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The psychophysics of chasing: A case study in the perception of animacy

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A B S T R A C T

Psychologists have long been captivated by the perception of animacy – the fact that even simple moving shapes may appear to engage in animate, intentional, and goal-directed movements. Here we report several new types of studies of a particularly salient form of perceived animacy: *chasing*, in which one shape (the 'wolf') pursues another shape ('the sheep'). We first demonstrate two new cues to perceived chasing – *chasing subtlety* (the degree to which the wolf deviates from perfectly 'heat-seeking' pursuit) and *directionality* (whether and how the shapes 'face' each other). We then use these cues to show how it is possible to assess the objective accuracy of such percepts, and to distinguish the immediate perception of chasing from those more subtle (but nevertheless real) types of 'stalking' that cannot be readily perceived. We also report several methodological advances. Previous studies of the perception of animacy have faced two major challenges: (a) it is difficult to measure perceived animacy with quantitative precision; and (b) task demands make it difficult to distinguish perception from higher-level inferences about animacy. We show how these challenges can be met, at least in our case study of perceived chasing, via tasks based on dynamic visual search (the *Find-the-Chase* task) and a new type of interactive display (the *Don't-Get-Caught!* task).

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1. Introduction: Perceiving animacy

The currency of visual experience consists not only of visual features such as color and shape, but also seemingly higher-level features such as *animacy*. Psychologists have long been captivated by the

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fact that even simple moving geometric shapes may be perceived in animate, goal-directed terms. We may perceive such shapes as alive, as having goals, and as interacting in social relationships such as chasing or fighting. For example, on the basis of their motion patterns, observers tend to perceive the large triangle depicted Fig. 1a as trying to catch the circle and small triangle, which are trying to flee (Heider & Simmel, 1944); the rectangle in Fig. 1b may be seen as jumping the barrier in order to satisfy the goal of approaching the circle (Gergely, Nádasdy, Csibra, & Bíró, 1995); and the large triangle in Fig. 1c may be seen as trying to persuade the smaller triangle to exit the box (Castelli, Happé, Frith, & Frith, 2000). Such displays give rise to richly animate percepts that nearly all observers can immediately appreciate.

These experiences are notable because they seem to reflect automatic (and even irresistible) visual processing, they are relatively unaffected by perceivers' intentions and beliefs, but they are tightly controlled by subtle aspects of the displays themselves (for a review, see Scholl & Tremoulet, 2000). We may *know* that the displays which give rise to the perception of animacy are completely lifeless – and of course we do know that for the simple geometric shapes in Fig. 1 – yet that will not stop us from reflexively *seeing* them as alive when they move in certain ways. Such percepts also occur cross-culturally (e.g. Barrett, Todd, Miller, & Blythe, 2005), and even in infancy (e.g. Csibra, 2008; Gergely et al., 1995; Rochat, Morgan, & Carpenter, 1997; Rochat, Striano, & Morgan, 2004), but they can be dramatically disrupted by developmental disorders such as autism spectrum disorder (e.g. Abell, Hap-

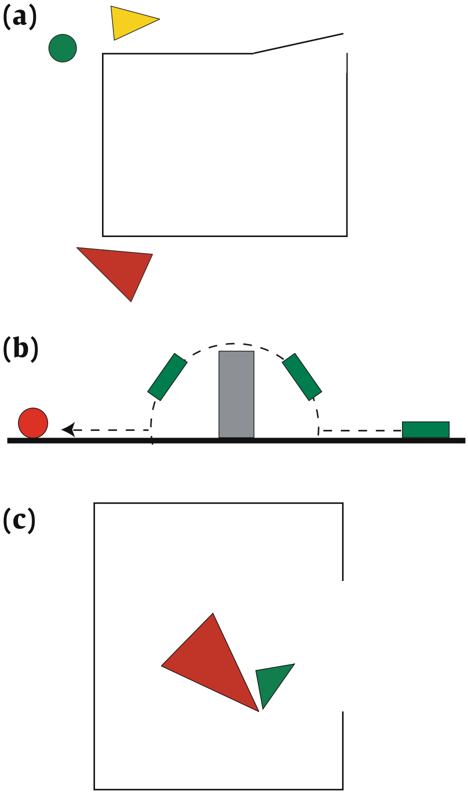

Fig. 1. Sample 'snapshots' of displays with simple shapes that have been used evoke the perception of animacy in previous studies. (a) A static frame from Heider and Simmel's (1944) classic animation, where the large triangle is seen to chase the two smaller shapes around the box. (b) A static frame from Gergely et al. (1995), where the rectangle is seen to jump over the barrier in order to satisfy its goal of reaching the disc. (c) A static frame from Abell et al. (2000) and Castelli et al. (2000), wherein the large triangle is seen to be coaxing the smaller triangle out of the box.

pé, & Frith, 2000; Klin, 2000; Rutherford, Pennington, & Rogers, 2006) and neuropsychological conditions such as amygdala damage (e.g. Heberlein & Adolphs, 2004). (Though these latter cases may be referred to as "impairments" because they deviate from the norm, individuals with these neuropsychological conditions may actually be better at intentionally discounting the animacy in such displays – whereas typical observers find it surprisingly difficult to describe the displays in purely physical terms, without anthropomorphizing.)

Perhaps because such phenomena seem to lie at an interesting intersection of perception and cognition, they have attracted the interest of researchers from many corners of cognitive science, and beyond – including cognitive psychologists (e.g. Blythe, Todd, & Miller, 1999), social psychologists (e.g. Mar & Macrae, 2006; Wheatley, Milleville, & Martin, 2007), developmental psychologists (e.g. Dasser, Ulbaek, & Premack, 1989; Gergely et al., 1995), cognitive neuroscientists (e.g. Blakemore et al., 2003; Castelli et al., 2000; Schultz, Friston, O'Doherty, Wolpert, & Frith, 2005; Schultz, Imamizu, Kawato, & Frith, 2004), vision researchers (e.g. Michotte, 1950/1991; Tremoulet & Feldman, 2000, 2006) – and even anthropologists (e.g. Barrett et al., 2005) and computer scientists (e.g. Gaur & Scassellati, 2006).

1.1. Chasing: a case study

What are the visual cues that trigger the perception of animacy? Previous research has identified several possibilities, including sudden direction and speed changes (Tremoulet & Feldman, 2000), synchronized motions (Bassili, 1976; Dasser et al., 1989), interactions with spatial contexts (Tremoulet & Feldman, 2006) and other objects (Dittrich & Lea, 1994; Santos, David, Bente, & Vogeley, 2008), apparent violations of Newtonian mechanics (Gelman, Durgin, & Kaufman, 1995), and other characteristic movements (Michotte, 1950/1991).[1]

For two types of reasons, however, research in this field has typically found it difficult to work out the nature of such cues in any detail: First, as discussed in the next section, the methods used to study perceived animacy have not often had the degree of rigor that is characteristic of other areas of vision science. Second, we suspect that there are actually many importantly different *types* of perceived animacy – e.g. fighting, playing, following, and guarding – and that these different categories (and percepts) may be triggered by different types of cues. Some previous studies have explicitly distinguished such categories (e.g. Barrett et al., 2005; Blythe et al., 1999), but many have not. This has made it difficult to understand how individual cues to animacy operate, since the results of one study may not transfer to another – and because some of the most well-known demonstrations (especially that of Heider & Simmel, 1944, which has since been used in many other studies) end up chaining together what may be many different event categories into a single long animation.

In contrast, we suspect that progress in this domain will only be made by both expanding and contracting the scope of such studies. We must expand their scope by assessing perceived animacy in several different ways – and, in particular, by not simply by asking observers to tell us what they saw. But we must simultaneously contract their scope by focusing on multiple cues (and on individual cues in detail) in the context of a single underlying category of perceived animacy. This approach may lack the richness of the almost-cinematic 'stories' of Heider and Simmel's (1944) iconic display, but we may then be able to replace richness in terms of the variety of different types of animacy with richness in terms of the level of detail we can specify about how the underlying cues actually operate.

In the present paper, we present a case study of this approach, focusing on what may be the most direct form of perceived social interaction which can nevertheless yield robust percepts of animacy: one object (what we will call the 'wolf') *chasing* another (the 'sheep') (Dittrich & Lea, 1994). A few previous studies have explored chasing (e.g. Dittrich & Lea, 1994; Rochat et al., 1997), but the present project seeks to do so via the manipulation of two new variables: *chasing subtlety* (the degree to which the wolf deviates from perfectly 'heat-seeking' pursuit) and *directionality* (whether and how the wolf 'faces' the sheep while approaching it). The resulting data are easily quantifiable, and can be used

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[1] We can also detect a type of animacy in other more particular contexts, such as when point-light displays are perceived in terms of biological motion on the basis of the relative motions of many points. We do not discuss such displays in this paper, however, as they are thought to reflect different and more specialized types of motion-based processing (see Blake & Shiffrar, 2007). Instead, we restrict ourselves to contexts in which the 'agents' are depicted by single shapes.

to determine just how and when such cues do and do not support the direct perception of chasing. The results of these studies also allow us to measure the objective *accuracy* of this type of perception, and to distinguish the immediate perception of chasing from those more subtle (but nevertheless real) types of pursuit that cannot be readily perceived.[2]

1.2. Measuring the perception of animacy: two challenges

With what methods can we study perceived chasing? Previous studies of the perception of animacy have been limited by two major challenges. First, previous research has had difficulty measuring animacy with quantitative precision. The reasons for this involve both the typical types of stimuli and the typical dependent measures that are used to measure reactions to them. Whereas some recent studies in this domain have constructed their stimuli according to well-defined algorithms and parametric manipulations of various spatiotemporal variables (e.g. Santos et al., 2008; Tremoulet & Feldman, 2000, 2006), this has not been the norm: instead, ever since the seminal demonstrations of Heider and Simmel (1944), most researchers have simply constructed haphazard animations in which various shapes move around on trajectories defined not by motion algorithms but by the intuitions of the 'director' who scripted each event by hand in an animation program. Such stimuli can be particularly rich and compelling – with displays of simple geometric shapes meant to exhibit not just animacy but also mental states involving fear, mocking, coaxing, and even seduction (Abell et al., 2000; Castelli et al., 2000) – but they seem impossible to describe in algorithmic terms. And as a result, it is perhaps no surprise that observers' percepts may be similarly rich but difficult to quantify.

An even more important source of the lack of quantitative precision in much of the research on perceived animacy, however, arises from the typical dependent measures that are used. Even the earliest animations (with geometric shapes chasing, fleeing, etc.; Heider & Simmel, 1944; Michotte, 1950/1991) are phenomenologically compelling, but the actual data were often just free reports: subjects were simply asked to view the displays and then to describe them. It is difficult to quantify such data, however, or to rigorously compare the relative degrees of perceived animacy in different displays. In the intervening 60 years, little progress has been made on this front. Recent studies have often either simply coded subjects' free reports for 'social' words in various elaborate ways (e.g. Heberlein & Adolphs, 2004; Klin, 2000), or have had subjects assign *ratings* of perceived animacy. Some of these ratings may be numerical – for example rating animacy on a 7-point scale, from 1 = "definitely not alive", to 7 = "definitely alive" (Tremoulet & Feldman, 2000). Others may simply assign numbers post-hoc to various categorizations – for example rating animacy on a 4-point scale that consists of "physical", "rather physical", "rather personal", and "personal" (Santos et al., 2008). In either case, however, these ratings do not seem so different from the free reports used in the initial studies of Michotte or Heider: they simply force such reports into arbitrary scales, which lend them only a rough quantitative scaffolding.

A second and related methodological challenge is that task demands have made it difficult to distinguish the *perception* of animacy from higher-level cognitive *inferences*. This distinction is difficult or impossible to make reliably for free reports such as "It seems alive." And even ratings of how 'alive' or 'goal-directed' a shape appears can be readily influenced by inferences about how reliable observers *think* the manipulations should be for diagnosing animacy. In part, this problem is intrinsic to such dependent measures: far from direct probes of perceptual processes, free reports and ratings can also be easily driven by observers' higher-level beliefs and expectations. Moreover, the contamination of reports of visual percepts from higher-level cognition may be particularly likely in those situations

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[2] Of course, there is no *actual* chasing in our study, since the 'agents' are merely points of light on a computer monitor. Nevertheless, we will refer below to the 'objective accuracy' of perceived chasing in several contexts. In using such terms, our point is not that there is actual pursuit that can be effectively or ineffectively perceived in our displays. Rather, our point here is that the *construct* of chasing in our experiments is objectively defined – in terms of systematic displacements of one moving object (the wolf) relative to another (the sheep) so as to decrease their relative proximity over time (see Nahin, 2007). And because our displays can be characterized in such terms, we can in turn objectively evaluate the accuracy of subjects' responses as they try to detect such dynamic patterns. Most dictionary definitions of "chasing" additionally refer to an intention (i.e. of the wolf, to 'catch' the sheep) – and indeed it is just this feature that is also evident in the percepts of such displays, and makes them specific examples of the more general phenomenon of perceived animacy.

where subtle manipulations are being employed: here, observers will feel compelled by task demands to give a range of responses, and may thus vary them on the basis of whatever salient cue in the displays seems like it *should* influence animacy, even if that cue has only a weak or nonexistent influence on the percepts themselves.

These two methodological challenges can both be illustrated in concrete ways in an examination of one of the most rigorous and interesting recent studies of perceived animacy (Tremoulet & Feldman, 2000; see also Tremoulet & Feldman, 2006). This study attempted to break animacy down into its simplest properties – a laudable goal, and one that also inspires the present project. In particular, this previous study used rating methods to determine just how perceived animacy was affected by changes in the direction and speed of a *single moving dot,* which was the only object in the display. Observers watched as the dot appeared on the display, moved for a short distance, changed its heading and/or speed (without stopping) exactly halfway through its visible duration, moved for another short distance, and then disappeared. The changes in heading and speed were parametrically varied within subjects (unlike the haphazard stimuli used in most studies), and for each display observers reported how animate the dot appeared to be on a 7-point scale. These ratings were simply a numerical report of the degree to which observers saw the dot as "alive". (Little other guidance was given in forming these ratings, other than the further instructions that subjects should give low ratings to dots whose motion seemed to be "artificial, mechanical, or strange".) Subjects did end up varying their ratings within this range (between roughly 3.5 and 4.75), but the use of such arbitrary rating scales makes it difficult or impossible to evaluate the magnitude of such effects.

A more basic concern with the studies of Tremoulet and Feldman (2000, 2006), however, is that the actual displays simply did not look very animate, regardless of the angles or speeds involved. Certainly, in contrast to the rich (and multi-object) displays of the initial studies of Heider and Simmel (1944), *we* would have consistently rated all of these simpler displays as a solid "1", especially in isolation. However, across 360 within-subjects trials of this sort, it is not surprising that the actual subjects varied their ratings, in response to the few variables that were obviously being manipulated. Indeed, to do otherwise – e.g. to give the same answer of "1" to each and every trial – could be deemed uncooperative or mischievous. Thus subjects would probably have felt compelled to vary their ratings in this study. But how to do so? To simply respond randomly on each trial would also constitute mischief, but that is unlikely in this context, since there are two variables (viz. the angle and speed of the direction changes) that are so clearly being manipulated. Moreover, it seems possible (and perhaps even plausible) that observers could readily infer how these variables *should* intuitively relate to animacy: even without viewing the displays, readers might readily predict that greater angle and speed changes would likely correspond to more animate entities. (Note that here we are making a point only about laypersons' intuitions, in a context where these are the *only* variables being manipulated from trial to trial. In contrast, some of the results of this study did argue against other *scientists*' intuitions about what should happen – such as the view that animacy should only be influenced by the violation of Newtonian mechanics; cf. Gelman et al., 1995.) As such, even if an observer's percepts did not differ much in terms of animacy when viewing the 360 trials, higher-level inferences fueled by task demands in the context of only a few obvious manipulations might still readily lead her to vary her responses systematically, and in the obvious ways.

Of course, these impressions of the single-dot stimuli used in this case study (Tremoulet & Feldman, 2000) reflect only our subjective impressions, which may or may not have been similar to those of the subjects in the actual study – which in any case is one of the most impressive and systematic studies of perceived animacy to date. But this case study does illustrate several general problems with these types of dependent measures, which are (1) that observers will typically feel compelled to vary their ratings even without differing percepts; (2) that they will often be able to do so on the basis of obvious variables across trials; and (3) that the ratings themselves are easily influenced by such task demands, in addition to being influenced by the perceptual character of the displays.

1.3. The current study

The problems discussed in the previous section could also readily infect a study of perceived chasing. We could manipulate our new variables (of chasing subtlety and directionality) systematically, and observe their effects on either observers' free reports describing the displays, or their ratings of how animate or goal-directed the displays appeared. Such results would lack both quantitative rigor and theoretical precision, though, for all of the reasons noted above. As such, this case study of perceived chasing required us, as a secondary goal, to develop new performance-based tests of such processing.

In the *Find-the-Chase* task (Experiments 1–3), subjects engaged in visual search, with their target being a particular type of interaction: one shape (the 'wolf') chasing another (the 'sheep') in a complex dynamic display (see Fig. 2). In the *Don't-Get-Caught!* task (Experiments 4–5), subjects had to detect and then avoid a 'wolf' which was chasing a *user-controlled* sheep. The resulting data are easily quantifiable in terms of search accuracy (in Experiments 1–3) and the percentage of trials where subjects successfully avoid being caught (in Experiments 4–5). These are both measures of visual *performance* (rather than perceptual reports) and cannot be influenced by observers' higher-level inferences or preferences.

Across trials with both tasks, we systematically manipulated both chasing subtlety and directionality, as potential mediators of this particular type of perceived animacy. Our primary goals were (1) to evaluate whether such cues effectively trigger the perception of chasing, (2) to quantify the influence of these cues, and (3) to evaluate the objective accuracy of such percepts, contrasting the immediate perception of chasing with the more subtle (but nevertheless real) types of 'stalking' that cannot be readily detected. Collectively, we hope that such results may serve as a case study for how at least some specific types of perceived animacy and goal-directedness may be approached in new ways.

2. Experiment 1: The search for chasing

Participants viewed a display containing several identical moving discs (see Fig. 2). Most moved haphazardly, but on half of the trials one disc (the "wolf") chased another disc (the "sheep"): instead of moving haphazardly, the wolf consistently headed toward the sheep on most frames of motion. On each trial, observers simply had to detect whether or not such a chase was present. On Chasing-Absent trials, the wolf moved in an identical manner, but the sheep that it was chasing was invisible; this ensures that any difference between the conditions must be due to the interaction of the wolf and the sheep, since the wolf's motions were always produced by the same algorithm on each trial. Accurate perception of chasing was measured in terms of detection accuracy: in displays wherein the chase is readily perceived, observers should be able to reliably distinguish Chasing-Present from Chasing-Absent trials; but in displays wherein the chase is not readily perceived, detection accuracy should suffer.

Our primary manipulation across trials in this experiment was a variable that we termed *chasing subtlety,* illustrated in Fig. 3. Chasing subtlety is essentially a measure of the maximal angular deviation of the wolf's heading compared to perfect heat-seeking. When the chasing subtlety was 0° (Fig. 3a), the wolf always headed directly toward the (moving) sheep, in a 'heat-seeking' manner

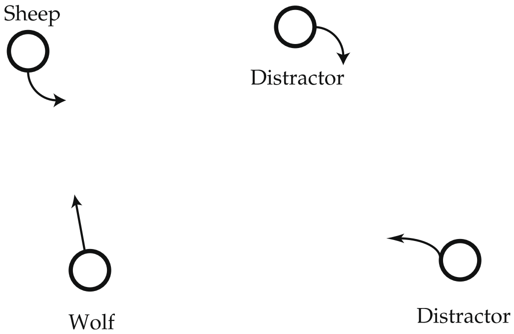

Fig. 2. A screenshot from the dynamic display of a Chasing-Present trial in Experiment 1. The curved arrows represent the haphazard motions of each item, and were not present in the actual display. Note that the wolf is heading directly toward the sheep.

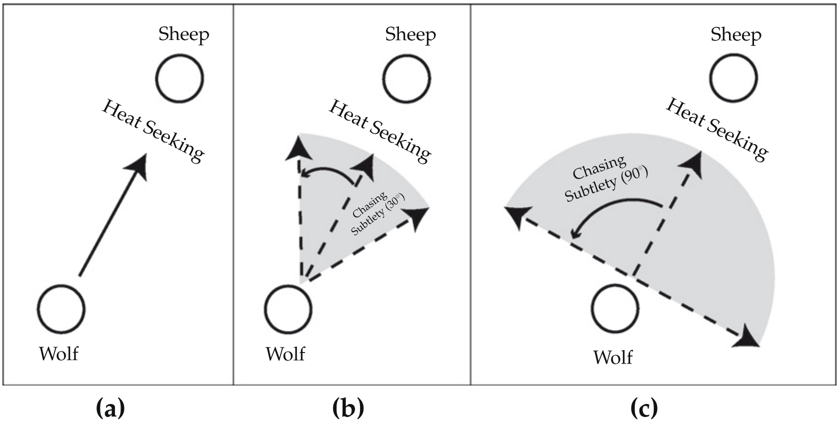

Fig. 3. An illustration of the *chasing subtlety* manipulation used in Experiments 1, 2, and 3. (a) When the chasing subtlety is 0°, the wolf always heads directly toward the (moving) sheep, in a 'heat-seeking' manner. (b) When the chasing subtlety is 30°, the wolf is always heading in the general direction of the sheep, but is not perfectly heat-seeking: instead, it can move in any direction within a 60° window, with the window always centered on the (moving) sheep. (c) When the chasing subtlety is 90°, the wolf's direction of movement is even less constrained: now the wolf may head in an orthogonal direction to the (moving) sheep, but can still never be heading *away* from it. The gray areas in (b) and (c) indicate the angular zone which constrains the wolf's direction of movement on that given frame of motion.

– i.e. its displacement on any given frame was in the direction of the sheep. (In fact, this was complicated on all trials by a variable lag of up to 170 ms. This inertial lag was introduced in order to avoid instantaneous 'reaction at a distance', and it also had the effect of making smoother motion patterns.) When the chasing subtlety was 30° (Fig. 3b), the wolf was always heading in the general direction of the sheep, but was not perfectly heat-seeking: instead, it could move in any direction within a 60° window, with the window always centered on the (moving) sheep. On each frame of motion, the wolf's displacement occurred at a random heading within this range. With even more extreme values of chasing subtlety such as 90° (Fig. 3c), the wolf's direction of movement was even less constrained: now the wolf could head in an orthogonal direction to the (moving) sheep, but could still never be heading *away* from it. Note that there is thus a statistical correlation between the wolf's trajectory and the sheep's location, as long as the chasing subtlety was less than 180°. Note also that a chasing subtlety of 160°, for example, does not mean that wolf is avoiding the sheep. Far from it: in this condition, the wolf has a wide range of possible headings on each frame, but because that range is truncated in the direction opposite the sheep, the wolf will still get closer and closer to it as time goes by.

This method allowed us to investigate the perception of animacy in chasing displays, quantifying it in terms of detection accuracy as a function of chasing subtlety. Sample animations of these types of displays – and those of each of the other experiments reported in this paper – can be viewed online at http://www.yale.edu/perception/chasing/.

2.1. Method

2.1.1. Participants

Twenty-two Yale University undergraduates participated in a single 45-min session in exchange for course credit or payment. Data from two observers were discarded based on detection accuracy worse than three standard deviations below the mean.

2.2. Materials and procedure

The displays were presented on a Macintosh iMac computer using custom software written using the VisionShell graphics libraries (Comtois, 2008). Observers sat without head restraint approximately 50 cm from the monitor (with measurements below computed based on this viewing distance). The visible black background subtended 32° × 24°. Each display contained five 1.0° discs: one sheep, one wolf, and three distractors). Four discs were drawn as white outlines with a stroke of 0.1°. The remaining disc – either a distractor or the sheep, depending on the trial-type (as explained below) – was not visible.

At the beginning of each trial, each disc immediately began moving at a constant speed of 14.5°/s. The sheep and each distractor moved haphazardly, randomly changing direction within a 120° window roughly every 170 ms. (On each frame of motion, each disc had a 9.8% chance of changing its direction; in practice, this led to direction changes every 170 ms on average.) The wolf moved toward the sheep with one of six chasing-subtlety values: 0°, 30°, 60°, 90°, 120° or 150°. With 0° of subtlety, the wolf's displacement on each update was directly toward the sheep. With other subtlety values, the wolf moved haphazardly (as described above), constrained only so that its heading on each frame of motion stayed within the angle specified by the subtlety value, centered on the line connecting the wolf and sheep (see Fig. 3). Participants completed 180 randomly-ordered trials, with 15 Chasing-Present trials and 15 Chasing-Absent trials for each subtlety value. (They first completed 20 practice trials, the results of which were not recorded.) The only factor that differentiated these trials was whether the sheep being chased was visible in the display (with a separate distractor as the invisible 5th object), or was invisible (with a different distractor taking its place). As a result, the wolf's motions were generated by identical algorithms on every trial, such that they always shared the same motion characteristics (which could differ slightly with different chasing-subtlety values, e.g. having more or less extreme direction changes). The trajectories were generated so that the wolf-sheep distance always exceeded 5°.

After each 10 s motion period ended, participants pressed a key to indicate whether a chase had been present, with immediate accuracy feedback via the pitch of an auditory tone. When participants correctly detected a chase, they subsequently made two mouse-clicks to indicate the wolf and sheep.

2.3. Results and discussion

Detection accuracy as a function of chasing subtlety is depicted in Fig. 4a, with statistical comparisons in Table 1. (Note that this is a measure of accuracy at distinguishing Chasing Present from Chasing Absent trials, rather than a simple hit rate.) The declining performance (from more than 85%-correct to chance) clearly indicates that this variable has a major impact on the perception of chasing ($F(5, 95) = 111.54$, $p < 0.001$). The shape of this performance curve further suggests that the perception of chasing is not a linear function of the actual degree of statistical correlation between wolf and sheep trajectories. Indeed, performance was only above 60% (where chance is 50%) for 0° and 30° – and was indistinguishable from chance for both 120° and 150°. These results indicate the psychophysical limits of perceived animacy in this context: there was significant *actual* chasing – i.e. statistical constraints that kept the wolf's trajectory bound to the sheep's moving location – present in the displays themselves at each of the subtlety values above 30°, but participants could not reliably *see* (and thus accurately detect) these degrees of chasing. Indeed, performance declined nearly 30% between 0° and 60°, but declined only a third as much between 60° and 150°. These patterns are mirrored in participants' ability to identify the wolf and sheep (as depicted in Fig. 4b), which was reliable only for the smallest subtlety values. The relationship between these figures clarifies the meaning of the 50% detection values with the greatest chasing subtlety: here, even in those Chasing-Present trials on which they answer correctly, they are still at chance at identifying the wolf and the sheep – suggesting that the 'hit' was simply a guess that happened to be correct.

These results suggest that the heuristic principle underlying perceived animacy in this context is especially strict, and can tolerate only a mild degree of statistical decorrelation between the movement of a 'wolf' and 'sheep'. Significant correlations are still present with chasing-subtlety values beyond 30° – i.e. the wolf still gets nearer and nearer to the sheep over time – but apparently observers are unable to reliably detect these correlations (i.e. they don't perceive chasing) and so they have no basis for accurate responses.

3. Experiment 2: The search for correlations with phantom sheep

In the previous experiment, chasing was 'implemented' via the introduction of statistical correlation between the movements of the wolf and sheep: when the sheep changed direction, the wolf

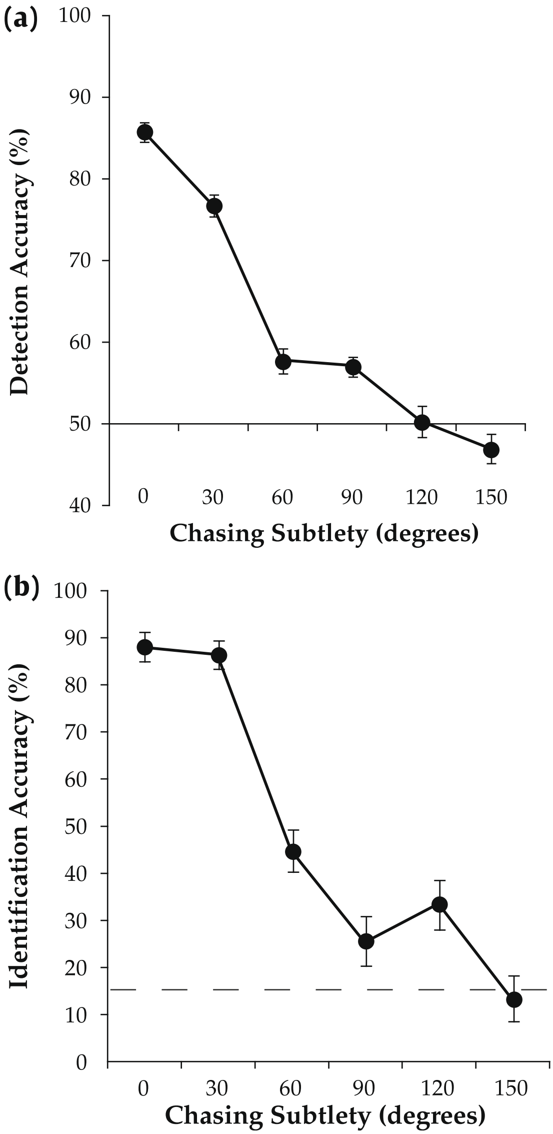

Fig. 4. Results from Experiment 1. (a) The accuracy (% correct) of determining whether a chase was present, as a function of chasing subtlety. Chance performance is 50%. (b) The accuracy (% correct) of identifying both the wolf and sheep correctly (given that the trial was accurately judged to contain a chase), as a function of chasing subtlety. Chance performance, as indicated by the dashed line, is 16.7%.

was likely to do so as well, a moment later. However, those results could simply reflect the psychophysics of this type of domain-general correlation-detection, without a role for animacy, per se. These possibilities can be unconfounded, however. A type of correlation detection is certainly intrinsic to the perception of chasing in such displays, but if our results reflect the perception of chasing, then not all correlations should be created equal: observers should be able to readily detect *those correlations that are reliable cues to chasing,* but should be unable to reliably detect equally strong correlations that are not cues to chasing or to other types of animacy.

Table 1
Results of paired-*t*-tests from Experiment 1.

	0°	30°	60°	90°	120°	150°	Random
0°	–	$t = 6.385$ $p < 0.001$	$t = 15.323$ $p < 0.001$	$t = 16.659$ $p < 0.001$	$t = 18.437$ $p < 0.001$	$t = 17.488$ $p < 0.001$	$t = 30.226$ $p < 0.001$
30°		–	$t = 11.918$ $p < 0.001$	$t = 11.494$ $p < 0.001$	$t = 10.741$ $p < 0.001$	$t = 14.545$ $p < 0.001$	$t = 20.394$ $p < 0.001$
60°			–	$t = 0.314$ $p = 0.757$	$t = 3.338$ $p = 0.003$	$t = 3.972$ $p = 0.001$	$t = 5.031$ $p < 0.001$
90°				–	$t = 2.940$ $p = 0.008$	$t = 5.238$ $p < 0.000$	$t = 5.946$ $p < 0.001$
120°					–	$t = 1.354$ $p = 0.191$	$t = 0.136$ $p = 0.893$
150°						–	$t = 1.798$ $p = 0.088$ (df = 19)

We tested this possibility in the present experiment by contrasting two equally strong correlations. One type of correlation, employed in *Chasing trials*, was identical to that used in Experiment 1: the wolf reliably moved toward the sheep, with its trajectory chosen at random from the range defined by a chasing-subtlety value on each trial. The other type of correlation, employed in *Mirror trials*, was identical, except that the wolf now reliably moved toward a different point on each frame: the reflection of the sheep's location through the center of the display (see Fig. 5). In effect, the wolf was thus chasing a 'phantom sheep' during each Mirror trial, which always perfectly mirrored the movement of the visible sheep.

As a result, the degree of statistical correlation between the movements of the wolf and sheep were identical across all trials, but the particular manner in which the wolf moved was not. When the sheep

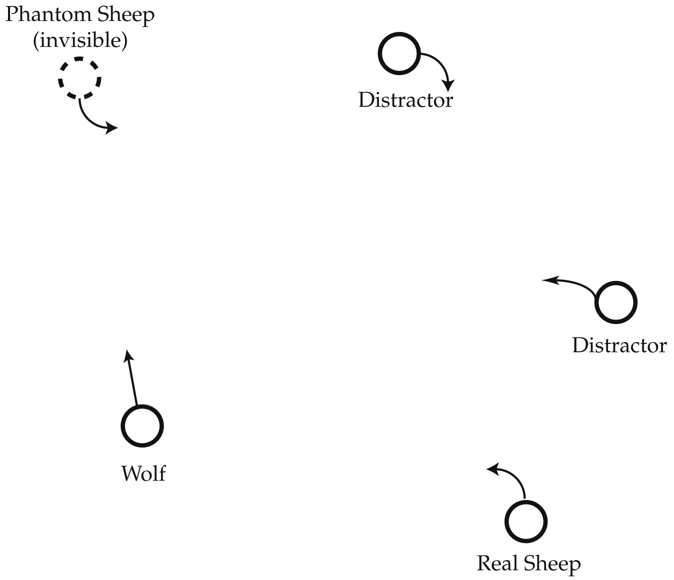

Fig. 5. A screenshot from the dynamic display of a Mirror trial in Experiment 2. The "phantom sheep" that the wolf is actually chasing (drawn here with a dashed contour) is invisible, and its position is always the mirror image of the (real) sheep, as reflected through the center of the display. The curved arrows represent the haphazard motions of each item, and were not present in the actual display.

made a sudden trajectory change, the wolf correspondingly adjusted its heading (via the adjustment of its possible heading range, as defined by the chasing-subtlety value) a moment later in both conditions, but on Mirror trials it did so by moving in the opposite direction from the sheep. (This does not mean that the wolf was constantly heading away from the sheep, as if it were avoiding it. Indeed, half of the time the wolf was still heading toward the sheep. If the sheep was heading from the upper-left quadrant toward the center of the display, for example, the wolf would be heading from the lower-right quadrant toward the center of the display – i.e. moving toward both the visible sheep and its phantom counterpart.)

Participants were fully informed about the nature of this relationship, and were given the analogous task: on all trials, they simply had to distinguish Correlation-Present from Correlation-Absent trials – with the conditions fully blocked and counterbalanced so that participants always knew exactly what type of correlation could be present on each trial. If the results of Experiment 1 reflect a general ability to perceive statistical correlations, then the results of the Chasing and Mirror conditions should be identical. If the psychophysical function obtained in Experiment 1 is specific to those correlations that imply a type of perceived chasing, however – consistent with the hypothesis of specialized perceptual routines for detecting this type of animacy – then performance should be much worse on Mirror trials.

3.1. Method

This experiment was identical to Experiment 1 except as noted here. Ten Zhejiang University undergraduates participated in a single 50-min session for payment. The displays were presented on a PC computer using custom software written in Matlab using the Psychophysics Toolbox libraries (Brainard, 1997; Pelli, 1997). Participants completed two blocks of 90 trials each in a counterbalanced order. Trials during the Chasing block were identical to those in the previous experiment, except that only three levels of chasing subtlety (0°, 30° and 90°) were used. Trials during the Mirror block were identical, except that the wolf's motion was always computed as if the sheep were located in its reflected position through the center of the display (see Fig. 5). Within each block, there were 45 Target Present and 45 Target Absent trials, 15 each for each chasing-subtlety value. Before each block, participants were fully informed about the nature of the target correlations, and they practiced detecting them on 15 practice trials (the results of which were not recorded) before the experimental trials in each block began.

3.2. Results

Detection accuracy as a function of chasing subtlety is depicted in Fig. 6a. As this figure suggests, performance on Chasing trials qualitatively replicated the results of Experiment 1: the detection of chasing was excellent for 0° and 30° of chasing subtlety, but was much worse for 90° (at chance, whereas the equivalent performance in Experiment 1 was slightly above chance). In contrast, performance was considerably worse on Mirror trials, with performance never reaching above 65% (and more than 20% worse than on Chasing trials) even for perfect correlations (i.e. 0° of chasing subtlety). These results were mirrored in the identification performance, as depicted in Fig. 6b.

These data were submitted to a repeated measures ANOVA, which revealed a main effect of Chasing vs. Mirror trials ($F(1,9) = 68.847$, $p < 0.001$), a main effect of chasing subtlety ($F(2,18) = 43.583$, $p < 0.001$), and a reliable interaction ($F(2,18) = 16.156$, $p < 0.001$). On Chasing trials, detection accuracy was high and did not differ with chasing subtleties of 0° and 30° (86.7% vs. 85.4%, $t(9) = 0.712$, $p = 0.495$). Performance with 90° of chasing subtlety was dramatically lower (51.9%), however, and worse than in the 30° condition ($t(9) = 11.002$, $p < 0.001$). On Mirror trials, detection accuracy differed between 0° and 90° of chasing subtlety (64.0% vs. 50.7%, $t(9) = 3.651$, $p = 0.005$), but neither value differed from that at 30° (56.7%; both *p*s > 0.20). Most importantly, detection performance for 0° and 30° of chasing subtlety was reliably worse on Mirror trials compared to Chasing trials (0°: $t(9) = 4.565$, $p = 0.001$; 30°: $t(9) = 8.136$, $p < 0.001$).

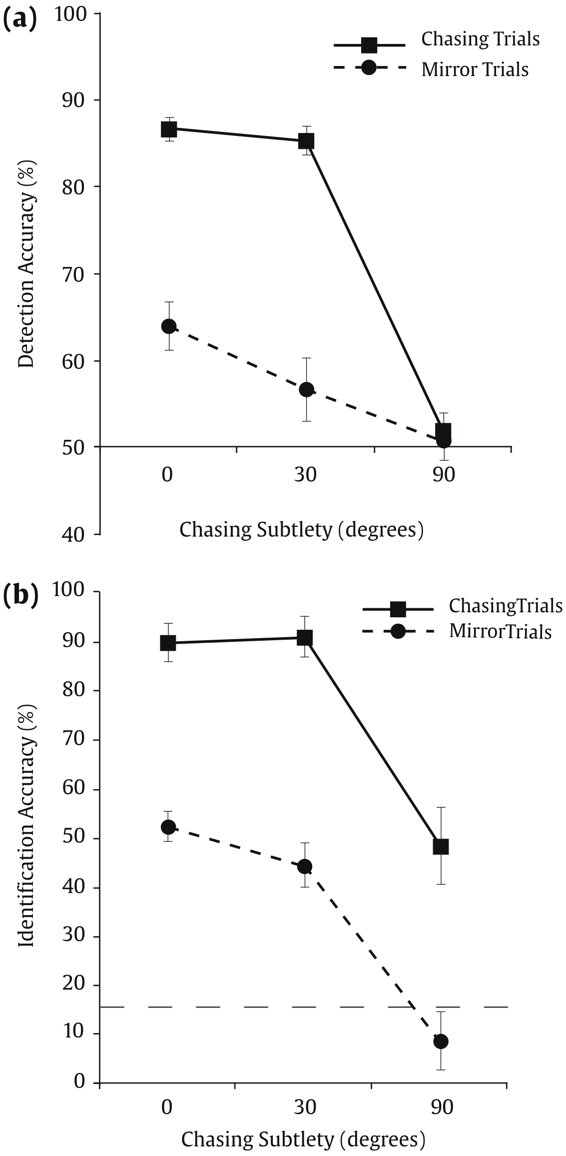

Fig. 6. Results from Experiment 2. (a) The accuracy (% correct) of determining whether a chase was present, as a function of chasing subtlety and trial type (Chasing vs. Mirror trials). Chance performance is 50%. (b) The accuracy (% correct) of identifying both the wolf and sheep correctly (given that the trial was accurately judged to contain a chase), as a function of chasing subtlety and trial type. Chance performance, as indicated by the dashed line, is 16.7%.

3.3. Discussion

These results distinguish the detection of chasing from the detection of more general forms of spatiotemporal correlations. The psychophysical function for Chasing trials again showed the characteristically high performance, but only for a constrained set of low chasing-subtlety values. In contrast, performance for Mirror trials was much worse, and this psychophysical function had the shallow linear slope that might be expected to result from a more domain-general ability to detect brute spatiotemporal correlations, per se. The perception of chasing thus may require a form of correlation-detection, but it appears to involve specialized processing for only certain forms of correlations.

4. Experiment 3: Reversed chasing

Actual chasing, in the displays used in Experiment 1, was implemented via a combination of two features: (1) correlated motion patterns between the wolf and sheep, and (2) the fact that the wolf gradually approached the sheep over time. Experiment 2 demonstrated that the psychophysical 'chasing' function from Experiment 1 did not simply reflect the detection of correlated motions. It is still possible, though, that the second feature resulted in Chasing-Present displays in which two discs (viz. the wolf and sheep) are in greater average spatial proximity than are any two discs in Chasing-Absent trials. If so, then our results could perhaps be explained simply as an 'average proximity detection' function.

In this experiment, we controlled for the average proximity of discs throughout each trial (holding chasing subtlety constant at 30°) by contrasting certain chasing displays with the very same animations played in reverse. Despite the preserved average proximity (and the motion correlations of the same strength), we predicted that such correlations could only be readily detected in the 'forward' animations, which would yield a reliable salient chasing percept. In contrast, the reversed animations would involved the same correlated motions, but with the wrong proximity profile over time, and as a result they would yield no such reliable percept – having to be detected via more general and less accurate inferences.

When played forward, the wolf is always heading directly toward the sheep, with only mild chasing subtlety. However, this does not mean that when reversed, the sheep will always be heading directly toward the wolf; instead, its local heading from moment to moment may be entirely different. To emphasize this difference in this experiment, we made two changes to the wolf's motions: (1) the wolf's speed was slightly slower than the sheep's speed; and (2) the wolf had less 'inertia', such that it could change its heading more frequently than the sheep. The upshot is that the Reversed displays do not effectively trigger a reliable perception of chasing – and indeed it is often difficult to detect the wolf and the sheep at all amidst the distractors in this condition. (And if the wolf and sheep are explicitly highlighted – e.g. by a different color – then it still does not reliably appear to involve chasing; instead, the sheep seems to just 'luckily' end up near the wolf, unintentionally.)

4.1. Method

This experiment was identical to Experiment 1 except as noted here. Thirteen Yale undergraduates participated in a single 30-min session for course credit. The displays were presented on a PC computer using custom software written in Matlab using the Psychophysics Toolbox libraries. The visible black background subtended $16^\circ \times 16^\circ$. The sheep and distractors moved at a speed of 10.8°/s, randomly changing direction within a 120° window roughly every 500 ms (with a direction-change occurring with a likelihood of 3.33% on each frame of motion). The wolf moved at a speed of 10.3°/s (i.e. 0.5°/s slower than the sheep and distractors, though observers did not notice this difference), changing direction roughly every 333 ms (with a possible direction-change occurring with a likelihood of 5% on each frame of motion). The wolf's trajectory was determined by a fixed chasing-subtlety value of 30° on every trial. *Forward-Chasing* trials proceeded as described above. *Reversed-Chasing* trials involved animations generated in the same manner, but simply played in a reversed temporal order. Participants were fully informed about the nature of these conditions, and were instructed simply to detect the presence of such correlations. There were 40 trials, 20 for each of the two temporal-direction conditions, presented in a randomized order.

4.2. Results and discussion

Detection accuracy was considerably better on Forward-Chasing trials (81.9%) than on Reversed-Chasing trials (69.7%; $t(12) = 2.945$, $p = 0.012$). This difference implies that chasing is not simply detected via a differing average proximity of discs, which was perfectly equated between these two conditions. Note also that this experiment again (like Experiment 2) controlled for the presence of correlated motions over time. As such, chasing appears to be detected not via these brute variables, but rather by a very particular combination of them – wherein the wolf approaches the sheep over time. Within the narrow window of effective chasing subtlety (including the 30° used here), such patterns appear to reliably trigger the perception of chasing even when observers are instructed to ignore such temporal patterns in their overt task. In short, detecting such correlated motions is easier for Forward-Chasing patterns of proximity over time – precisely because such displays yield a reliable salient chasing percept.

Perhaps unsurprisingly, the absolute level of performance with Reversed-Chasing, while considerably worse than with Forward-Chasing, was still above chance. This may indicate (a) that a general process of motion-correlation detection plays a role (though not the only role!) in the detection of chasing more broadly; (b) that the Reversed-Chasing stimuli themselves activate a specialized detector for chasing, though imperfectly, and not as strongly as the Forward-Chasing animations; and/or (c) that the above-chance performance for Reversed-Chasing simply reflects a completely independent and stimulus-general perceptual ability, with no contribution to or from any more specific processes involved in perceiving animacy. The present results do not allow us to untangle these possibilities, but they do make clear that the perception of chasing transcends the perception of 'mere' motion correlation.

5. Experiment 4: Don't get caught!

Experiments 1 and 2 revealed that the perception of chasing is poor when chases are even mildly 'subtle' – but do such limitations really matter? That is, does the remaining degree of (largely unperceived) *actual* chasing with subtlety values beyond 30° really make a difference as to whether the sheep will get caught? Here we show that it does – that subtle chases may nevertheless be highly effective – and we do so in an especially direct way, since in this experiment the participant *was* the sheep.

Participants now used the mouse to control the trajectory of one of the discs (the sheep) while the wolf pursued the sheep in the same manner as in Experiment 1. Trials could last up to 25 s, but ended immediately if the wolf became closer than 2.5° to the sheep. Thus participants had to identify the wolf (i.e. to perceive the wolf chasing *them*) and then avoid it. In practice, the second part of this task – the avoidance, per se – was easy and straightforward, once the participant successfully determined which of the other identical discs was chasing them. The dependent measure was simply the percentage of trials on which the participants were 'caught'.

This *Don't-Get-Caught* task allows for a measure of the perception of animacy in terms of visual performance – now assessed via a different type of accuracy score. To the extent that observers can readily detect the wolf chasing them, they should be able to effectively avoid it; to the extent that observers have difficulty detecting the chasing, however, the wolf should in effect be able to 'sneak up' on the participant. At the same time, though, this method also allows for a direct assessment of the *accuracy* of chasing itself (as distinct from the accuracy of the *perception* of chasing), insofar as we can evaluate the likelihood of the wolf catching the sheep. That was not possible in Experiments 1 and 2, since those search displays were constrained to prevent the wolf from 'catching' the sheep. Here, though, the accuracy of chasing has a direct meaning: it is simply the effectiveness across of trials with which the wolf is able to catch the sheep. It could turn out that such 'catching efficacy' is perfectly correlated with the perception of chasing, such that chasing is only effective in that range of chasing-subtlety values that promote efficient chasing detection in the previous experiments. However, it is also possible that the accuracy of chasing itself could continue to vary as a function of chasing-subtlety in this experiment, even below of the range of efficient chase detection (i.e. beyond roughly 30° of chasing subtlety). In any case, this is to our knowledge the first study that has been able to quantify the effectiveness of various forms of chasing in actual interactive displays (cf. Nahin, 2007). Moreover, note that performance in the Don't-Get-Caught task reflects (a) the perception of chasing, but also (b) the ability to make effective use of that information. Therefore, by evaluating subjects' ability to effectively avoid the wolves, this task helps show how the perception of chasing actually *matters* for behavior.

5.1. Method

This experiment was identical to Experiment 1 except as noted here. Ten new Yale University students participated. Participants directly controlled the trajectory of the sheep (now drawn in green) with the mouse. To avoid making it trivially easy to avoid all other discs, the display was crowded, containing 24 additional white discs (as in Experiment 1), one of which was the wolf (see Fig. 7). Across trials, the wolf pursued the sheep with chasing-subtlety values between 0° and 180°, in steps of 30°. There were 105 randomly-ordered trials, 15 for each subtlety value. (Participants first completed 15 practice trials, the results of which were not recorded.) The wolf-sheep distance was initially greater than 9°. Trials ended either when the wolf-sheep distance became less than 2.5° (*caught!*) or after 25 s (*escaped!*). The first 10 s was a warm-up period wherein the maximum wolf/distractor speed gradually increased from 8.7°/s to 14.5°/s, while the sheep's maximum speed gradually increased from 17.4°/s to 23.2°/s.

These display parameters were constructed in order maximize the chances of the user-controlled sheep being able to escape from the wolf when the wolf was identified, but to allow the wolf to gradually get closer to the sheep when it was not identified – especially with larger chasing-subtlety values (such as 90°) which subjects were poor at detecting in Experiment 1. To demonstrate that this latter property accurately characterized these types of motions – i.e. that the wolf would in fact gradually approach the sheep even with 90° of chasing sublety, we recorded the wolf-sheep proximity over time in a simulation of 40 trials in which the sheep simply stayed in one location toward the edge of the display, maximally distant (30.5°) from the initial position of the wolf. As can be appreciated from the results of this simulation, depicted in Fig. 8, the wolf-sheep proximity does indeed gradually decline over time with such parameters, and well within the timeframe of this interactive experiment.

5.2. Results and discussion

The percentage of 'successful escape' trials as a function of chasing subtlety is depicted in Fig. 9, with the relevant statistical comparisons given in Table 2. Overall levels of performance in this task

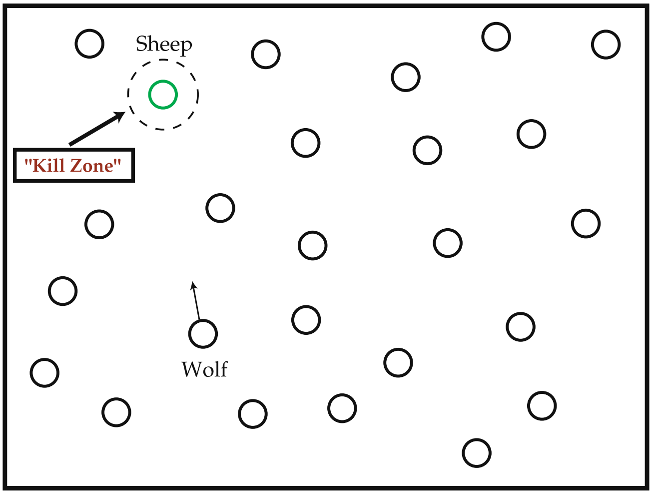

Fig. 7. A screenshot from the dynamic display in the Don't-Get-Caught task from in Experiment 4. The subject must use the mouse to move the sheep around the crowded display so that the moving wolf that is chasing it never enters its 'kill zone'.

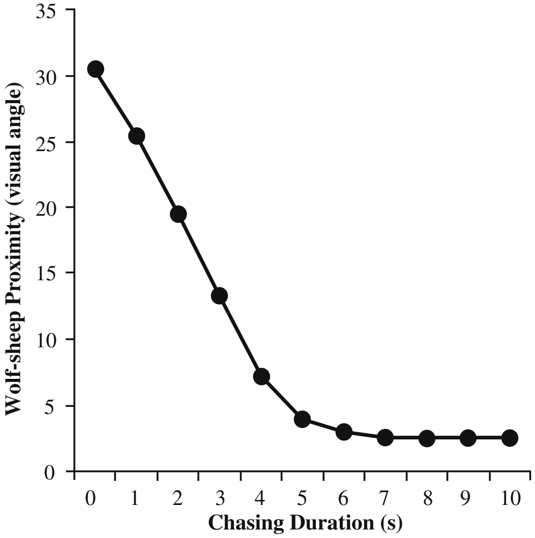

Fig. 8. Results from a simulation of the degree to which the wolf gradually approaches the sheep with 90° of chasing-subtlety in Experiment 4. The wolf-sheep distance (depicted on the vertical axis) is sampled here each second for 10 s (varied on the horizontal axis). (These simulations ended when the wolf-sheep distance became less than 2.5° – at which point the wolf was deemed to have 'caught' the sheep.)

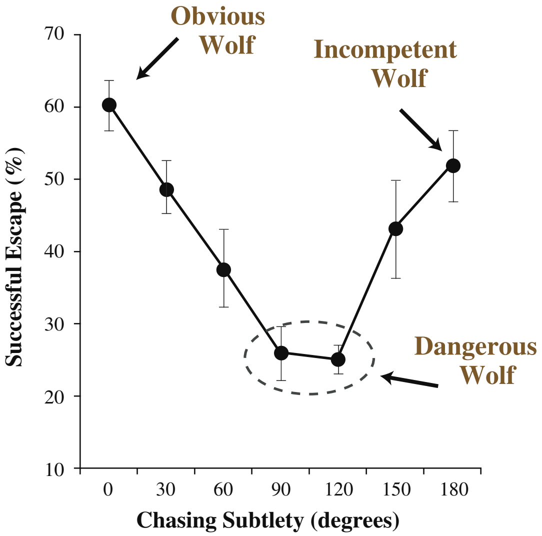

Fig. 9. Results from the Don't-Get-Caught task of Experiment 4: The percentage of trials in which the participant successfully avoided being caught by the wolf, as a function of chasing subtlety.

are essentially meaningless, since for example we can impair performance to any desired degree simply by speeding up the movements of the wolves, or increasing the number of distractors (all of which are potential wolves at the start of a trial, as far as the participant is concerned). In fact, we set these

Table 2
Results of paired-*t*-tests from Experiment 4.

	0°	30°	60°	90°	120°	150°	180°
90°	$t = 7.637$ $p < 0.001$	$t = 4.722$ $p = 0.001$	$t = 1.833$ $p = 0.10$	–	$t = 0.327$ $p = 0.751$	$t = 2.258$ $p = 0.050$	$t = 4.510$ $p = 0.001$
120°	$t = 11.521$ $p < 0.001$	$t = 6.528$ $p < 0.001$	$t = 2.431$ $p = 0.038$	$t = 0.327$ $p = 0.751$	–	$t = 2.328$ $p = 0.045$	$t = 5.770$ $p < 0.001$ (df = 9)

parameters during pilot testing in order to bring performance to a level that was close to neither ceiling (perfect escapes) nor floor (infrequent escapes); in this range, the critical data relate to the shape of the performance curve as a function of chasing subtlety.

The clear U-shaped function in Fig. 9 dramatically reveals both the accuracy of *perceived* chasing and the ultimate import of *actual* (statistical) chasing. Performance was good with both the lowest and highest chasing-subtlety values – but for different reasons. With low subtlety (e.g. 0°, 30°), it is easy for subjects to escape, because they readily detected the wolf chasing them, and so could avoid it; we have thus labeled this point as the ‘‘Obvious Wolf’’ in Fig. 9. Note that this condition highlights the fact that bona fide *chasing* can occur without necessarily resulting in any *catching* (as any child on a playground could tell you!). Perhaps another way to make this point is to note that the most *obvious* chases (a primary focus of the present study, insofar as we’re studying the *perception* of animacy) are seldom going to be the most *effective* chases. With high subtlety (e.g. 150°, 180°), in contrast, subjects were not really *avoiding* the wolf, since they could not detect it; rather, the wolf was just ‘chasing’ them very ineffectively. Indeed, the 180° case is a baseline, with no actual wolf/sheep correlation present at all, such that subjects were ‘caught’ only by chance; we have thus labeled this point as the ‘‘Incompetent Wolf’’ in Fig. 9.

The most intriguing results are those with moderate chasing subtleties (e.g. 90°, 120°), where performance was significantly worse than with all other values (see Table 2). Critically, this is in the same range that yielded very poor detection in Experiment 1: evidently the wolf was able to catch the sheep in the present experiment because subjects could not readily detect the wolf; we have thus labeled these points as ‘‘Dangerous Wolves’’ in Fig. 9.

Methodologically, these results validate the usefulness of the Don’t-Get-Caught method introduced here for quantifying the perception of chasing. Theoretically, these results indicate (a) that the ability to detect chasing is highly constrained; (b) that the accurate detection of chasing lies within a window that is far narrower than the full range of ‘effective’ pursuits; and (c) that poor detection of chasing in Experiment 1 did not arise simply because chasing at those subtlety values (larger than 60°) are ineffective. In other words, a substantial degree of the unperceived chasing in this experiment really does deserve the name ‘‘chasing’’, because those subtlety values do promote considerably more ‘catches’ than would be expected from chance. The activity of the wolves in this special range of ‘unperceived chasing’ might thus be likened to a type of *stalking*: the wolves are getting efficiently closer and closer to the sheep, but they are in effect masking this pursuit by frequently deviating from the types of perfect heat-seeking that are so readily perceived. (In addition, note that the wolves are by definition getting closer and closer over time to the sheep on all trials in which the subject is ‘caught’; this further emphasizes that such patterns of proximity over time effectively promote the detection of chasing only in some circumstances.)

6. Experiment 5: Escaping from wolves that are or are not facing you

The previous experiments measured the perception of chasing based on variation of a single novel cue: the ‘chasing subtlety’ that controlled how directly the wolf approached the sheep. It is our hope, however, that the methods introduced here may also be able to identify and quantify additional cues to the perception of chasing. In this final experiment we present one example of a distinct type of cue, using the Don't-Get-Caught task to explore the role of the objects' *directionality* in mediating the perception of chasing.

In natural environments, humans and other animals may chase each other, in that we move so as to get closer and closer to our prey. This is not the only way in which our behaviors are correlated with those of our targets during chasing, however. In addition, we tend to be *facing* the targets of chases. This of course is correlated with the efficiency of approach in nearly all natural settings – since it is a rare animal that can chase its prey just as effectively when it is running or swimming or flying *sideways*! However, it is possible that this form of directionality is processed as an independent cue to the perception of chasing, controlling for the efficiency of approach. Directionality of this type is certainly processed by the visual system; for example, it can directly influence the perceived direction of motion in the first place, with perceived trajectories biased toward being consistent with the direction that a shape is facing, based on its symmetry (Morikawa, 1999). The question, then, is whether directionality of this type directly influences perceived chasing.

This cue has been used incidentally in many studies, in that the shapes are drawn with an axis of symmetry, such that they are seen to be facing other objects as they move (e.g. Abell et al., 2000; Blythe et al., 1999; Castelli et al., 2000; see also Fig. 1a and c). This factor has often been used without varying or analyzing it, but it does seem to have marked perceptual consequences, strengthening the impression of animacy when it is used. (For example, compare the two movies depicting displays similar to those of Heider and Simmel, with and without directionality, at http://www.yale.edu/perception/chasing/.)

Moreover, one study that did vary this cue found that it had a statistically significant (though small) effect on animacy ratings: Tremoulet and Feldman (2000) varied whether their single moving shape on each trial was displayed as (a) a small circular disc, (b) an oriented line segment that began 'facing' its direction of motion, but never changed this orientation, or (c) an oriented line segment that switched its orientation to remain consistent with the direction of motion when the angle of motion was changed. This variable affected the reported animacy ratings in a mild way (varying by about 1 point on a 7-point scale), with aligned lines being judged as more animate than either discs or misaligned lines. This effect is difficult to interpret in two ways, however. First, the aligned-lines condition in this study was also the only condition where the orientation (or indeed any feature of the object aside from its location) was changed during a trial. This change could thus have simply attracted attention, promoting a more careful analysis of its movements. More importantly, however, this result suffers from the same potential problem raised above in the Introduction: because of the task demands associated with this type of rating study, it is unclear whether the rating differences reflect a true change in the *perception* of animacy, or simply a change in how likely subjects thought a shape *should* be judged as animate. (Note again that we might have predicted this result even without seeing any displays, given that task demands lead subjects to vary their ratings according to some variables. Surely everyone would predict that aligned movements would be more likely to reflect animate movements than would unaligned movements, even without any visual displays.)

In the current experiment, we used the Don't-Get-Caught task from Experiment 4 in order to examine the influence of directionality on perceived animacy using a measure of visual performance. We used only a single chasing-subtlety value (30°), and instead we varied the nature of the objects' orientations randomly across trials. (The participant-controlled sheep was again always drawn as a small disc.) Two of our categories were similar to those used by Tremoulet and Feldman (2000). First, the wolf and all distractors could be drawn as orientation-less *Discs* (Fig. 10a), or as *Oriented Darts* (Fig. 10b) whose headings always matched the directions in which they were moving. Our final two directionality conditions were novel. In the *Misoriented Darts* condition (Fig. 10c), the darts' orientations were constantly shifting, but in a way that was uncorrelated with their directions of movement. Because these directionality shifts were exactly as fast and frequent as those in the Oriented Darts condition, however, they control for the overall amount of orientation-related motion in the darts, in a way that was not taken into account in previous studies. Finally, in the *Perpendicular Darts* condition (Fig. 10d), the darts' orientations were always varying so that they 'faced' *90° away* from their directions of movement. This controls for the overall correlation between objects' movements and their orientation changes, in a way that was not taken into account in previous studies.

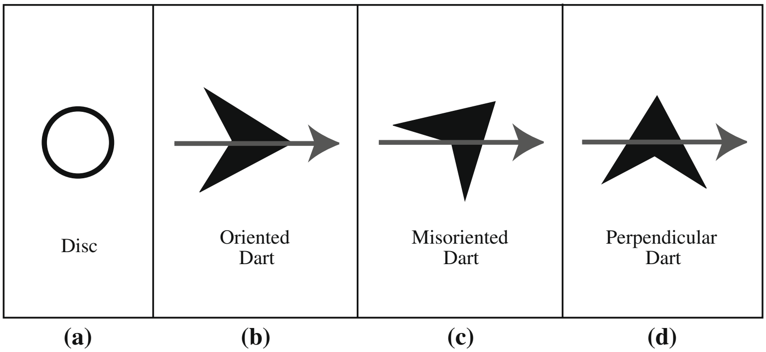

Fig. 10. An illustration of the *directionality* manipulation used in Experiment 5. (a) The wolf and all distractors are drawn as orientation-less *Discs*. (b) The wolf and distractors are drawn as *Oriented Darts* whose headings always match the directions in which they are moving. (c) The wolf and distractors are drawn as *Misoriented Darts* whose orientations are constantly shifting, but in a way that is uncorrelated with their directions of movement. (d) The wolf and distractors are drawn as *Perpendicular Darts* whose orientations are always varying so that they 'face' *90° away* from their directions of movement.

If directionality is used as a cue to perceived chasing, then performance – again measured in terms of the likelihood of escape – should vary as a function of this cue, despite its irrelevance to the actual behavior of the wolf (and the distractors). Moreover, if directionality per se – i.e. the heading of a wolf in the direction of its movement – is the relevant cue, then performance with Oriented Darts should exceed that with either Misoriented Darts or Perpendicular Darts.

6.1. Method

This experiment was identical to Experiment 4 except as noted here. Twelve new Yale University students participated. Chasing subtlety was fixed at 30° for all trials. There were always 21 items on the display in total (see Fig. 11). The sheep was a green disc with a 0.6° radius. The directionality of the distractors and the wolf were systematically manipulated, always in the same manner. In the *Discs* condition, the shapes were white circles, the same size as the sheep. In each of the other three condi-

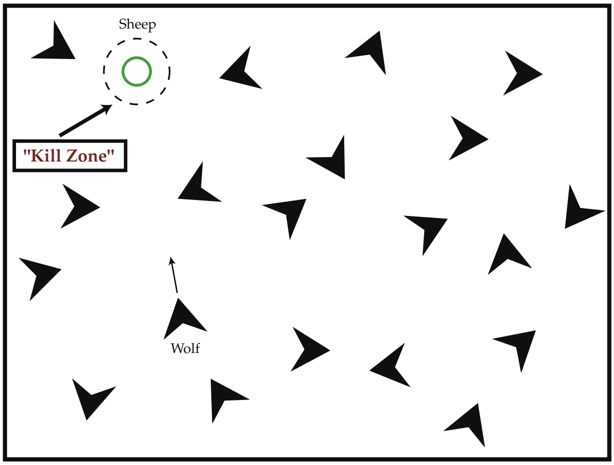

Fig. 11. A screenshot from the dynamic display of an *Orientated Darts* trial in Experiment 5. Note that the wolf is 'facing' the sheep, toward which it is also moving.

tions, the shapes were ‘dart’ figures that possessed a salient axis of symmetry (see Fig. 10), roughly sized to have an equivalent area to the discs in the Disc condition. The center of mass of the dart was always drawn in the same location as the center of the discs in the Disc condition, and the ‘nose’ and the right and left ‘wings’ were all located on the perimeter of an invisible 2°-diameter circle. The angles between the two wings and the nose were 120°.

In the *Oriented Darts* condition, the directions of the darts (i.e. the angle at which the ‘nose’ was pointing) perfectly matched the directions of their motions. In the *Misoriented Darts* condition, the darts’ noses were uncorrelated with their motion directions, but were manipulated so as to equate the overall degree and frequency of motion: at the beginning of each trial, the 20 items were randomly assigned to 10 pairs, such that each dart would be oriented during its motion so as to match its *partner’s* motion direction. In the *Perpendicular Darts* condition, the orientation of each dart always correlated perfectly with its motion direction, but was offset (in a clockwise direction) by 90°. Participants completed 60 trials – 15 trials for each of the 4 directionality conditions – in a separate randomized order. (They first completed 12 practice trials – 3 for each of the 4 directionality conditions – the results of which were not recorded.)

6.2. Results

The percentage of ‘successful escape’ trials as a function of directionality is depicted in Fig. 12, with the relevant statistical comparisons given in Table 3. Performance differed marginally as a function of directionality ($F(3, 33) = 2.87$, $p = 0.051$), with the Oriented Darts condition significantly better than each of the other conditions, and no other differences were reliable.

6.3. Discussion

The results of this experiment are important for three reasons:

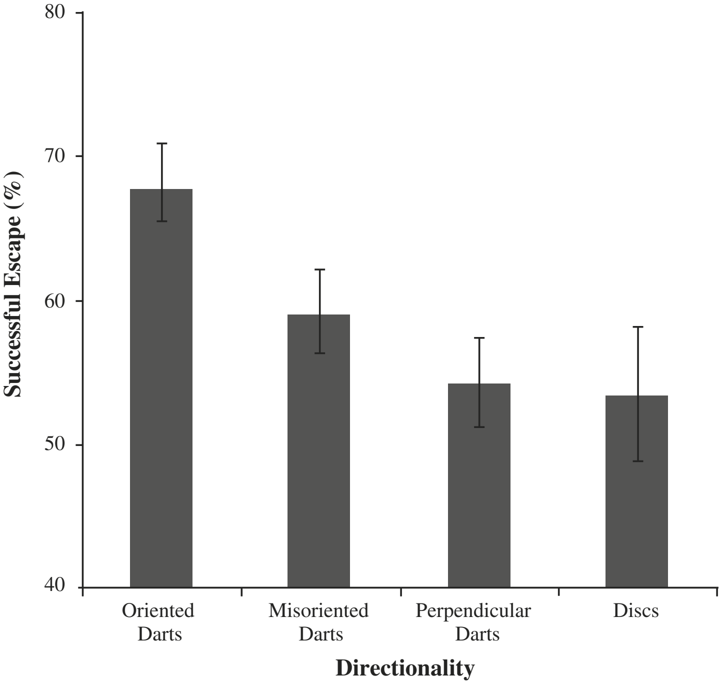

Fig. 12. Results from Experiment 5: The percentage of trials in which the participant successfully avoided being caught by the wolf, as a function of the directionality of the wolf and distractors.

Table 3
Results of paired-*t*-tests from Experiment 5.

	Discs	Oriented Darts	Misoriented Darts	Perpendicular Darts
Discs	–	$t = 2.100$ $p = 0.060$	$t = 0.881$ $p = 0.397$	$t = 0.102$ $p = 0.920$
Oriented Darts		–	$t = 2.406$ $p = 0.035$	$t = 3.585$ $p = 0.004$
Misoriented Darts			–	$t = 1.000$ $p = 0.339$ (df = 11)

First, we note in passing that the results of this experiment support the conclusions of both Experiments 2 and 3. These experiments considered (and ruled out) alternative hypotheses that what we had been calling the perception of "chasing" (as a case study of a type of animacy) was in fact just the perception of either correlated motion (assessed in Experiment 2) or differing average spatial proximity (assessed in Experiment 3). Note that if this was the case, then performance should not have varied by condition in this experiment, since the motion correlations and spatial proximity profiles were always identical. In contrast, the large (14%) and reliable differences obtained in this experiment emphasize that the perception of chasing is driven by factors beyond movement-based correlations.

Second, the primary importance of this study is that it demonstrates a role for directionality in perceived chasing in a way that goes beyond previous experiments. We observed a reliable advantage for Oriented Darts that is consistent with the motivation noted above: many objects in the natural world tend to face in the direction that they are moving. We suspect that the visual system has come to incorporate this assumption over evolutionary time, using it as heuristic to detect animacy and goal-directed behavior. As a result, we are better able to detect a wolf that is chasing us in this study (and are thus better able to escape) when the wolf (and the other objects in the displays) are pointed in the direction that they are moving. Our results also help to isolate this factor as reflecting this type of orientation per se. In particular, the advantage for Oriented Darts cannot be due simply to the greater degree of orientation-related local motion, as these same motions occurred with Misoriented Darts (which did not promote any better 'escape' rates than did Discs). Similarly, the advantage for Oriented Darts cannot be due simply to the mere correlation of orientation and movement, as these same correlations were present with Perpendicular Darts (which also did not promote any better escape rates than did Discs). Thus, it seems that the relevant cue to perceived chasing is not just correlated orientation; rather, it must be a *particular* correlated orientation, such that the objects are 'facing' in the direction that they are moving. Note also that unconfounding this cue from effects of lower-level correlations or local-motion artifacts would not have been possible in previous displays; they require the kind of algorithmically-controlled varying directions that characterize the displays used here to implement 'chasing' in the first place.

Finally, as a secondary methodological point, the present results illustrate the general utility of the Don't-Get-Caught task, showing how this new performance measure can be used to reveal cues to perceived animacy beyond the chasing subtlety explored in the previous experiments.

7. General discussion

This study focused on the psychophysics of chasing for three reasons. First, we deemed chasing to be a form of animate behavior whose detection has considerable adaptive value. Second, chasing was our candidate for what may be the most direct form of perceived social interaction which can nevertheless yield robust percepts. Third, and most generally, we suspected that "the" perception of animacy (as in Heider and Simmel's famous animation) actually reflected several different types of percepts (including chasing but also playing, fighting, guarding, etc.) that may operate according to different principles. As such, progress in understanding the perception of animacy may be hindered by studies which combine different "categories" of animacy – and may be furthered by more focused performance-based studies of particular visual cues (cf. Barrett et al., 2005; Blythe et al., 1999; Tremoulet & Feldman, 2000). In this context, chasing was our candidate for a 'case study' of perceived animacy that could yield new insights. The nuances of particular cues to perceived chasing might not transfer to other types of perceived animacy, but our hope is that these results may serve to highlight some of the important features of this type of visual cognition as a whole, as illustrated in the discussion below.

The primary goals of this study were to identify cues that trigger the perception of chasing, to quantify their influence, and to objectively evaluate the accuracy of this form of perception. Because these goals required the development of new methods for assessing this type of perceived animacy, however, we begin our discussion by focusing on this secondary methodological goal.

7.1. Measuring perceived animacy

We suggest that the two tasks developed here meet the two major methodological challenges noted in the Introduction, at least for this one particular form of perceived animacy. Perceptual reports and ratings can clearly be contaminated by higher-level inferences about what kinds of behaviors *should* be judged as animate – and we suspect that such inferences may actually influence some studies, e.g. in leading subjects to judge that more extreme speed changes are more likely to reflect animate behavior. In contrast, both the Search-for-Chasing and Don't-Get-Caught tasks measure visual *performance*. These measures are unlikely to reflect higher-level inferences for a reason stressed by Michotte and others in the context of perceived causality (e.g. Choi & Scholl, 2004; Michotte, 1946/1963; Newman, Choi, Wynn, & Scholl, 2008): these results reveal dramatic effects of very subtle stimulus manipulations. This is a hallmark of perception, but is uncharacteristic of higher-level inference: we may have intuitions about some factors that lead to animacy, but we do not have intuitions about the difference between 30° and 60° of 'chasing subtlety'. Moreover, performance-based studies of this sort measure an underlying ability, whose limits cannot be influenced merely by decisions about what features *should* matter for detecting animacy; rather, only those factors that actually *do* matter will facilitate detection and avoidance. Finally, as made clear in the preceding analyses, these tasks can measure perceived chasing with quantitative precision – spanning a wide range of performance and dramatically distinguishing subtly different stimulus conditions.

It is our hope that these performance-based methods might also be used as general tools to study multiple cues to chasing, beyond chasing subtlety. One example, from Experiment 5, is directionality: previous experiments had manipulated one form of this cue (e.g. Tremoulet & Feldman, 2000), but the present study shows how it can directly influence visual performance, beyond any higher-level intuition subjects may have about how likely it would be to reflect animacy. Indeed, this point is particularly powerful in the Don't-Get-Caught task of Experiment 5, since in fact directionality was unhelpful: the wolf gradually approached the subject-controlled sheep in this study in the same manner in all conditions, regardless of its orientation. Thus the present study was able to show how this factor influences visual performance even when observers should be inclined to discount it. This type of encapsulation from overt intentions is also a hallmark of perceptual processing, whereas some types of cognitive interpretations can be more readily overruled.

In sum, the Search-for-Chasing and Don't-Get-Caught methods (a) allow for the measurement of perceived chasing with quantitative precision, and (b) involve measures of visual performance that are better insulated from higher-level cognitive factors than are direct reports or ratings of animacy. As a result, these methods allow us not only to identify new cues (such as chasing subtlety), but also to place previously studied cues (such as directionality) on firmer perceptual footing – helping the scientific study of at least one form of perceived animacy live up to its brute phenomenological appeal.

7.2. How accurate is the perception of chasing?

Our primary goal in this case study of perceived chasing was to identify new theoretical features that might be hallmarks of perceived animacy more generally. One of the central conclusions of this project in this regard relates to the *accuracy* of perceived chasing. Many previous studies have documented subjects' phenomenal reports that the relevant displays appeared animate. Are subjects correct in making such attributions? Of course, the ultimate answer must be ‘no’ – since, after all, most of these displays are simply animated shapes on a computer screen. (We doubt that IRB panels would favor studies with *actual* predators and prey.) Abstracting away from this, however, we can still ask: are subjects correct in attributing animacy to *those types of dynamic behaviors?* In a way, it seems impossible to answer this question, because there is no objective way to interpret the displays. In many previous studies – including the early demonstrations of Heider and Simmel (1944), but also many contemporary experiments (e.g. Abell et al., 2000; Bloom & Veres, 1999; Castelli et al., 2000; Klin, 2000; Rutherford et al., 2006) – the stimuli were simply constructed haphazardly, such that they appeared to the experimenters to involve animacy, intentions, and goals. Another way of putting this is that the experimenters had reason to believe ahead of time that the displays would appear animate to their subjects, since the displays were constructed in the first place in order to appear animate to the experimenters themselves.

As a result of these common methods of stimulus construction, there is no way to objectively assess the presence of animate behaviors in such displays, except via appeal to consensus. Suppose, though, that a subject (or group of subjects) disagreed, either underattributing or overattributing animacy in their perceptual reports, relative to the overall population. For example, suppose that children with autistic spectrum disorder (ASD) perceived less animacy in some displays (cf. Klin, 2000; Rutherford et al., 2006). Would they be wrong to have done so? We cannot say; all we can say is that their perception of animacy differs from that of clinically normal observers – but of course it remains possible that it is the ASD children who are more accurate, and the clinically “normal” observers who are overattributing animacy (thus committing many more false alarms). This puzzle reflects the general difficulty with any attempt to evaluate the perception of animacy, since the presence of actual animacy in such displays is often defined in the first place only by a stable set of phenomenal percepts across observers and contexts.

Note that this is also a problem for those recent studies that have constructed their displays according to formal algorithms (e.g. Santos et al., 2008; Schultz, Friston, O’Doherty, Wolpert, & Frith, 2005; Tremoulet & Feldman, 2000, 2006). For example, in the experiments of Tremoulet and Feldman (2000) discussed in the Introduction, there is a right answer about just how extreme the speed and/or angle changes in the single dot were on any given trial, but there is no objective way to evaluate how such changes should correlate with animacy, beyond the percepts themselves. This same circularity bedevils even those studies that have explicitly instructed subjects to *produce* animate movements. For example, Blythe et al. (1999) and Barrett et al. (2005) had one group of subjects attempt to produce movements that matched certain labels (such as ‘fighting’ and ‘playing’) and then had another group of subjects attempt to match the labels to the replayed animations. In this case, one can objectively evaluate the fit of the second group’s labels, in terms of how accurately they matched the producers’ intentions. Even here, however, this form of ‘accuracy’ is defined only by consensus – so that in principle both the producers and the labelers could be wrong!

In this context, our choice of chasing as a case study in this paper might have special advantages: it is a particularly salient form of perceived animacy, but unlike most such forms its presence can in some ways be objectively identified. In particular, by employing the novel manipulation of ‘chasing subtlety’ (in Experiments 1–4), the current study can assess the degree of ‘actual’ chasing on each trial, without appeal to any perceptual reports. In other words, there is an objective answer for each display, defined in terms of whether the wolf is *actually* approaching the sheep over time (see Nahin, 2007). Moreover, this form of ‘objective chasing’ can be precisely quantified in terms of how efficiently the wolf approaches the sheep. This is in effect what we have depicted in Figs. 4 and 6, graphing our performance measures of observers’ ability to perceive chasing along the vertical axes, and the efficiency of actual chasing along the horizontal axes.

This advance transcends methodology: as discussed in more detail below, the characterization of the accuracy of perceived animacy yields a new distinction between perceived chasing and ‘stalking’. In addition, this method of stimulus construction allows us to contrast the perception of chasing per se with the perception of other types of similar correlations (such as that between the wolf and the ‘phantom sheep’ in Experiment 2). The upshot of this contrast highlights the apparent special-ness of this particular form of perceived animacy: observers can readily detect chasing (as in Experiment

1), but are much worse at detecting other equally strong correlations that do not imply chasing (as in Experiments 2 and 3).

7.3. Chasing vs. stalking?

The dissociation between perceived and actual chasing also illustrates the theoretical utility of such studies in other ways. Whereas many previous studies have shown that chasing *can* be perceived (e.g. Blythe et al., 1999; Heider & Simmel, 1944; Rochat et al., 1997, 2004), the present results go beyond such demonstrations to show the nature and limits of such perception. Indeed, the chasing that was actually present in our displays with moderate subtlety values was ultimately more akin to a type of *stalking*: chasing that was highly effective but was nevertheless very difficult to perceive. The participants in our experiments did not use the full range of information present in the display, at least in the timeframe they had to work with. Instead, they could only use the range of chasing-subtlety values that their visual systems automatically tagged as being especially reliable cues to chasing. Of course, this type of 'stalking' is a familiar pattern from actual animal behavior, but to our knowledge this is the first time that such patterns have been studied in the context of the perception of animacy.

Moreover, this category of "reliable cues to chasing" apparently includes factors which do *not* influence actual chasing in particular displays. The case study of this phenomenon explored here was the directionality cue that was manipulated in the Don't-Get-Caught task, in Experiment 5. In this experiment, recall that directionality was manipulated *independently* from chasing subtlety. As a result, directionality played no role whatsoever in whether (or how efficiently) the wolf actually approached the subject-controlled sheep. Nevertheless, it played a dramatic role in influencing subjects' ability to escape from the wolf. In effect, wolves that approached the subject-controlled sheep while "facing away" were engaging in another form of stalking (perhaps best captured in the term "sidling"): they were approaching the sheep while hiding that approach via the simultaneous manipulation of a different cue. This demonstrates that effective cues to perceived animacy are not simply those that are useful in any particular display. Rather, such cues must be learned over time (perhaps with an innate basis) such that they are judged to be generally reliable. As a result, such cues appear to operate (as in Experiment 5) even when they are of no objective use. (Indeed, our more recent work has shown in even more striking ways that certain types of directionality are so powerful that they can induce the perception of chasing even where is *no* actual pursuit; Gao, McCarthy, & Scholl, 2009; McCarthy, Gao, & Scholl, 2009.)

In the end, the nature of perceived chasing may thus be characterized best by appeal to its limitations, as reflected in the two forms of perceived stalking that we identified: (a) observers fail to utilize the full range of chasing-subtlety values that carry information about chasing; and (b) they fail to ignore properties such as directionality even when they carry *no* information about chasing. Both of these limitations speak to the ultimate perceptual nature of these phenomena, and are consistent with the idea that perceived animacy reflects a type of constrained modular processing (e.g. Michotte, 1950/1991; Scholl & Tremoulet, 2000).

7.4. Coda: Advice for assassins

In an especially gripping scene from a 2007 action movie, two assassins are chasing a newspaper reporter through a crowded train station, while the hero watches from afar, tracking the assassins. The assassins are dressed nondescriptly, and they keep their weapons hidden beneath their jackets, so that they cannot be readily identified by their looks. Instead, the hero must identify and track them based on the spatiotemporal dynamics of their movements – i.e. the fact that they are chasing the newspaper reporter. On the basis of such features, the hero successfully tracks and subdues the assassins, who thus fail in their objective. They should have read this paper. If they had, they would have realized that they made two mistakes. First, they constantly headed directly toward their intended prey, moving with a chasing-subtlety value that was close to zero. Second, they resolutely gazed directly at their prey, keeping their bodies oriented in his direction during the pursuit. Future assassins in such situations might be advised in contrast to *stalk* their prey, by manipulating their directionality in a different manner, and increasing their chasing subtlety.

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