; Baayen, 2008).

In all experiments, modeling was performed on a natural logarithm transform of reaction times (after error trials had been removed) to normalize the skewed reaction time distributions, and all continuous variables were centered prior to analysis. An initial mixed effects model was computed with the simplest random effects structure (by-subjects intercepts only), and data from this model were inspected for normality prior to analysis via quantile-quantile plots of residuals against fitted model values. All after outliers (residuals > 2.5 SD from the mean) were trimmed from the simplest random

\footnote{All current R packages are available for open-source download at http://cran.r-project.org/}
effects structure model, the optimal model was fitted by performing likelihood ratio tests, comparing the fit of models with mixed effects to the null model with by-subjects random effects only. Models that did not differ significantly from the null model were rejected. Throughout the results, conservative lower-bound estimated p-values significant at alpha = .05 are reported (see Appendix A for notes on model fitting and p-value estimation).

3 Experiment 1

3.1.1 Participants

Twenty-one participants were recruited via the University of Toronto undergraduate Psychology research subject pool and via recruitment posters approved by the UT Office of Research Services. Informed consent was obtained prior to participation and participants were compensated for participation either with course credit or $10. Of these, three participants were excluded from the analysis on the basis of technical problems with the eye tracking system.

3.1.2 Stimuli

A set of three stimuli was used to create two stimulus pairs for this experiment: an upright biological motion walker, an inverted walker, and a scrambled (upright) biological motion walker. In this experiment, walkers and the scrambled stimulus were front-facing and appeared to be traveling directly towards the observer (though the stimuli themselves maintained the same position on the screen and did not appear to become closer to the observer over time). One stimulus pair featured the upright walker and the scrambled stimulus together, while the second pair contained the inverted walker and the scrambled stimulus (one of either side of fixation, and both appeared with equal frequency on the left and right sides). All stimuli fit inside a 300x300 pixel region, subtending approximately 10 degrees of visual angle, and moved at an average speed of 2 deg/sec. The disappearance of the human or the scrambled stimulus was equiprobable for both stimulus pairs. Stimulus pairs were presented 40 times each for every combination of Stimulus Offset Time and Compatibility (which stimulus disappeared) for a total of 640 trials.
Prior to data analysis, stimuli were coded on the basis of the predicted attention capture effect(s). Trials on which the biological human walker disappeared were coded as “compatible” (regardless of orientation), based on the prediction that human motion may be more attentionally salient than the motion of animate, but non-human entities. Trials on which scrambled stimuli disappeared were coded as “incompatible”. However, there is some evidence to suggest that sensitivity to local motion in biological motion stimuli is greater in early processing, where sensitivity to global shapes is greater in later processing (e.g., Jiang, Zhang & He, 2009; Chang & Troje, 2009). Thus, a three-way interaction between Stimulus Pair, Compatibility, and Stimulus Offset Time was predicted based on the inversion of the walker in the second stimulus pair.

### 3.1.3 Results & Discussion

A summary of the best fitting model can be found in Table B1 (Appendix B). The optimal LME model for this experiment included ratings of Speed as a covariate, and a random effects structure that included by-subject intercept adjustments to RT, as well as by-subjects slope adjustments to both the effects of Compatibility and Stimulus Offset Time (see Appendix A). The fixed effects modeled included: Stimulus Pair (SP), Compatibility, Stimulus Offset Time (SOT), Alive ratings, and Human ratings.

There was a significant main effect found for SOT, $F(3,10870) = 5.91, p = .0005$ (Figure 2). Post-hoc analyses, Bonferroni-corrected for six comparisons, indicated that participants responded significantly faster to stimuli after the 200 msec offset than to all other offset times (200 vs. 100: $t(10870) = 4.90, p = .0003$; 200 vs. 500: $t(10870) = 3.04, p = .0144$; 200 vs. 900: $t(10870) = 2.86, p = .0257$). Reaction times for the 100, 500, and

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2 As continuous variables, ratings could theoretically be modeled as random effects, as their values can be said to have been drawn from a probability distribution of ratings in a population (e.g., McCullough, Searle & Neuhaus, 2008). However, each subject made only 3 ratings (one for each stimulus in the experiment), which were entered into the data on a per-trial basis and thus repeated within subjects. Thus ratings are fixed for each subject, and modeled as fixed effects. Additionally, the conceptual motivation for including ratings in the model is to assess whether they can be used as predictors for reaction time (as in multiple regression), so they are treated as factors. The optimal LME model supported this choice, as likelihood ratio comparisons of models with ratings as random effects were not significantly better than the null model.

3 Unless otherwise stated, all corrections were performed using the Bonferroni adjusted $p$-values.
900 msec offset times did not differ significantly from one another.

An analysis of error rates for each SOT did not indicate the presence of a speed-accuracy tradeoff on trials with 200 msec offset times. Event-related potentials (ERP) research on biological motion perception demonstrates differential processing of upright and inverted stimuli as early as 150-200 msec post-stimulus-onset (e.g., Jokisch, Daum, Suchan & Troje, 2005). Visual adaptation studies have further suggested that integration of form and motion cues occurs prior to 200 msec post-stimulus onset (Baccus, Mozgova & Thompson, 2009), indicating that local motion cues are processed very rapidly. Jiang, Zhang and He (2009) have also shown using ERP that local motion signals may be processed prior to 160 msec post-stimulus. It is possible that, since all stimuli in this experiment contained at least one instance of upright local biological motion cues, a

Error bars are not plotted because this function is not currently supported for the lme4 package in R. The benefit of plotting in R is that figures may be generated based on model data, for which adjusted intercepts are plotted to visualize effects as they are calculated by the model (e.g., rather than using another plotting software to generate figures from a data spreadsheet).

Figure 2. Reaction time in milliseconds at each SOT in Experiment 1.4
global effect of attentional salience was observed, such that responses were fastest for the SOT most closely corresponding to actual processing speed. In other words, if local motion cues are indeed processed early, with integration of form and motion cues occurring prior to 200 msec, the speeding of RTs for the 200 msec offset may indicate an effect of facilitation in processing animate stimuli.

Figure 3. Reaction time in milliseconds plotted for compatible and incompatible trials. The difference in reaction time across compatibility indicates an effect of attention capture by scrambled motion (i.e., participants are faster to respond on incompatible trials).

A significant main effect was also found for Compatibility, $F(1,10870) = 9.07, p = .0026$ (Figure 3). Contrary to the hypothesis that human motion would capture attention over scrambled biological motion (which appears animate, but not human), response times were significantly faster overall for trials coded as incompatible relative to compatible trials (approximately 15 msec). That is, when the scrambled stimulus disappeared, participants responded faster than when a human stimulus disappeared, regardless of the orientation of the human stimulus (upright vs. inverted). Following Beck and Kastner (2005), an analysis of error rates was performed for compatible vs.
incompatible trials; if spatial attention is captured by scrambled stimuli, error rates should be lower when scrambled stimuli disappear (i.e., error rates for “incompatible” trials should be lower than for “compatible”). A paired-samples t-test on the percent errors made during compatible and incompatible trials confirmed this ($t(17) = 4.39, p = .0002^5$), suggesting that scrambled biological motion induced a shift in spatial attention when paired with human biological motion in this experiment. Thus, participants were faster and more accurate in responding to the disappearance of scrambled stimuli.

![Figure 4](image)

*Figure 4.* Reaction time in milliseconds plotted for the interaction of SP x Alive ratings at each SOT. Blue lines represent the effect of Alive ratings for SP1 (upright+scrambled); red lines indicate the effect of Alive ratings for SP2 (inverted+scrambled).

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^5 There was no evidence that the proportion of errors differed across SOT (i.e., no effect of speed accuracy tradeoff, particularly with respect to the 200 msec offset time), and no evidence that errors on compatible vs. incompatible trials differed across SOT, thus error analyses were collapsed across this factor.
There was also a significant 3-way SP x SOT x Alive Rating interaction, \( F(3,10870) = 4.34, p = .0046 \) (Figure 4). Post-hoc analyses, corrected for eight comparisons, were performed to compare the SP x Alive simple effects separately at each SOT. For SP1 (upright walker + scrambled) at 900 msec SOTs, there was a significant effect of Alive ratings on reaction time \( (b = .0007, SE = .00025, t(10881) = 2.75, p = .0475) \) such that RT increased with increased ratings of Aliveness, with a difference of approximately 23 msec between the lowest and highest ratings (Figure 4, panel D). No other comparisons survived correction for multiple comparisons, though for SP2 (inverted walker + scrambled) at 100 msec offsets, there was a significant effect of Alive ratings before correction \( (b = .0005, SE = .00025, t(10881) = 2.107, p = .0351, \) uncorrected), such that RT increased approximately 15 msec between the lowest and highest Aliveness ratings (Figure 4, panel A).

The SP x SOT x Alive interaction demonstrated in two instances an increase in RT with higher subjectively-perceived stimulus “Aliveness”. From the attention literature reviewed above, which suggests that a higher degree of animacy should be associated with faster reaction times, these findings are puzzling. The results suggest, however, that attention was captured by scrambled stimuli in this experiment; these stimuli were rated as significantly less animate than upright biological motion walkers (see Appendix C). Parallel to slower RTs for “compatible” stimuli, it is likely that the longer RTs for highly ‘alive’ stimuli also represent this reversed compatibility effect; participants were faster to respond to less animate (scrambled) stimuli, than they were to respond to biological human motion.

In this experiment, all stimuli depicted front-facing motion (i.e., the biological motion walker appeared to be directly facing the observer, and the scrambled stimulus was matched to create this effect as well). Because stimuli are presented approximately 12 degrees into the visual periphery, it is possible that front-facing motion was simply too ambiguous to allow for rapid processing of global shape. Biological motion research investigating perception in the visual periphery has shown that left/right judgments of walker direction are possible even when masked in noise, provided that stimuli are scaled upward in size to compensate for their reduced representation in visual cortex. To further investigate the possibility that front-facing stimuli were too ambiguous, the following
two experiments used only left- and right-facing walkers and control stimuli.

4 Experiment 2

4.1.1 Participants

Seventeen participants were recruited via the University of Toronto undergraduate Psychology research subject pool and via recruitment posters approved by the UT Office of Research Services. Informed consent was obtained prior to participation and participants were compensated for participation either with course credit or $10.

4.1.2 Stimuli

Upright biological motion walkers moving to the left and to the right were used to create two stimulus pairs for this experiment. In one stimulus pair, both walkers faced the right while in the other stimulus pair, both walkers faced left. These stimuli all fit inside a 300x300 pixel square subtending 10 degrees of visual angle, and moved at an average speed of 2 deg/sec. The motivation for stimulus pair selection in this experiment was to determine, when stimuli on either side of the screen are identical, whether attention capture effects may be observed based on the direction of motion of the walker with respect to the observer. In the case that both walkers appear to be moving in the rightward direction, the stimulus on the left side of the screen will appear to participants to be approaching the central fixation (and thus, appear to be entering the central visual field), while the stimulus on the right will appear to be leaving the visual field (though again, stimuli walked ‘in place’ as if on a treadmill). This was motivated by the question of whether the potential for social interaction with a stimulus may be attentionally salient (e.g., do we automatically orient attention to animate entities that appear to be approaching us?).

For this experiment, stimuli were coded as compatible or incompatible on the basis of direction of motion with respect to the central fixation cross. Compatibility effects were predicted to occur for stimuli “approaching” the visual field, as motion towards the observer’s attentional focus was predicted to be more salient than motion away. Participants viewed 50 stimuli for each combination of direction of motion,
stimulus offset time (500 and 900 msec), and compatibility, for a total of 400 trials.

4.1.3 Results & Discussion

A summary of the best fitting model can be found in Table B2 (Appendix B). The optimal LME model for this experiment included Stimulus Pair as a covariate\(^6\), and a random effects structure that included by-subject intercept adjustments to RT, as well as by-subjects slope adjustments to the effect of Stimulus Offset Time. The fixed effects modeled included: Compatibility, Stimulus Offset Time (SOT), Alive ratings, and Human ratings.

\[ F(1, 6356) = 23.22, \ p < .0001, \]

A significant main effect of SOT was found, such that participants responded on average approximately 20 msec faster at the longer SOT.

\(^6\) In this experiment, the Stimulus Pair factor denotes only the direction of motion for stimulus pairs that are otherwise identical. Each pair contains two biological motion walkers, and both are walking to the right (SP1) or to the left (SP2). Stimulus Pair was included as a covariate in this analysis with the aim of accounting for variance due to individual differences in bias to direction of motion, but was not evaluated as a factor of interest in any interaction terms.
(900 msec) relative to the short (500 msec; see Figure 5). This effect of speeded responses on trials in which the response occurs later (i.e., long SOTs) is generally found in attentional cueing paradigms (e.g., Prinzmetal, Park & McCool, 2005). With longer pre-response intervals, more information is processed and there is more time to prepare the appropriate motor response.

![Graph](image)

**Figure 6.** Reaction time in milliseconds plotted for compatible and incompatible trials in Experiment 2. Faster responses indicate attention capture on compatible trials.

There was also a significant main effect of Compatibility, $F(1,6356) = 14.63, p = .0001$ (Figure 6). Unlike the results of Experiment 1, the effect appeared in the predicted direction, such that trials coded as “compatible” were responded to significantly faster than trials coded as incompatible (an effect of approximately 8 msec). Thus, when stimuli on both sides of the screen are identical, there is an effect of attention capture by direction of motion with respect to the observer. It is worth emphasizing that this is not simply a direction of motion effect, since both stimuli are moving in the same direction. Rather, the directional effect depends on whether the motion of the stimulus is salient from the point of view of the participant; motion into the central visual field captures attention, but motion in the same direction out of the visual field does not.
A two-way SOT X Human rating interaction was found, $F(1,6356) = 9.33, p = .0023$ (Figure 7), as well as a marginally significant SOT X Alive rating interaction, $F(1,6356) = 3.02, p = .08217$ (Figure 8).

Figure 7. Reaction time in milliseconds plotted for the effect of Human ratings at each SOT in Experiment 2. Red=500 SOT; Blue=900 SOT.

Post-hoc analyses were performed to examine the simple effect of Human ratings at each level of SOT. At both 500 and 900 SOTs, the slopes of the Humanness effect ($b = .0042, SE = .0034$; and $b = .0010, SE = .0032$, respectively) failed to reach significance, most likely due to the magnitude of standard errors for each. However, a comparison of the magnitude of slopes indicated that the effect of Human ratings at the 500 SOT was significantly bigger than that observed at the 900 SOT ($t(6356) = 3.06, p = .0023$); at 500 SOT, the lowest Human ratings were associated with RTs approximately 90 msec faster than those observed at the highest Human ratings. At 900 SOT, lower ratings were also associated with faster RT, an effect of approximately 25 msec.

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Because interactions with Alive ratings were predicted a priori, post-hoc tests are reported for this marginal interaction.
Figure 8. Reaction time in milliseconds plotted for the effect of Alive ratings at each
SOT in Experiment 2. Red=500 SOT; Blue=900 SOT.

Post-hoc tests for the SOT X Alive interaction did not reveal significant simple
effects of Alive ratings at either SOT (again, likely due to the magnitude of standard
error of the two slope estimates), but the comparison of the Alive effect between SOTs
(i.e., slope of Alive@500 SOT vs. slope of Alive@900 SOT) showed a significant
difference in the effect of Alive ratings ($t(6356) = 3.44, p = .0006$). For the 500 SOT,
there was a decrease in RT as Alive ratings increased, with a difference of approximately
65 msec between the lowest and highest ratings. For the 900 SOT, there was about a 25
msec increase in RT with increasing Alive ratings.

Comparing the pattern of reaction times for the SOT x Human and SOT x Alive
interactions, it appears that in both cases, the largest effect of ratings is manifest at the
500 SOT. The main effect of SOT indicated that the average reaction times for the 500
and 900 SOTs were approximately 455 and 435 msec, respectively. At 500 SOT, when
Human ratings were ‘average’ (i.e., near 0), RT was approximately the same as that
observed in the main effect of SOT (~450 msec). As is shown in Figure 7, much faster RTs are associated with very low ratings of humanness, while much slower RTs are associated with very high ratings. On the other hand, for the SOT x Alive interaction, the pattern of RTs at the 500 SOT is reversed; higher perceived aliveness is associated with a large decrease in reaction time. This effect is so large that, at the highest aliveness rating, the effect of SOT is eliminated altogether (see Figure 8).

As would be predicted by findings in the attention literature (e.g., Pratt et al., 2010), an increase in subjective sensitivity to perceiving animate entities predicts faster responding in this experiment, but only at the short (500 msec) SOT. Conversely, an increase in subjective sensitivity to perceiving global shape in point-light walker animations (i.e., perceiving human motion) predicts slower responding at both SOTs, with the largest effect observed at the short SOT. It appears that increased subjective sensitivity to perceiving animacy in moving displays is associated rapid responding, regardless of SOT. That is, if an individual has a low threshold for perceiving animate motion, perceptual processing (as reflected by RT) seems to be faster in general, eliminating the typically-observed slowing of RT on short trials. These results fit nicely with the effect of SOT observed in Experiment 1, where participants were overall fastest to respond after 200 msec. It appears that RT may be predicted to be faster not only when stimuli physically contain more animacy, but also when participants’ subjective impressions of animacy are higher. On the other hand, sensitivity to the type of animate entity in a display (i.e., sensitivity to human motion) predicts slower RTs. This may be explained by the complexity of processes that may be associated with animacy vs. social engagement. Detecting that an entity is human may be associated with a number of other processes (e.g., gender/affect/identity discrimination) that interfere with programming of motor responses.

These effects, as well as the lack of interaction between Alive and Human ratings, provide support for the idea that simple animacy detection and sensitivity to social relevance (i.e., sensitivity to type of animacy) are separate processes occurring rapidly but independently. Interestingly (though there is no interaction between ratings), the fastest RTs should be predicted for instances in which a stimulus appears highly animate, but not at all human. Implications of this are explored further in the general discussion.
5 Experiment 3

5.1.1 Participants

Twenty participants were recruited via the University of Toronto undergraduate Psychology research subject pool and via recruitment posters approved by the UT Office of Research Services. Informed consent was obtained prior to participation and participants were compensated for participation either with course credit or $10.

5.1.2 Stimuli

Three stimuli were used to create a set of five stimulus pairs for this experiment: an upright biological motion walker, a scrambled biological motion walker, and a coherent dot motion stimulus, matched for speed and the number of point-lights to the biological motion stimuli. Again, all stimuli fit in a 300x300 pixel box subtending 10 degrees of visual angle, and moved at an average speed of 2 deg/sec. Participants viewed 30 repetitions for each combination of stimulus pair, stimulus offset time and compatibility, for a total of 600 trials.

The first two stimulus pairs in the set were designed to further examine the effect of compatibility for motion towards the central visual field found in Experiment 2, to determine whether attention to motion towards fixation is a general phenomenon, unrelated to animacy or human motion. As such, compatibility effects for these two stimulus pairs was coded as per Experiment 2, with motion toward central fixation as “compatible”, and motion away from fixation as “incompatible”. Stimulus pair 1 consisted of identical coherent dot motion displays on either side of the screen, both moving in the same direction. Coherent displays (100% coherence) were matched to biological stimuli on the number dots, overall spread/size and speed of motion. Stimulus pair 2 contained scrambled stimuli on both sides. In both stimulus pairs, motion could be rightward or leftward, but both stimuli always traveled in the same direction.

The final three stimulus pairs were designed to examine whether attention capture by motion towards fixation is modulated by stimulus animacy. For all three pairs, motion on both sides of the screen was toward the centre, but stimuli in each pair differed.
Stimulus pair 3 featured coherent motion towards centre on one side and scrambled motion towards centre on the other; the fourth stimulus pair featured coherent motion and an upright walker; and the final stimulus pair featured an upright walker and a scrambled stimulus. As in Experiment 1, the fifth stimulus pair directly compared biological motion walkers to scrambled motion, but in Experiment 1 the stimuli faced frontward as if approaching the observer. As discussed above, it is possible that with these ambiguous stimuli, front-facing biological motion is simply more difficult to recognize in the periphery than side-facing motion, in which the movement of legs and arms is clearer. This stimulus pair was thus also designed to determine whether the reverse compatibility effect observed in Experiment 1 was replicable for side-facing biological motion.

For the last three stimulus pairs, in which motion on both sides of the screen appeared to be towards fixation, “compatibility” coding corresponded to the stimulus that was rated as more animate (see Appendix C) to assess whether attention capture by motion towards the centre is modulated by animacy. For instance, in stimulus pair 3, which compared coherent inanimate motion with scrambled biological motion, scrambled motion was predicted to capture attention (as it appears to be generated by a living entity, and ratings of animacy are significantly higher). For stimulus pair 5, however, which compared biological motion walkers to scrambled motion, scrambled was coded as “incompatible”, as ratings of animacy were significantly higher for the biological motion walker relative to the scrambled stimulus.

5.1.3 Results & Discussion

The optimal LME model for this experiment included Speed ratings as a covariate, and a random effects structure that included by-subject intercept adjustments to RT, as well as by-subjects slope adjustments to the effects of Compatibility and Stimulus Offset Time. The fixed effects modeled included: SP, Compatibility, SOT, Alive ratings, and Human ratings. A summary of the best fitting model can be found in Table B3.

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8 There was no significant difference in ratings of speed across the three stimuli used in the stimulus pairs for this experiment, as determined by a repeated-measures ANOVA (see Appendix B). Thus, Speed was added as a covariate to control for individual differences, but not as a predictor of interest.
The results of this experiment contained a number of main effects and 2-way interactions that were involved in 3-way interaction terms. The full report of significant effects for this model can be found in Table B3. For the purposes of simplicity and theoretical interest, only a subset of the significant main effects, interactions, and relevant post-hoc analyses are reported here.

**Figure 9.** Reaction time in milliseconds plotted for the effect of Stimulus Pair in Experiment 3. Participants are significantly faster to respond to SP5 than all other stimuli; SP2 also has significantly faster responses than SPs 1, 3, and 4. SPs 3 and 4 do not differ, and both are responded to significantly faster than SP1. Overall, this effect demonstrates increasing speed in parallel with increased physical animacy.

A main effect of SP was found, $F(4, 11169) = 51.39, p < .0001$ (see Figure 9). Post-hoc pairwise comparisons, corrected for 10 tests revealed that RT decreased proportionally with increased stimulus animacy. Responses were slowest overall for SP1, which contained only non-animate coherent motion (SP1 vs. SP2: $t(11197) = -12.22, p < .0001$; SP1 vs. SP3: $t(11197) = -8.68, p < .0001$; SP1 vs. SP4: $t(11197) = -8.37, p <$
and SP1 vs. SP5: \( t(11197) = -13.96, p < .0001 \). Stimulus pairs 3 & 4, in which one of the two stimuli contained animate motion, were responded to significantly faster than SP1 (but RTs did not differ between SP3 and SP4). Stimulus pair 2, in which both stimuli contained scrambled biological motion, was responded to significantly faster than SPs 1, 3, and 4 (SP2 vs. SP3: \( t(11197) = 4.83, p < .0001 \); SP2 vs. SP4: \( t(11197) = 3.66, p < .0003 \)). Finally, SP5, which contained a biological motion walker and scrambled biological motion was responded to fastest overall (SP5 vs. SP2: \( t(11197) = 3.09, p = .0020 \); SP5 vs. SP3: \( t(11197) = 7.16, p < .0001 \); SP5 vs. SP4: \( t(11197) = 7.53, p < .0001 \)).

In summary, the stimulus with no animate motion was responded to slowest; stimuli with a “middle range” of animacy were responded to faster than stimuli with no animacy, but slower than stimuli with high animacy. The stimuli with the most animate motion (i.e., both stimuli animate) were responded to fastest; further, stimuli containing human motion as one of the instances of animacy were responded to significantly faster than stimuli containing only scrambled biological motion. These findings fit well with previous research on animacy detection (e.g., Pratt et al., 2010; New, Cosmides & Tooby, 2007; Kirchner & Thorpe, 2006) and suggest that type of animacy (i.e., human vs. alive but non-human) may also modulate attention. An analysis of error rates across stimulus pair indicated that participants were not only faster for SPs 2 and 5, but significantly more accurate in these conditions than all for all other SPs.

A significant SP x Human ratings interaction was found, \( F(4,11169) = 2.89, p = .0211 \) (see also Figure 10). Simple effects tests, corrected for five comparisons, were performed to compare Human ratings at each SP. The effect of Human ratings on RT was only significant at SP4 (\( b = .0004, SE = .0001, t(11199) = 4.09, p = .0002 \)). High ratings of humanness were associated with slower RT, an effect of approximately 20 msec between the lowest and highest ratings. This stimulus pair contained coherent motion and a biological motion walker, and in this context it appeared that coherent motion captured attention (see below). As in Experiment 1, the effect of slower RTs with increased Human ratings in this context is likely a reflection of this reversed compatibility effect; coherent motion stimuli were rated significantly less human than the biological motion walker (see Appendix B), and so it is perhaps not surprising that, when collapsing across Compatibility at this SP, where coherent stimuli were responded to
approximately 25 msec faster, higher ratings are associated with slower responses.

Figure 10. Reaction time in milliseconds plotted for the Stimulus Pair X Human ratings interaction in Experiment 3. Each line represents the change in reaction time at one SP as a function of Human ratings. Black=SP1; Green=SP2; Blue=SP3; Brown=SP4; Red=SP5. The effect of Human ratings is significant for SP4 only.

An SP x Compatibility x Alive ratings interaction was found, $F(4,11169) = 3.46$, $p = .0079$ (see Figure 11). Simple effects analyses were performed at each SP, examining the effect of Compatibility (corrected for 5 tests) as well as the slope of Alive ratings (corrected for 10 tests).
Figure 11. Reaction time in milliseconds plotted for the Stimulus Pair X Compatibility X Alive ratings interaction in Experiment 3. Each panel represents the Compatibility X Alive ratings simple interaction at one SP. Blue lines represent the effect of Human ratings on Compatible trials; red lines represent the effect of Human ratings on incompatible trials. The simple effect of Compatibility was significant at SPs 1, 3, and 4 (panels A, C, and D, respectively), while the Compatibility X Alive simple interaction was significant at SPs 1 and 2 only (A and B).

At SP1, which contained only inanimate coherent motion, there was a significant effect of Compatibility ($t(11190) = 3.66, p = .0002$) such that stimuli coded as compatible were responded to significantly faster. The size of the Compatibility effect was modulated by Alive ratings. For low Alive ratings, the effect was approximately 7 msec, while at high Alive ratings, the effect was approximately 30 msec in magnitude. The effect of Alive ratings was only significant for compatible trials ($b = -.0006, SE = .0002, t(11190) = -3.42, p = .0060$), indicating that as subjective sensitivity to animacy increased, RT decreased (see Figure 11, panel A). It should be noted that “compatibility” in this stimulus pair refers to direction of motion with respect to the observer, as in Experiment 2. Importantly, as SP1 contained no actual animate motion, these results
suggest that this compatibility effect is sensitive to individual differences in animacy sensitivity; when participants subjectively perceived more animacy in coherent motion, the compatibility effect was approximately three times larger. Further, while participants responded at approximately the same speed regardless of Alive ratings for incompatible trials, high Alive ratings were associated with decreased RT for compatible trials. This distinction highlights the salience of animate motion coming towards the observer; regardless of animacy sensitivity, RT to motion away from the observer is about the same speed, but when stimuli move towards the central visual field, high animacy sensitivity predicts a stronger capture of attention.

For SP2 (scrambled + scrambled), no effect of Compatibility was observed ($t(11190) = 0.43$), but the slope of Alive ratings was significant for trials coded as incompatible ($b = -.0008, SE = .0002, t(11190) = -3.39, p = .0070$ (see Figure 11, panel B). This effect indicates that RT decreases significantly as ratings of aliveness increase, an effect of approximately 40 msec from the lowest Alive rating to the highest. Though the slope of Alive ratings for compatible trials failed to reach significance, the analysis showed that the effects of Alive ratings did not differ significantly between compatible and incompatible trials (indicating that RT for compatible trials also showed a negative trend with increased ratings of aliveness).

Both SP3 and SP4 showed significant effects of Compatibility, but no significant effects of Alive ratings after correcting for ten comparisons. For SP3, participants were approximately 35 msec faster to respond on trials coded as incompatible ($t(11190) = -9.31, p < .0001$). For SP4, RTs were approximately 25 msec faster for trials coded as incompatible ($t(11190) = -2.79, p = .0265$). Importantly, SPs 3 and 4 were pairs in which both stimuli depicted motion towards the central visual field; in SP3, coherent motion was paired with scrambled biological motion, while in SP4, coherent motion was paired with a biological motion walker. The finding that “incompatible” trials are responded to faster indicates that coherent, inanimate motion seems to be capturing attention. As in Experiment 1, an analysis of error rates was performed to determine whether accuracy differed for compatible vs. incompatible trials for SPs 3 and 4; for both SPs, error rates were significantly lower on incompatible trials (SP3: $t(19) = 3.32, p = .0018$; SP4: $t(19) = 4.59; p = .0001$), suggesting that participants’ spatial attention is allocated to coherent
motion in the context of these stimulus pairs. These results are opposite of the predicted effect of attention capture by animate motion. However, since stimuli are presented in the visual periphery, it may be easier to discriminate the direction of motion of coherent stimuli. In biological motion walkers (and scrambled control stimuli), though the overall direction of walking may be leftward, at any given subset of frames of the animation, some point-lights may be moving towards the right (e.g., the swinging back-and-forth trajectory of arm motion during the gait cycle contains motion in both directions). At the level of local motion cues, this may make the biological motion stimulus more ambiguous than the coherent motion stimulus, in which all point-lights move consistently in the same direction. It may be the case that in SPs 3 and 4, the direction of motion of the coherent stimulus was too salient/easy to discriminate, and decreased the sensitivity of the paradigm to observing differences between animate and inanimate motion. The results shown for SP1, however, in which both stimuli are coherent, do reliably suggest an effect of animacy sensitivity on attention capture by motion direction. Further research comparing these coherent stimuli with biological motions should control for this potential confound via matching stimuli on the amount of dots moving in either direction.

No significant effect of Compatibility, and no effect of Alive ratings on Compatibility were observed at SP5, which contained a biological motion walker and a scrambled stimulus, both moving towards centre with respect to the observer. The lack of Compatibility effect here indicates that attention was not captured by one stimulus relative to the other. Contrary to the findings of Experiment 1, which demonstrated a ‘reverse’ compatibility effect for scrambled stimuli, when the stimuli face left or right rather than towards the front, neither the walker nor the scrambled control seem ‘win out’ in terms of salience. Anecdotally, it seemed that participants were more likely to recognize the global shape of biological stimuli in this experiment as compared to Experiment 1, with many participants commenting that some stimuli looked like men walking or chickens/dinosaurs/a person riding a horse (subjective perception of scrambled stimuli was varied and quite creative, but the general tendency was to describe motion in terms of an animate entity). A direct comparison of ratings between front- and side-facing stimuli was not performed, as participants different between experiments, and
within each, participants rated only the stimuli they viewed in the task. Left/right-moving stimuli are used in a large number of studies on biological motion perception, and performance on tasks requiring discrimination of motion direction is about equal for walkers and scrambled controls, even within autistic participants (e.g., Rutherford & Troje, in press; Murphy et al., 2009). Because the walker and the scrambled control do contain identical motion trajectories, it is possible that the lack of Compatibility effect in SP5 results from a combination of the fact(s) that stimuli are easier to discriminate, and that physically, they contain the same amount of animacy at the level of local motion cues.

![Figure 12](image)

**Figure 12.** Reaction time in milliseconds plotted for the Stimulus Pair X SOT X Alive ratings interaction in Experiment 3. Each panel represents the SOT X Alive ratings simple interaction at one SP. Red lines indicate the effect of Alive ratings on response times at the 500 SOT; blue lines represent the effect of Alive ratings at the 900 SOT. The simple effect of SOT was significant at all SPs, while the SOT X Alive simple interaction was significant at SPs 3 and 4 only (panels C and D, respectively).

The SP x SOT x Alive ratings interaction was also significant, $F(4,11169) = 3.28$, $p = .0108$ (see Figure 12). Simple effects analyses were performed to examine the effect of SOT and the influence of Alive ratings on SOT at each SP. For SPs 1, 2 and 5,
significant effects of SOT were found (SP1: \( t(11190) = -6.33, p < .0001 \); SP2: \( t(11190) = -5.22, p < .0001 \); SP5: \( t(11190) = -5.63, p < .0001 \), but there was no modulation of the SOT effect by Alive ratings. In all cases, the simple effect of SOT was the same as the main effect of SOT, in that the 900 SOT was responded to faster than the 500 SOT.

For SP3, there was a significant effect of SOT (\( t(11190) = -8.24, p < .0001 \)). At this SP, there was a significant effect of Alive ratings on the 500 SOT (\( b = .0011, SE = .0002, t(11190) = 6.06, p < .0001 \)) such that as ratings of aliveness increased, participants were slower to respond (by approximately 50 msec between the lowest and highest ratings; see Figure 12, panel C). These effects were also observed in SP4, where there was a significant SOT effect (\( t(11190) = -5.70, p < .0001 \)) and effects of Alive ratings at both the 500 and 900 SOTs. For the short SOT, an increase in subjective sensitivity to animacy was associated with slower responses (\( b = .0013, SE = .0002, t(11190) = 8.55, p < .0001 \)). Response times increased approximately 60 msec between the lowest and highest Alive ratings (see Figure 12, panel D). For the long SOT, higher Alive ratings were also associated with slower RTs, an effect of about 33 msec (\( b = .0007, SE = .0002, t(11190) = 4.82, p < .0001 \)). As discussed above in the context of the SP x Human interaction, these effects seem simply to parallel the Compatibility effect observed for SPs 3 and 4. Coherent motion is rated as less alive than human and scrambled motion (see Appendix B), but in these SPs, coherent motion is responded to more rapidly. The effect of slower responses with higher ratings of aliveness here reflects the general finding that participants are faster to detect the disappearance of coherent motion relative to biological motions.

6 General Discussion

The experiments reported here replicate and extend previous research on animacy detection and animacy experience. Using a modified target detection paradigm, in which participants were presented with displays containing two moving stimuli, one on either side of a central fixation (where the ‘target’ is the disappearance of one stimulus), the present study demonstrates attention capture effects by animate motion, and how capture is modulated by the degree of both physically present and subjectively perceived animacy. Using participants’ own subjective ratings of stimuli as predictor variables in a
linear mixed-effects regression, the results demonstrate that subjective ratings do reliably predict response times on these perceptual/attentional tasks. These results provide support for the hypothesis that perceptual processes related to animacy detection and recognition may form the basis for more complex ‘higher order’ processes involved in social cognition (equivalently, reaction times could be used to predict subjective ratings, with the theoretical perspective that perceptual processes are involved in these complex judgments). Because stimulus/motion type is task-irrelevant in all experiments, and because stimuli are presented in the periphery while participants are instructed to attend to a central fixation, there is no reason to expect that ‘higher order’ subjective impressions are responsible for modulating reaction time in a top-down fashion in this context. Further, Experiment 1 demonstrates effects of attention capture and subjective ratings as early as 100 msec post-stimulus-onset, suggesting that the differences predicted by knowing participant ratings arise from extremely early (possibly pre-attentive) processes.

6.1 Attention capture by motion towards the observer

To the author’s knowledge, this is the first study to report an animacy-modulated attention capture effect by direction of motion with respect to an observer. This effect was shown in Experiments 2 and 3, in which participants were presented with displays containing two identical stimuli moving in the same direction. In both cases, attention was captured by the stimulus appearing to enter the observer’s central visual field; in other words, in a display where the only difference between task-irrelevant stimuli was their direction of motion with respect to the participant, the stimulus that appeared to be approaching the participant’s region of fixation captured attention. In Experiment 2, this was observed for displays containing biological motion walkers. In Experiment 3, the same effect was found for displays in which stimuli contained only coherent, inanimate motion; however, in this context, the attention capture effect observed was highly dependent on participants’ subjective sensitivity to animacy (see Figure 11, panel A). That is, the effect of attention capture in the coherent condition was approximately three times larger (30 msec vs. 7 msec) for participants who rated coherent stimuli as “very alive”. Further, ratings predicted reaction time for compatible trials only: when the stimulus moving out of the observer’s visual field disappeared (Incompatible), there was
no difference in RT across ratings, but when the stimulus appearing to move into the observer’s central visual field disappeared (Compatible), participants who rated coherent motion as highly animate responded approximately 32 msec faster than those who rated low on the animacy scale. Additionally, in Experiment 3, though the Compatibility effect for the scrambled condition (SP2) failed to reach significance, there was a significant decrease in RT with increasing Alive ratings, indicating that higher subjective sensitivity to animacy was again associated with faster processing. From the present results, the effect of attention capture by motion direction seems to be influenced by either physically present animacy or subjectively perceived animacy, depending on available visual information. In Experiment 2, no effect of ratings was found modulating the capture effect for human biological motion walkers (i.e., capture was by physically present animacy); in Experiment 3, subjective sensitivity to animacy explained most of the variance related to the compatibility effect found for coherent motion (i.e., capture by subjectively perceived animacy). This pattern of findings suggests that the salience of animate motion is increased when motion is detected as being towards the central visual field of the observer. The lack of modulation by ratings in Experiment 2 may be reflective of the smaller range of Alive ratings given by participants to the human walker.

These findings present compelling evidence that subjective impressions of animacy may arise from perceptual processes. When the type of stimulus on either side of the screen is identical and task-irrelevant, it is unlikely that attention capture would arise from top-down modulation. Further, for inanimate stimuli, only those participants who were highly sensitive to perceiving animate motion where there was none exhibited showed large attention capture effects in this context, indicating that capture is dependent on animacy experience (whether motion is animate, or inanimate motion is perceived as animate). These effects cannot be explained simply in terms of direction selectivity; both stimuli always moved in the same direction, thus capture by one indicates an effect of self-relevant salience. Further, the salience of motion approaching the observer was modulated by whether it was perceived to be animate; the approach of inanimate motion did not result in large attention capture, while approaching animate motion decreased reaction times by a much larger magnitude (the fact that magnitude of capture varied
between human and coherent stimulus pairs may be an effect of motion signal strength; for more discussion of this, see section 6.3.2).

The mechanism by which this attention capture occurs would have to be carried out very early in visual processing. Research on non-human primates has demonstrated direction-selectivity of cells as early as area V1 (Hubel & Wiesel, 1977), with increasingly selective tuning as processing moves further upstream (e.g., Maunsell & van Essen, 1983). Cells in area MT of the macaque brain have been shown to possess both direction-selective properties and sensitivity to patterned motion, requiring specific tuning for both object orientation and direction (Rodman & Albright, 1989). Further research indicates that some neurons within macaque MT have the capacity to integrate motion signals over time to perform structure-from-motion recognition (Grunewald, Bradley & Anderson, 2002). With respect to the present findings, attention capture by self-relevant direction of motion by animate entities would necessarily incorporate these capabilities of the visual system; activity in direction-selective cells would have to be modulated by stimulus salience/animacy to distinguish which of two stimuli moving in the same direction should be considered important. This finding suggests that evaluation of animacy in moving stimuli must occur during or prior to analysis of motion direction within area MT/MST. Zhang and Luck (2008) demonstrate that attention to specific features of a stimulus can influence feed-forward visual processing when multiple stimuli compete for visual representation. Participants in this experiment were instructed to attend to one of two colours in an array of dots presented in one visual field; the authors recorded ERPs while participants performed luminance change detection for either red or green dots in the display. Periodically, a task-irrelevant display of dots (either all red or all green) was presented in the opposite, unattended visual hemifield. Results showed that the amplitude of the P1 component (first positive ERP component, occurring approximately 100 msec post-stimulus) was modulated by feature-specific attention. When participants’ task was to attend to luminance changes in red dots, the P1 was larger to distractor arrays in the opposite visual field when they were red relative to green. From this the authors concluded that feature-based attention may influence how subsequent visual information will be processed.
There is strong evidence that animacy detection is an ‘ultra-rapid’ (e.g., Kirchner & Thorpe, 2005) reflexive process occurring extremely early in visual processing. It is possible that in the absence of instructions to attend to specific stimulus features, animacy is salient enough to influence feed-forward processing in the visual stream. In other words, detecting motion as animate may influence how direction-selective cells will respond to competing stimulus inputs, upregulating responses to stimuli that appear to be moving in a particular direction with respect to the observer, and allowing further cognitive resources to be devoted to processing potentially self-relevant agents. Such a finding would be highly suggestive that at least some aspects of social cognition, such as the capacity to participate in interactive behaviours, may be rooted in perceptual processes.

6.2 What drives attention capture?: Local vs. global cues

The results of Experiment 3 demonstrate that the compatibility effect seems particularly sensitive to local motion cues. When presented with stimulus pairs containing a biological motion walker paired with scrambled motion, with both stimuli moving towards centre, no effect of compatibility (i.e., attention capture) was observed. Though interpreting null effects is generally not advised, because the physical parameters of these stimuli are matched so tightly (i.e., they contain identical motion trajectories, and differ only in global shape), it is reasonable to conclude that at the level of attention, these stimuli are perceived as equally animate. Though participants rated scrambled stimuli as significantly less animate than upright walkers (see Appendix C), it is possible that in the periphery it is harder to discern global shape (direction of motion discriminations are highly accurate in the periphery for unmasked stimuli, e.g. Gurnsey, Roddy & Troje, 2010; Thompson, Hansen, Hess & Troje, 2007; to the author’s knowledge, no study has explicitly tested whether global form recognition suffers outside of central vision). If this is the case, it is likely that the observed effects (or lack thereof) of compatibility for these stimuli are driven by sensitivity to local biological motion cues. Troje and Westhoff (2006) demonstrate that direction information is retained in scrambled stimuli as long as they are presented in the upright orientation. Performance accuracy for discerning direction of scrambled stimuli was lower than for biological motion, but still well above chance levels. Williamson, Jakobson and Troje (2007) have shown further that people
are able to discern the direction of side-facing biological motion and scrambled stimuli in the periphery on the basis of local motion cues when stimulus presentation is as short as 170 msec (i.e., depicting only a fraction of the gait cycle). Chang and Troje (2008) demonstrate similar effects in the central visual field for heavily masked stimuli, regardless of whether the point-light stimulus depicts a human, cat, or pigeon; under these circumstances, participants were again less accurate for scrambled stimuli, but still able to discern motion direction at stimulus presentations as short as 200 msec.

Additionally, though attention capture effects were not observed in all conditions, the results of both Experiments 1 and 3 suggest that there may be some attentional facilitation effects induced by animate motion that are not reflected in compatibility comparisons. In Experiment 1, a significant effect of SOT was observed such that participants were much faster (about 25 msec, on average) to respond on trials after 200 msec SOTs than on all other trials. Previous research suggests that local animate motion cues are processed very early and facilitate responding on attention-related tasks. Wang, Zhang, He, and Jiang (2009) have shown that sensitivity to local biological (and scrambled biological) motion cues speeds visual search. The authors demonstrated a visual search asymmetry dependent on upright local motion cues when stimuli depicted scrambled biological motions or consisted of animations depicting only the feet of a point-light walker. Participants were significantly faster at detecting an upright stimulus in an array of inverted distractors (completing the task in an average of 209 ms) than they were at detecting an inverted target in an array of upright distractors. Jiang, Zhang and He (2009) also provide evidence that local biological motion cues are processed reflexively and automatically. Using a similar paradigm as the present study, the authors presented participants with visual displays containing upright and inverted scrambled biological motions on either side of fixation; these ‘cues’ were shown for 500 msec, after which they disappeared. Following the disappearance, participants were required to respond to the appearance of a target on one side of the screen. Participants were significantly faster to detect targets appearing in locations preceded by upright scrambled motion, though they were unable to report which stimuli were upright and inverted while viewing them in the visual periphery. Further, ERP measures indicated that sensitivity to
upright local motion cues was manifest as early as 160 msec post-stimulus over cortical regions involved in processing prior to MT-STS biological motion processing.

These results suggest that attention is captured by local biological motion cues that are upright with respect to gravity. If this is the case, it is possible that attention is captured in a more global sense on trials in which motion is animate, and that participants demonstrated a facilitation of responding at the 200 msec SOT because it occurs in close temporal proximity to the early processing of these motion cues. This interpretation would also suggest that the attentional mechanism by which this facilitation occurs is anatomically close to (if not the same as) the area involved in processing local biological motion cues.

The main effect of Stimulus Pair in Experiment 3 is also indicative of a broader influence of animacy on attention than can be described by compatibility comparisons. This main effect demonstrated a proportional decrease in RT with increasing stimulus animacy. Overall, coherent inanimate stimulus pairs were responded to slowest, and stimuli with two instances of animate motion were responded to fastest. Further, stimuli with a human walker as one of the animate motions were responded to significantly faster than stimuli with two scrambled animations. There was no evidence of speed-accuracy tradeoff for the speeded responses to biological motion (indeed, participants were more accurate for these stimulus pairs). Again, these results seem to demonstrate a broader effect of attention capture by animate motion, in addition to the observed compatibility effects. The fact that stimuli containing human motion were responded to more quickly than stimuli containing two scrambled motions suggests that at this level of attention, there may be some modulation by type of animacy, indicating a sensitivity to global motion cues (and possibly to social relevance) that is not manifest in compatibility effects.

This interpretation is supported by previous findings in the attention literature. New, Cosmides and Tooby (2007), as described in the Introduction, demonstrate that people are significantly faster and significantly more accurate at detecting changes in natural scenes with animals than with any other object category, suggestive of an overall capture of attention by animate entities (e.g., changes to these scenes did not necessarily
occur on the animals themselves, indicating that attention to animate entities in the scene broadened attentional focus to the surroundings as well. However, New and colleagues did not find any differences in attention capture for scenes with human vs. non-human animals, while the main effect of Stimulus Pair here indicates that there may be some such effect when stimuli involve dynamic motion information in addition to object/shape information. Kirchner and Thorpe (2006) also show that when presented simultaneously with two visual scenes and instructed to make eye movements towards scenes with animals, participants make saccades to scenes containing animals in as little as 120 msec. Importantly, because this task required a decision to make eye movements by subjects, these findings indicate that visual analysis of two natural scenes, detection of an animate entity, and conscious execution of an eye-movement to the scene containing an animal all occur reliably within 120 msec of stimulus presentation, in what the authors term ‘ultra-rapid’ detection of animate ‘objects’. The presence of broad attentional effects induced by animacy fit well with previous research suggesting that the presence of animacy shifts the focus of attention and facilitates more rapid processing of visual inputs.

6.3 Reconciling unexpected effects

6.3.1 Reversed compatibility: Upright vs. Scrambled

The present set of experiments contains some puzzling results in addition to predicted outcomes. For instance, the results of Experiment 1 stand in conflict to those of Experiment 3, in which no compatibility effect was observed for the comparison of biological motion walkers and scrambled motion. Experiment 1 also directly compared these stimuli and showed that scrambled stimuli captured attention, as participants responded on average 15 msec faster to the disappearance of scrambled stimuli. However, as mentioned in the discussion of Experiment 1, the stimuli depicted front-facing motions rather than the left/rightward motion used in Experiment 3. These stimuli contain, overall, shorter motion trajectories than side-facing stimuli (e.g., the display is 2-dimensional, thus depth information regarding stride and arm movement is reduced), and have been shown in some cases to be perceived as bistable (Vanrie, DeKeyser & Verfaillie, 2004), meaning that the direction of motion is also more ambiguous, with
some observers reporting that the walker appears to be facing away. In this context, the stimuli are likely more unfamiliar to the observer, with the scrambled stimulus appearing quite odd.

Developmental research on animacy detection indicates that attention may be captured by ‘anomalous’ animate entities (Poulin-Dubois et al., 1996). In a study of infant looking-time and affective reaction, the authors compared responses to prototypical biological motion and ‘anomalous’ animacy (a remote-controlled robot performing biological motions), and found that infants looked more at the robotic agent and reacted negatively to it, which the authors interpreted as indicating that the agent was anomalous. This affective reaction was modulated by whether infants had previously been exposed to the robot in a non-motion condition, leading the authors to suggest that perceived ‘anomaly’ was dependent on the likelihood or appropriateness of autonomous motion by a previously inanimate agent. From this, the authors concluded that infants as young as nine months demonstrate sensitivity to the distinction between inanimate and animate agents, and that when an agent appears anomalous, attention is drawn to its motion. There is very little research on biological motion perception in adults involving ‘anomalous agents’, but it has been shown that the same structures responsive to biological motion are activated by the same types of motion depicted by non-human agents such as computer-generated robotics animations (Pelphrey, Mitchell, McKeown, Goldstein, Allison, & McCarthy, 2003). Whether attention was increased when participants viewed this agent was not investigated.

Further to the hypothesis of attention capture by anomalous animacy, the interactions with ratings observed in Experiment 2 indicated that, while increased ratings of Aliveness are associated with decreases in RT, increased ratings of Humanness predict slower responding. As mentioned, from this one would predict that the fastest responses should occur for stimuli rated as very alive, but not very human (e.g., ‘anomalous’ biological entities). Such an explanation would be evolutionarily parsimonious; it would of course be adaptive to rapidly orient to atypically encountered entities, since their presence could signal danger. Further testing of this hypothesis is necessary to draw such a conclusion, especially as there was no interaction between Alive and Human ratings in Experiment 2, but it is possible that front-facing scrambled stimuli are perceived as
‘anomalous’ biological entities in the context of Experiment 1 and that this is responsible for the observed ‘reverse’ compatibility effect.

6.3.2 Reversed compatibility: Coherent vs. Biological motion

Reverse compatibility effects were also observed in Experiment 3 when comparing coherent, inanimate motion to scrambled and biological motions. As suggested in the discussion of Experiment 3, it is not possible to tell whether this effect of attention capture by coherent motion is genuine or due to potential confounds within the stimuli. Coherent motion stimuli were matched only for the general direction of biological motion, not taking into account that within biological motion stimuli, subsets of point-lights may be moving in different directions at any given time. It may be the case that direction of coherent motion in this context is more salient simply because the motion signal is stronger and/or more predictable. Coherent motion is known to robustly activate human area MT/MST (e.g., Braddick, O’Brien, Wattam-Bell, Atkinson, Hartley & Turner, 2001), and performance on coherent motion detection tasks is equally accurate throughout the visual field if peripherally presented stimuli are scaled adequately in size (van de Grind, van Doorn & Keonderink, 1983). When paired with biological motion containing ambiguous bi-directional motion cues, perfect coherence may have been too strong a motion signal. Thus it is not possible to conclude whether such inanimate motion would always capture attention when placed in competition with biological animacy, or whether the stimuli used in these particular conditions reduced the sensitivity to detecting such an effect. Further testing using inanimate stimuli matched for degree of bi-directional motion is required to draw conclusions regarding attention capture.

6.3.3 Ratings results

At first glance, the effects of ratings seem to conflict as well. In Experiment 1, for SOTs 100 and 900, Alive ratings predict slower responses. This is also the case in Experiment 3, for SPs 3 and 4. However, for SPs 1 and 2 (Experiment 3), higher ratings of aliveness predict faster responding, an effect which is also observed in Experiment 2. Importantly, when both stimuli in the pair are identical, Alive ratings are associated with faster responding. Further, in the coherent stimulus condition, subjective sensitivity to animacy is largely driving the attention capture effect, in that only those highly sensitive to
perceiving animacy demonstrate a large (32 msec) decrease in RT for compatible trials. When stimuli differ, higher Alive ratings predict slower responses (with the exclusion of the biological motion vs. scrambled comparison in Experiment 3). It should be noted that all instances in which high Alive ratings predict slower responding, there have been ‘reverse’ compatibility effects. For Experiment 3, in comparing coherent motion with biological motion, this compatibility effect is attributed to a potential confound, as discussed in the previous section, thus it is difficult to reliably conclude whether subjective sensitivity to animacy slows responses. In this context, ratings data seem to echo the compatibility effect by showing that less animate stimuli are capturing attention; however, given the evidence that, more broadly, a higher degree of physical animacy leads to significantly faster responses regardless of compatibility or SOT (see section 6.3.1), it is likely that the effect of ‘slowing’ by Alive ratings is not predictive of anything beyond what is demonstrated by Compatibility. The same slowing of responses with increased animacy ratings is observed in Experiment 1, in which stimuli also elicited a reverse compatibility effect. The potential attention capture by anomalous animate motion discussed in section 6.3.1 should be further explored; when allowed to look directly at stimuli for as long as was necessary to assess them for the purpose of subjective ratings, participants rated the human walker significantly more alive than the scrambled stimulus. However, with front-facing stimuli, accuracy of recognition in the visual periphery has not been explicitly tested. It may be that when ambiguous front-facing biological motion and scrambled stimuli are only viewed in the periphery for intervals ranging between 100 and 900 msec, the subjective impression of stimuli may differ. Further testing should examine recognition abilities and subjective impressions of peripheral front-facing motion to assess this question.

6.4 Summary & Conclusions

The present set of experiments investigated the nature of attention capture by animate motion and the relationship between early perceptual/attentional processes and ‘higher order’ subjective impressions of animacy. Evidence suggests that these subjective impressions, traditionally considered to be higher functions separate from modal processes, may be integrally rooted in early mechanisms of animacy detection and recognition. Though Experiment 3 suggests that attention may be captured by coherent
motion when viewed in competition with biological motion, the potential for stimulus confounds in these conditions should be further investigated before conclusions are drawn. Results from other conditions across experiments suggest strongly that both physical and perceived animacy have robust effects on attention capture, as measured by reaction time. Results are interpreted as indicating that rapid perceptual processes and subjective judgments are related because the former are required for the latter.
References


Baccus, W., Mozgova, O., & Thompson, J. (2009). Adaptation of early ERP responses to biological motion by both form and motion. *Journal of Vision, 9*(8), 615.


Appendix A

Notes on linear mixed effects modeling.

1. Fitting the optimal model:

Model fitting is carried out by computing multiple linear models, varying either the fixed or random effects structures, and comparing the models statistically until the best fitting model is found. First and foremost, this requires theoretical consideration of what effects should be modeled as fixed vs. random, as the decision to designate a factor as random may depend on the context. For example, in linguistics data, the words within a stimulus set may be modeled as random effects, as any given experiment uses only a random subset of words in the English language as stimuli (e.g., Baayen, 2008). Once these theoretical considerations have been made, model fitting can proceed.

The models for this study were computed manually, and verified using the LMERConvenienceFunctions package\(^9\) (Tremblay, 2011), which contains a function to automatically fit models based on the following steps:

(1) Compute the initial model, which models only Subjects as random effects. For this explanation, Experiment 2 is used as an example. This process is conceptually similar to performing a repeated-measures ANOVA; by-subjects adjustments are made to the dependent variable (in this case, reaction time). In other words, the initial model only takes into account that subjects will differ

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\(^9\) This appendix is a simplified explanation of a small subset of functions available in LMERConvenienceFunctions. For more detail, the package and its documentation are available at http://cran.r-project.org/web/packages/LMERConvenienceFunctions/index.html
broadly in reaction time, with some being inherently fast responders, and others being slower. In R, this model is computed via the syntax:

\[
\text{mod0} = \text{lmer}(\text{lnRT} \sim \text{StimPair} + \text{Compatibility} \times \text{StimOffsetTime} + (1 | \text{subjs}), \text{data}=\text{expt2}, \text{REML} = \text{FALSE})
\]

where lnRT is the dependent variable, modeled as a function of Compatibility and StimOffsetTime, with StimPair as a covariate.

(2) Examine the residuals of the initial model to inspect for outliers and violations of the assumption of normality. The data in this study are all ln(RT) transformed, but must be trimmed to remove outliers. After trimming, the initial model is updated (i.e., re-run on trimmed data for “cleaner” output).

(3) Forward-fit random effects\textsuperscript{10}. At this stage, additional random effects structures may be added to the initial model, and compared against it to determine whether their inclusion provides additional explanatory power, e.g.:

\[
\text{mod1r} = \text{lmer}(\text{lnRT} \sim \text{StimPair} + \text{Compatibility} \times \text{StimOffsetTime} + (1 + \text{StimOffsetTime} | \text{subjs}), \text{data}=\text{expt2}, \text{REML} = \text{FALSE})
\]

The above notation of \((1 + \text{StimOffsetTime} | \text{subjs})\) now indicates that, in addition to computing by-subject adjustments to RT, we would also like to model the slope of the StimOffsetTime effect as random ("calculate by-subject random slopes for SOT"). In other words, though we know there is a main effect of SOT such that RTs are faster after

\textsuperscript{10} The automated fitLMER.fnc command starts by back-fitting fixed effects, proceeds to forward-fit random effects, and finishes by re-fitting the fixed effects. The first stage is left out here for simplicity.
900 msec offsets, this specification takes into account that the size of this effect may be smaller or larger for different participants. It is simply an additional source of variance that we can now count as “explained” rather than “error”. Whether adding this term improves our model can be assessed with a log-likelihood ratio test that compares the fit of mod0 with the fit of mod1r, using the command:

\[
\text{anova(mod0,mod1r)}
\]

This gives as output:

**Models:**

mod0: lnRT ~ StimPair + StimOffsetTime * Compatibility * AliveC * HumanC + (1 | subjs)

mod1r: lnRT ~ StimPair + targetsettime * Compatibility * AliveC * HumanC + (targetsettime | subjs)

<table>
<thead>
<tr>
<th></th>
<th>Df</th>
<th>AIC</th>
<th>BIC</th>
<th>logLik</th>
<th>Chisq</th>
<th>Chi Df</th>
<th>Pr(&gt;Chisq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mod0</td>
<td>67</td>
<td>-9259.1</td>
<td>-8769.6</td>
<td>4696.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mod1r</td>
<td>76</td>
<td>-9405.4</td>
<td>-8850.1</td>
<td>4778.7</td>
<td>164.29</td>
<td>9</td>
<td>&lt; 2.2e-16 ***</td>
</tr>
</tbody>
</table>

The above output re-states the specification and measurements of goodness-of-fit of each model (AIC, BIC, and logLik are measures of model fit, see Baayen, 2008). The log-likelihood ratio test compares the logLik values of the two models to assess which is a better fit, and is evaluated on a chi-square probability distribution\(^{11}\). If the corresponding probability is sufficiently small (< .05), it indicates that the models explain significantly different amounts of variance in the data, and that the addition of the random effect is justified. For this particular example, the additional modeling of random slopes for SOT explains significantly more variance than by-subjects intercepts alone, so this random

\(^{11}\) The log-likelihood ratio is computed by taking twice the difference between the logLik values for each model (e.g., \(2 \times (4778.7 - 4696.6)\)) and evaluating the resulting value against a chi-square distribution with df = the difference in df between the two models (e.g., 76 – 67). For a more technical explanation of likelihood estimation and ratio testing, consult McCullough, Searle, & Neuhaus (2008).
effect should stay in the model. If the chi-square is non-significant, the two models don’t differ in explanatory power and thus the simpler one is maintained. This process is iterated until all of the potential (theoretically motivated) random effects have been evaluated, and a final random effects structure is settled on.

(4) Back-fit fixed effects. Once the random effects structure is designated, the significance of fixed effects can be evaluated in much the same way as is done in multiple regression (e.g., REF). That is to say, the “full model” specifying all of the fixed and random effects, and all interaction terms for the fixed effects is run, and non-significant terms are removed until all of the highest order interactions contained in the model are significant. The resulting model is the optimal fitted LME model.

2. Interpreting the model output

2.1 Random effects summary (e.g., Experiment 2 fitted model)

Linear mixed model fit by maximum likelihood
Formula: lnRT ~ StimPair + targonsettime * Compatibility * AliveC * HumanC + (targonsettime | subjs)

<table>
<thead>
<tr>
<th></th>
<th>AIC</th>
<th>BIC</th>
<th>logLik</th>
<th>deviance</th>
<th>REMLdev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-3816</td>
<td>-3674</td>
<td>1929</td>
<td>-3858</td>
<td>-3652</td>
</tr>
</tbody>
</table>

Random effects:

<table>
<thead>
<tr>
<th>Groups</th>
<th>Name</th>
<th>Variance</th>
<th>Std.Dev.</th>
<th>Corr</th>
</tr>
</thead>
<tbody>
<tr>
<td>subjs</td>
<td>(Intercept)</td>
<td>0.0164522</td>
<td>0.128266</td>
<td></td>
</tr>
<tr>
<td></td>
<td>stimoffsetttime900</td>
<td>0.0013826</td>
<td>0.037183</td>
<td>-0.384</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>0.0317943</td>
<td>0.178310</td>
<td></td>
</tr>
</tbody>
</table>

Number of obs: 6508, groups: subjs, 17

This part of the model output describes the random effects that were calculated.

The first part of the model summary restates the specification and parameters for
goodness-of-fit (as above). In the random effects table, the summary indicates that the by-subjects adjustments to lnRT are defined with respect to the intercept. The Variance column lists the variance around the mean of each random effect (by definition, random effects have mean = 0, and unknown variance; see Baayen, 2008). The variance and standard deviations output here are parameters for the mixed model, derived empirically from the dataset, while the actual corresponding adjustments for subjects and stimulus offset are estimates derived from these parameters.

2.2 Fixed effects summary (e.g., optimized\textsuperscript{12} model for Experiment 2)

<table>
<thead>
<tr>
<th>Df</th>
<th>Sum Sq</th>
<th>Mean Sq</th>
<th>F value</th>
<th>lower.den.df</th>
<th>lower.p.val.</th>
<th>expl.dev.(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>StimPair</td>
<td>1</td>
<td>0.0247</td>
<td>0.0247</td>
<td>0.8929</td>
<td>6356</td>
<td>0.3447</td>
</tr>
<tr>
<td>Stimoffsettime</td>
<td>1</td>
<td>0.6650</td>
<td>0.6650</td>
<td>24.0732</td>
<td>6356</td>
<td>0.0000</td>
</tr>
<tr>
<td>Compatibility</td>
<td>1</td>
<td>0.3923</td>
<td>0.3923</td>
<td>14.2006</td>
<td>6356</td>
<td>0.0002</td>
</tr>
<tr>
<td>AliveC</td>
<td>1</td>
<td>0.0204</td>
<td>0.0204</td>
<td>0.7369</td>
<td>6356</td>
<td>0.3907</td>
</tr>
<tr>
<td>HumanC</td>
<td>1</td>
<td>0.0028</td>
<td>0.0028</td>
<td>0.0998</td>
<td>6356</td>
<td>0.7521</td>
</tr>
<tr>
<td>Stimoffsettime:Alive</td>
<td>1</td>
<td>0.0899</td>
<td>0.0899</td>
<td>3.2554</td>
<td>6356</td>
<td>0.0712</td>
</tr>
<tr>
<td>Stimoffsettime:Human</td>
<td>1</td>
<td>0.2526</td>
<td>0.2526</td>
<td>9.1448</td>
<td>6356</td>
<td>0.0025</td>
</tr>
</tbody>
</table>

The above table is a summary of the fixed effects for the data from Experiment 2, as estimated by the pamer.fnc command in \textit{LMERConvenienceFunctions} (Tremblay, 2011). This table contains F-values that can be interpreted the same way as ANOVA output. Importantly, the “lower.den.df” and “lower.p.val” columns report conservative estimates for the denominator degrees of freedom for the F test, and the corresponding conservative p-value, respectively\textsuperscript{13}. The conservative degrees of freedom are estimated

\textsuperscript{12} The output for the optimized model here is presented for brevity. The fixed effects table for the full model looks the same, but contains the non-significant terms that were removed from the model.

\textsuperscript{13} pamer.fnc also reports anti-conservative df and p-values, not presented here. There is controversy surrounding the appropriate selection of these values as they are estimates based on the specific model implemented (e.g, Faraway, 2006). Only conservative df and p-values are reported in the current study.
by taking the total number of data points and subtracting both the number of fixed effects and the product of number of subjects X number of random effects.

2.3 Post-hoc analysis

Pairwise comparisons of means and testing the significance of slopes for continuous variables are performed as per regular ANOVA or multiple regression post-hoc testing. Functions have been written to perform these tests on models rather than the data itself, so that the variance explained by random effects is still accounted for during post-hoc comparisons (e.g., posthoc.fnc in LMERConvenienceFunctions). Otherwise, t- and b-value estimates are evaluated against estimated degrees of freedom (see above), and their corresponding p-values are interpreted in the same way as for ANOVA and regression.
### Appendix B

Linear Mixed-Effects Model Outputs

**Table B1.** Optimal LME model fitted for Experiment 1. U- and L- designations represent anti-conservative upper-bound and conservative lower-bound estimations for denominator degrees of freedom and corresponding p-value estimates, respectively.

\[
\text{mod6f} = \text{lmer}(\text{lnRT} \sim \text{SpeedC} + (\text{StimPair} + \text{targonsettime} + \text{AliveC})^3 + (\text{StimPair} + \text{targonsettime} + \text{Compatibility} + \text{AliveC} + \text{HumanC})^2 + (\text{Compatibility} \mid \text{subjs}) + (\text{targonsettime} \mid \text{subjs}))
\]

<table>
<thead>
<tr>
<th></th>
<th>Df</th>
<th>Sum Sq</th>
<th>Mean Sq</th>
<th>F</th>
<th>U-df</th>
<th>U-pval</th>
<th>L-df</th>
<th>L-pval</th>
<th>expl.Dev(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>1</td>
<td>0.170</td>
<td>0.170</td>
<td>7.006</td>
<td>10978</td>
<td>0.008</td>
<td>10870</td>
<td>0.008</td>
<td>0.043</td>
</tr>
<tr>
<td>StimPair</td>
<td>1</td>
<td>0.026</td>
<td>0.026</td>
<td>1.053</td>
<td>10978</td>
<td>0.305</td>
<td>10870</td>
<td>0.305</td>
<td>0.006</td>
</tr>
<tr>
<td>SOT</td>
<td>3</td>
<td>1.146</td>
<td>0.382</td>
<td>15.794</td>
<td>10978</td>
<td>0.000</td>
<td>10870</td>
<td>0.000</td>
<td>0.290</td>
</tr>
<tr>
<td>Alive</td>
<td>1</td>
<td>0.077</td>
<td>0.077</td>
<td>3.169</td>
<td>10978</td>
<td>0.075</td>
<td>10870</td>
<td>0.075</td>
<td>0.019</td>
</tr>
<tr>
<td>Compatibility</td>
<td>1</td>
<td>0.329</td>
<td>0.329</td>
<td>13.585</td>
<td>10978</td>
<td>0.000</td>
<td>10870</td>
<td>0.000</td>
<td>0.083</td>
</tr>
<tr>
<td>Human</td>
<td>1</td>
<td>0.080</td>
<td>0.080</td>
<td>3.301</td>
<td>10978</td>
<td>0.069</td>
<td>10870</td>
<td>0.069</td>
<td>0.020</td>
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<tr>
<td>SPxSOT</td>
<td>3</td>
<td>0.130</td>
<td>0.043</td>
<td>1.791</td>
<td>10978</td>
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<td>0.033</td>
</tr>
<tr>
<td>SPxAxAlive</td>
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<td>0.004</td>
<td>0.004</td>
<td>0.161</td>
<td>10978</td>
<td>0.688</td>
<td>10870</td>
<td>0.688</td>
<td>0.001</td>
</tr>
<tr>
<td>SOTxAxAlive</td>
<td>3</td>
<td>0.092</td>
<td>0.031</td>
<td>1.264</td>
<td>10978</td>
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<td>10870</td>
<td>0.285</td>
<td>0.023</td>
</tr>
<tr>
<td>SPxCompatibility</td>
<td>1</td>
<td>0.001</td>
<td>0.001</td>
<td>0.026</td>
<td>10978</td>
<td>0.872</td>
<td>10870</td>
<td>0.872</td>
<td>0.000</td>
</tr>
<tr>
<td>SPxHuman</td>
<td>1</td>
<td>0.005</td>
<td>0.005</td>
<td>0.192</td>
<td>10978</td>
<td>0.661</td>
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<td>0.661</td>
<td>0.001</td>
</tr>
<tr>
<td>SOTxCompatibility</td>
<td>3</td>
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<td>0.024</td>
<td>1.010</td>
<td>10978</td>
<td>0.387</td>
<td>10870</td>
<td>0.387</td>
<td>0.019</td>
</tr>
<tr>
<td>SOTxHuman</td>
<td>3</td>
<td>0.074</td>
<td>0.025</td>
<td>1.022</td>
<td>10978</td>
<td>0.382</td>
<td>10870</td>
<td>0.382</td>
<td>0.019</td>
</tr>
<tr>
<td>AliveXCompatibility</td>
<td>1</td>
<td>0.007</td>
<td>0.007</td>
<td>0.270</td>
<td>10978</td>
<td>0.604</td>
<td>10870</td>
<td>0.604</td>
<td>0.002</td>
</tr>
<tr>
<td>CompatibilityxHuman</td>
<td>1</td>
<td>0.001</td>
<td>0.001</td>
<td>0.055</td>
<td>10978</td>
<td>0.815</td>
<td>10870</td>
<td>0.815</td>
<td>0.000</td>
</tr>
<tr>
<td>AlivexHuman</td>
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<td>0.000</td>
<td>0.000</td>
<td>0.003</td>
<td>10978</td>
<td>0.960</td>
<td>10870</td>
<td>0.960</td>
<td>0.000</td>
</tr>
<tr>
<td>SPxSOTxAxAlive</td>
<td>3</td>
<td>0.321</td>
<td>0.107</td>
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<td>10978</td>
<td>0.004</td>
<td>10870</td>
<td>0.004</td>
<td>0.081</td>
</tr>
</tbody>
</table>
Table B2. Optimal LME model fitted for Experiment 2. U- and L- designations represent anti-conservative upper-bound and conservative lower-bound estimations for denominator degrees of freedom and corresponding p-value estimates, respectively.

mod3f = lmer(lnRT ~ StimPair + targonsettime + Compatibility +
(targonsettime + AliveC)^2 + (targonsettime + HumanC)^2 +
(targonsettime | subjs))

<table>
<thead>
<tr>
<th></th>
<th>Df</th>
<th>Sum Sq</th>
<th>Mean Sq</th>
<th>F</th>
<th>U-df</th>
<th>U-pval</th>
<th>L-df</th>
<th>L-pval</th>
<th>expl.Dev(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>StimPair</td>
<td>1</td>
<td>0.018</td>
<td>0.018</td>
<td>0.662</td>
<td>6390</td>
<td>0.416</td>
<td>6356</td>
<td>0.416</td>
<td>0.00</td>
</tr>
<tr>
<td>SOT</td>
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<td>0.643</td>
<td>0.643</td>
<td>23.222</td>
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<td>0.405</td>
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<td>0.018</td>
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<td>0.258</td>
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</tbody>
</table>

Table B3. Optimal LME model fitted for Experiment 3. U- and L- designations represent anti-conservative upper-bound and conservative lower-bound estimations for denominator degrees of freedom and corresponding p-value estimates, respectively.

mod4f = lmer(lnRT ~ SpeedC + (StimPair + Compatibility + AliveC)^3 +
(StimPair + targonsettime + AliveC)^3 + (StimPair + targonsettime + Compatibility)^3 + (StimPair + targonsettime + Compatibility + AliveC + HumanC)^2 + (Compatibility | subjs) + (targonsettime | subjs))

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<th></th>
<th>Df</th>
<th>Sum Sq</th>
<th>Mean Sq</th>
<th>F</th>
<th>U-df</th>
<th>U-pval</th>
<th>L-df</th>
<th>L-pval</th>
<th>expl.Dev(%)</th>
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<td>Avg 2</td>
<td>Avg 3</td>
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Appendix C

Analyses of ratings data

1. Summary of ratings analyses

For all experiments, subjective ratings were collected from participants regarding animacy, humanness and speed for the stimuli used in the experiment. For example, in Experiment 1, ratings were collected for the upright biological motion walker, the inverted walker, and the scrambled stimulus. Ratings were collected on a continuous scale by having participants bisect a 16 cm line (using pen and paper), where each end of the line represented the low or high end of the scale. Ratings were measured and converted to a score out of 100. For each category of ratings (Alive, Human, Speed), a repeated measures ANOVA was performed to determine whether mean ratings differed across stimulus type. Where appropriate, post-hoc pairwise comparisons revealed the nature of differences between stimuli.

1.1 Experiment 1

The repeated measures ANOVA indicated a significant effect of Stimulus, $F(2,36) = 7.41, p = .002$. Paired samples t-tests were used to compare ratings across stimuli (see also Figure B1). Upright walkers were rated as appearing significantly more alive than both inverted ($t(17) = 2.75, p = .0067$) and scrambled ($t(17) = 3.49, p = .0014$) stimuli. The inverted walker and the scrambled stimulus did not differ significantly from one another on the Aliveness scale ($t(17) = .24, p = .4061$).

A repeated measures ANOVA indicated a significant effect of Stimulus on Human ratings, $F(2,36) = 53.35, p < .0001$. Upright walkers were rated as appearing significantly more human than both inverted walkers ($t(17) = 6.15, p < .0001$) and scrambled motion ($t(17) = 12.18, p < .0001$). Inverted walkers were also rated as appearing significantly more human than scrambled motion ($t(17) = 2.62, p = .0089$). Figure B2 summarizes the results.

A repeated measures ANOVA indicated a significant effect of Stimulus on ratings, $F(2,36) = 7.39, p = .002$. Upright walkers were rated as significantly faster than
scrambled stimuli, \( t(17) = 2.76, p = .0067 \). Inverted walkers were also rated as faster than scrambled, \( t(17) = 2.62, p = .0089 \). Upright and inverted walkers did not differ from one another on ratings of Speed, \( t(17) = .68, p = .75 \). Figure B3 summarizes these results.

*Figure B1.* Mean Aliveness ratings for each stimulus. Error bars represent 95% confidence intervals.

*Figure B2.* Mean Humanness ratings for each stimulus. Error bars represent 95% confidence intervals.
1.2 Experiment 2

As only one stimulus (an upright walker) was used to create the stimulus pairs in this experiment, no comparisons of ratings were performed on this dataset.

1.3 Experiment 3

A repeated measures ANOVA revealed a significant main effect of Stimulus on Aliveness ratings, $F(2,38) = 39.26, p < .0001$ (see also Figure B4). Post-hoc pairwise comparisons of ratings between stimuli indicated that the upright walker was rated as significantly more alive than both the scrambled stimulus ($t(19) = 5.89, p < .0001$) and the coherent motion stimulus ($t(19) = 8.07, p < .0001$). The scrambled stimulus was also rated as significantly more alive than the coherent motion stimulus ($t(19) = 3.76, p = .001$).

A repeated measures ANOVA on Human ratings revealed a significant main effect of Stimulus, $F(2,38) = 173.26, p < .0001$ (see also Figure B5). Post-hoc comparisons
showed that the upright walker was rated significantly more human than both the scrambled (t(19) = 16.34, p < .001) and the coherent stimulus (t(19) = 16.85, p < .0001). The scrambled and coherent stimuli did not differ from one another with respect to ratings of humanness (t(19) = .44, p = .67).

A repeated measures ANOVA on Speed ratings revealed no effect of Stimulus on ratings, F(2,38) = 3.18, p = .053, thus no post-hoc comparisons were performed. This result was expected, given that stimuli were matched for speed.

*Figure B4.* Mean Aliveness ratings for each stimulus in Experiment 3. Error bars represent 95% confidence intervals.
Figure B5. Mean ratings of humanness for stimuli in Experiment 3. Error bars represent 95% confidence intervals.
Appendix D
Repeated measures ANOVA analyses

1. Experiment 1

Data were coded for compatibility as described in the Methods section, and a Stimulus Pair (2) x Stimulus Offset Time (4) x Compatibility (2) repeated measures ANOVA was performed, with reaction time as the dependent variable. This analysis showed no main effect of Stimulus Pair, and no interactions with this factor, so data were collapsed across Stimulus Pair and a 4 x 2 repeated measures ANOVA was run (Table C1). This analysis demonstrates the same main effects found in the optimal LME model. Post-hoc tests (not shown) reveal the same findings as post-hocs for main effects in the LME model. For Stimulus Offset, participants respond fastest overall on trials with 200 msec offset, and on average, responses to “incompatible” trials were faster than to “compatible”.

Table C1.
ANOVA output summary for Experiment 1 (analyzed in SPSS, IBM Corp. Armonk NY)

<table>
<thead>
<tr>
<th>Tests of Within-Subjects Effects</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
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<td>Source</td>
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</table>

14 Typical corrections applied by SPSS for violations of the sphericity assumption are not shown here for the purpose of brevity. This assumption was not violated in any dataset, thus it was not necessary to apply corrections to the analysis.
2. Experiment 2

Because the two stimulus pairs employed in this experiment were essentially identical (differing only in the direction of the biological motion walkers), Stimulus Pair was not included as a factor of interest in this analysis. A Compatibility (2) x Stimulus Offset Time (2) repeated measures ANOVA was performed (Table C2). As in Experiment 1, this ANOVA analysis showed the same lower-order effects as the optimal LME model. Participants were faster to respond after 900 msec offsets than 500 msec, and on average, participants responded significantly faster on compatible relative to incompatible trials.

Table C2.
ANOVA output summary for Experiment 2 (analyzed in SPSS, IBM Corp, Armonk NY).

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3. Experiment 3
A Stimulus Pair (5) x Compatibility (2) x Stimulus Offset Time repeated measures ANOVA showed the same pattern of main effects and interactions for categorical independent variables as the optimal LME model (Table C3). Main effects of Stimulus Pair, StimOffset Time and Compatibility were significant, as well as a 2-way Stimulus Pair x Compatibility and a 3-way interaction.

Table C3.
ANOVA output summary for Experiment 3 (analyzed in SPSS, IBM Corp, Armonk NY).

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4. Summary
More traditional repeated measures ANOVA analyses show the same pattern of findings for all three experiments that were found via linear mixed-effects modeling. The use of a more complex procedure replicates and extends these findings by enabling a richer description of the variance in the datasets that can be explained (e.g., modeling the size of StimOffset effects for each participant), and allows the incorporation of subjective ratings as predictors for reaction time.