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Infants' perception of chasing

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ABSTRACT

Two significant questions in cognitive and developmental science are first, whether objects and events are selected for attention based on their features (featural processing) or the configuration of their features (configural processing), and second, how these modes of processing develop. These questions have been addressed in part with experiments focused on infants' perception of faces, human body shapes, and biological motion of individual agents. Here, we investigate 4- and 10-month-old infants' ($N = 192$) attention to social motions, specifically to chasing—a ubiquitous, ancient, and fitness-relevant mode of interaction. We constructed computer-generated animations of chasing that had three properties: acceleration, high turning rates, and attraction (“heat-seeking”). In the first experiment we showed chasing side-by-side with a control display of inanimate, billiard-ball-like motions. Infants strongly preferred attending to chasing. In the next three studies, we systematically investigated the effect of each property in turn (acceleration, turning, and attraction) by showing a display of that property side-by-side with the control display. Infants preferentially attended to acceleration, and to attraction, but not to turning. If infants preferred chasing for its configuration, then the sum of the effect sizes of individual properties should be smaller than their combined effects. That is not what we found: instead, on three measures of visual behavior, the summed effects of individual properties equaled (or exceeded) that of chasing. Moreover, although attraction drew little attention and turning no attention at all, acceleration drew (nearly) as much attention as chasing. Our results thus provide evidence that infants preferred chasing because of its features, not its configuration.

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1. Introduction

Infants, like adults, actively scan their environments and select the objects and events they attend to (Bertenthal, 1993; Frankenhuis, Barrett, & Johnson, in press; New, Cosmides, & Tooby, 2007; Scholl, 2001; Turkewitz & Kenny, 1982). Attention affects what information enters the mind for further processing, guiding both

current action and learning that shapes future capacities (Gibson, 1988; Johnson, 2010). Therefore, the cognitive sciences can benefit from a detailed understanding of attention allocation and its ontogeny.

Attending to living things, especially their goal-directed motions, is critical for survival. Here, we focus on chasing—an ancient, ubiquitous, and fitness-relevant mode of interaction. For many animals, the outcome of a chase means the difference between life and death: a prey that escapes lives to flee another day, and a predator that catches prey fends off starvation for itself and its offspring. Hunting and scavenging, as well as avoiding predation, have been key to human survival for millions of years (Barrett,

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2005). Furthermore, humans chase and evade each other for various fitness-important reasons, including competition, social dominance, and play (Thomsen, Frankenhuis, Ingold-Smith, & Carey, 2011; Steen & Owens, 2001). For these reasons, we might expect infants, children, and adults to be sensitive to chasing, and to attend to it for its immediate importance as well as its learning affordances. Indeed, prior work shows that children and adults are good at recognizing chasing, and even infants may be sensitive to chasing, and understand aspects of it (Frankenhuis & Barrett, *in press*; see below).

Previous work has shown perceptual specializations for faces (Maurer, Le Grand, & Mondloch, 2002), biological motion (Bertenthal, 1993), and human body shapes (Slaughter, Heron, & Sim, 2002) by demonstrating configural processing of these stimuli in early infancy. It is not currently known whether infants' attention to social motions, such as chasing, depends on configural information (arrangements of elements) or featural information (individual elements). Here, we examine this question.

We adopt an approach that is common in evolutionary biology. We first determine an adaptive problem that infants must solve: navigating attention toward social interactions, specifically chasing. Then we postulate possible psychological designs that natural selection might have favored to solve this task. We focus on featural and configural processing, each of which entails benefits as well as costs. Configural processing helps in discriminating chasing from other types of social interactions (e.g., playing), and enabling an appropriate behavioral response (e.g., alerting caregiver). However, a focus on configural events may result in missed targets, if properties contributing to configuration are not always simultaneously visible (e.g., if one is occluded). Featural processing does not face this problem, and may work well if particular motion cues (e.g., anti-gravitational accelerations) reliably correlate with fitness-relevant events. However, it is coarse, and so it might navigate attention toward stimuli (e.g., a leaf blown by the wind) that will prove insignificant.

To find out whether infants attend to chasing for its configural or featural properties, we conducted a series of preferential-looking experiments examining infants' attention to individual constitutive properties of chasing (acceleration, high turning rates, and attraction), as well as their combination (chasing). Before presenting these, we provide a selective review of the growing literature on perceptions of animate motion, and chasing in particular, in infants, children, and adults.

1.1. Previous research on chasing

Psychologists have long known that motion generally attracts the attention of infants (Tronick, 1972). Moreover, infants are especially attuned to biological motion (Bertenthal, 1993; Fox & McDaniel, 1982; Rakison & Poulin-Dubois, 2001). When neonates are presented with two displays side-by-side—one depicting a point-light display of an animal walking and the other non-biological motion—they tend to navigate their gaze towards the biological motion (Simion, Regolin, & Bulf, 2008).

Adults judge faster motion as more animate (Scholl & Tremoulet, 2000) whether it results from accelerations (Tremoulet & Feldman, 2000) or from faster constant speed (Szego & Rutherford, 2007). These judgments are further enhanced when entities move in a direction that violates gravity (e.g., upward; Szego & Rutherford, 2008). Adults also detect an unfolding chase more easily among moving distractor stimuli when the chaser moves relatively faster; in contrast, a slower “lamb” following its “mother” is harder to detect (Dittrich & Lea, 1994).

Adults also judge entities that exhibit sudden directional changes to be animate, especially when the object is oriented towards (or ‘facing’) the direction in which it moves (Tremoulet & Feldman, 2000). Directional changes occur frequently in chasing events, and prey may adopt erratic fleeing patterns, or “Protean” strategies, frequently changing direction in unpredictable ways (Humphries & Driver, 1970; Miller, 1997). Though studies have explored infants' perception of self-propelled motion (Premack, 1990; Rakison, 2006), little is known about the extent to which high turning rates (changes in direction) draw the attention of infants, and may elicit perceptions of animacy.

Chasing is also characterized by relational properties. Rochat, Morgan, and Carpenter (1997) presented 3-month-old infants with two displays side-by-side, each depicting two discs (blue and red) moving across the screen. Movements were identical in both displays, except in one display the discs were chasing each other, whereas in the other they moved independently. A subset of the 3-month-olds, those with longer overall looking times, looked longer at the chasing display. Two kinds of social contingency might have generated this preference: either the “chaser” taking the shortest path to its victim (“attraction”), or the “evader” accelerating away when the chaser came too close (“fleeing”). Our studies, reported below, examine these factors independently.

Other work has explored whether infants, like adults (Bassili, 1976; Heider & Simmel, 1944), interpret chasing in goal-directed terms. Rochat, Striano, and Morgan (2004) showed 4- and 9-month-old infants a video of one disc chasing another (e.g., red chasing blue), until looking times decreased. If infants had habituated just to motion patterns alone, they should remain habituated if a role reversal occurred (blue chasing red), since this was perceptually similar to what they had seen before. However, if infants had assigned different goals to the chaser and the evader, they should regain interest in response to a role reversal, because the agents had changed their goals. This result was found only in the older age group (9-month-olds).

A developmental milestone occurs when infants begin to use inferred intentions to predict a chaser's future trajectory. Csibra and colleagues (2003) presented 9- and 12-month-old infants with an animation of a large ball chasing a small ball. The small ball then moved through a hole in a barrier too small for the large ball to pass through, and the large ball moved around the barrier. In the test phase, infants were presented with two different endings: Either the large ball “caught” (contacted) the small ball, or the large ball slid past the small ball and came to a halt. Twelve-month-olds, but not 9-month-olds,

appeared to expect the large ball to contact the small ball. This shows that at least by 12 months infants may infer the intention to capture another agent based on motion cues alone, and use the inferred intention to predict a chaser's trajectory.

Other work has studied adults' judgments of moving objects as animate and goal-directed (Heider & Simmel, 1944; Morris & Peng, 1994), even single geometrical shapes (Michotte, 1963; Szego & Rutherford, 2007; Szego & Rutherford, 2008; Tremoulet & Feldman, 2000), and which parameters affect the ability to detect goal-directed motion at a perceptual level. For instance, Gao, Newman, and Scholl (2009) showed that chasing is more readily detected when a chaser pursues its victim in a perfectly "heat-seeking" manner—that is, if the chaser moves directly towards the evader, always taking the shortest path. As the chaser adopts a more oblique approach ("stalking"), chasing becomes harder to detect. Detection is further impacted by the orientation of the chaser with respect to its path of travel: when the chaser (a triangle) "faces" the direction in which it is moving, detection of chasing is enhanced (Gao, McCarthy, & Scholl, 2010; Gao & Scholl, 2011).

1.2. The present research

In four experiments, we examine 4- and 10-month-old infants' perceptions of chasing. Our goals are to first document a preference for chasing, and then examine whether this preference depends on configural (arrangements of elements) or featural (individual elements) processing. Our strategy is to first present infants with a display showing full-blown chasing, paired with a control display (Experiment 1). Next, we isolate the properties distinguishing chasing from the control in order to determine which of chasing's constituent properties draw infants' attention (Experiments 2–4).

We want to know whether infants prefer chasing, and if so how much each property contributes, as given by Cohen's *d*. If, as we expect, infants preferentially attend to chasing, this may be driven by particular motion features, or by their configuration. If features are driving the preference, one property may be responsible or alternatively multiple properties. If the former, we expect a single property to "cover" the entire effect size of chasing (because in that scenario, it was this property that caused the preference). If the latter, each property would have boosted the preference for chasing—hence the independent effects of each property should add up to (or exceed) the total effect size of chasing. In contrast, if the preference for chasing depended on its configuration, individual properties by themselves should draw little or no attention, because these lack the configuration. If so, the effect sizes of individual properties will be small, because these properties will be looked at the same amount as the control display. Here, we investigate the effects of isolated cues alone, leaving two-cue combinations for a future study.

As noted, previous research indicates a change in conceptual understanding of chasing towards the end of the first year (Csibra, Bíró, Koós, & Gergely, 2003; Rochat et al., 2004). To be able to capture developmental changes

in attention, we included two age groups, 4- and 10-month-olds. In addition, we analyze for potential sex differences because some previous studies have found sex differences in early social perception. For instance, at 12-months of age, girls appear to be making more eye-contact with their mother than boys do (Lutchmaya, Baron-Cohen, & Raggatt, 2002), and boys display a preference for moving cars over moving faces, while girls do not (Lutchmaya & Baron-Cohen, 2002). Thus, our experimental designs are balanced in terms of both age and sex.

2. Four experiments

2.1. Methods

2.1.1. Participants

Forty-eight infants constituted the final sample in all four experiments: 24 4-month olds (12 female), 24 10-month olds (12 female). All 4-month-old infants were in the range 3.5–4.5 months. All 10-month-old infants were in the range 9.5–10.5 months. An additional 14 infants were excluded in Experiment 1, 17 in Experiment 2, 17 in Experiment 3, and 13 in Experiment 4, either because they did not attend 60 s or more to the displays (e.g., due to fussiness), or because of calibration failure.

2.1.2. Stimuli and apparatus

Animations were generated using Matlab© and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). We used Adobe Premier© to cut the animations to 20 s in duration and to pair the chasing and the control motion into a new stimulus depicting both motion displays simultaneously, side-by-side. Gaze and pupil size were measured using a Tobii model 1750 corneal-reflection eye tracker (Tobii Technology, Falls Church, VA). Stimuli were presented on a 43-cm flat panel (thin-film transistor) monitor, and refresh rate 50 Hz. All images were presented at 30 frames per second. A standard 5-point infant calibration was used. Experiments were controlled with ClearView software provided by Tobii.

In Experiment 1 (*chasing*), we created two discs that represented the chaser and the evader, each with a diameter of 30 pixels. One disc was red (Matlab color code [255 0 0]) and the other green (Matlab color code [0 225 0]). Both chaser and evader had turning rates of 5%: With each pixel they moved, there was a 5% probability of changing direction. The chaser approached the evader at a constant velocity of .6 pixels per frame, continually reducing their absolute distance in a "heat-seeking" manner ("attraction"). The baseline velocity of the evader was .3 pixels per frame. The chaser's speed remained constant, but the evader's speed was variable. Whenever the chaser came within 80 pixels of the evader, the evader would "flee" by turning away from the chaser and accelerating to 4 times its baseline speed (1.2 pixels per frame) for 50 frames. At this point the evader returned to its baseline speed. The average number of fleeing bouts per 20 s animations was 15. The discs never overlapped.

Control displays were generated using the same program that generated the chasing displays. However, the

discs moved independently of each other (i.e., non-contingent) except when the discs came too close to overlapping (within 60 pixels), and then the slower disc would change direction—this happened on average two times per clip. There were no “fleeing” bouts (no accelerations), and the discs turned at lower rates (.005%). Thus, the control motion differed from chasing on three dimensions: no accelerations (i.e., no speeding up), lower turning rates, and no attraction between the discs. Control displays were identical across all four experiments reported in this paper.

In Experiment 2 (*acceleration*), we used the same stimuli, apparatus, and programs described in Experiment 1, with the following exceptions. In the animate displays, both discs had turning rates of .005% (just like the control displays). The red disc had a baseline velocity of .6 pixels per frame, the green disc of .3 pixels per frame. While the red disc's velocity remained constant, the green disc sometimes accelerated to 4 times its baseline speed (1.2 pixels per frame) for 50 frames. These accelerations were independent of the position of the red disc (i.e., non-contingent), except when the discs' paths came too close to overlapping (within 60 pixels); in that case, the accelerating disc changed direction. Such directional changes occurred on average two times per clip. The average number of acceleration bouts per 20 s animations was 15.

In Experiment 3 (*high turning rates*), we used the same stimuli, apparatus, and programs described in Experiment 1, with the following exceptions. In the animate displays, the red disc had a baseline velocity of .6 pixels per frame, the green disc of .3 pixels per frame, and both discs had turning rates of 5%. The discs moved independently of each other (non-contingent). However, when the discs came too close to overlapping (within 60 pixels), they would change direction; this happened on average two times per clip.

In Experiment 4 (*attraction*), we used the same stimuli, apparatus, and programs described in Experiment 1, with the following exceptions. In the animate displays, both discs had turning rates of .005%. When the two discs were far apart, the red disc approached the evader at a constant velocity of .6 pixels per frame, continually reducing the absolute distance to the green disc in a “heat-seeking” manner. The green disc moved at a constant velocity of .3 pixels per frame, and this motion was not contingent on the motion of the red disc. Whenever the red disc came too close to the green disc (i.e., within 80 pixels), the red disc would change direction and move away from the green disc for 50 frames, after which it would approach again. These directional changes increased turning rates above the baseline of .005%, so attraction and turning rates could not be fully isolated. The average number of “approach events” per 20 s animations was 5.

In Experiment 1, we created four orders of presentation: two in which the green disc chased the red disc, and two in which the red disc chased the green disc. Each order consisted of 12 trials—a trial being a 20 s animation showing chasing and control motion side-by-side. Trials were separated by an attention-getter to re-center the point of gaze. Infants viewed only one order of presentation. Within a given order of presentation, half of the animations (i.e., 6 out of 12) presented chasing on the left and control motion on the right, and vice versa. Presentation side was

pseudo-randomized within each presentation to prevent infants from developing expectations about the motions' locations. In Experiments 2–4, presentation orders and counterbalancing were identical to Experiment 1, except we created only two orders of presentation.

2.1.3. Procedure

The procedure was identical in all experiments. Each infant was tested individually. During the session the infant sat on a caregiver's lap 60 cm from the monitor, while the eye tracker recorded the infants' eye movements. Infants' gaze was first calibrated, after which trials began. Before each trial infants were shown an attention-getter (a short graphic clip with sound) that appeared at the center of the screen, between where the two motion displays would appear. The experimenter sat in an adjacent room and initiated each trial when the child's attention was fixated on the attention-getter. Infants were presented with 12 trials of 20 s (4 min), so the total duration of a session was maximally 5 min. Parents were asked to close their eyes during testing, and were not told the study's hypothesis until it was completed. Each family received a small gift (e.g., a toy) for their participation.

2.1.4. Data reduction

In all four experiments, we defined two areas of interest (AOIs) within each video display. AOIs measured 16.5×13.2 cm ($15.7^\circ \times 12.6^\circ$ visual angle at the infant's 60-cm viewing distance) and were separated by 1.2 cm (1.1°). One AOI contained the animate motion and the other contained the control motion. For each infant we obtained three dependent measures of visual activity: total fixation preference (in seconds), longest fixation preference (in seconds), and pupil dilation (in mm). These measures were analyzed as difference scores. We determined a priori that infants would be included in the final analyses only if they attended at least 60 s to the AOIs.

We computed *total fixation preference* by subtracting the total amount of time fixated on the control display from the total amount of time fixated on animate motion. This measure corresponds to the commonly used index of infants' looking preference for one stimulus over another. However, total fixation preference confounds different kinds of attentional processes, such as attention-getting and attention-holding (Cohen, 1972; Valenza, Simion, Macchi Cassia, & Umiltà, 1996). Moreover, research indicates that bouts of sustained attention might facilitate learning about stimulus properties, more so than multiple shorter fixations (Richards, 1997). Because infants may attend to animate motion for its learning affordances as well as its immediate importance, we included a measure of sustained attention, *longest fixation preference*, which was computed by subtracting the longest fixation on the control motion from the longest fixation on animate motion.

Pupil dilations often accompany perceptions that are arousing (Beatty & Lucero-Wagoner, 2000) and may serve as an index of the extent to which individuals are actively engaged in a task (Jackson & Sirois, 2009). This is informative for two reasons. First, even when looking times do not differ, infants might still discriminate between displays, more actively processing one over another (Cohen, 1972).

Second, less engaged infants might pull the mean performance towards non-significance, even though some infants—the more engaged ones—do discriminate. To find out, we can analyze whether those infants who were the most engaged discriminated or not (Rochat et al., 1997). For this purpose, we include a third dependent measure, *pupil dilation*, which was computed by subtracting the average pupil diameter on the control motion from the average pupil diameter on animate motion.

In each study, we computed Cohen's *ds* for these dependent measures by dividing the mean difference score by the standard deviation. The resultant Cohen's *ds* describe the extent to which infants preferred chasing, or one of its properties, compared with the control display (in standard deviation units). Note that Cohen's *d* is more informative about the extent of preference than just the mean differences alone, because the mean differences, by themselves, ignore variance.

2.1.5. Stimulus validation with adults

To ensure the chasing videos actually looked more animate than the control videos, we used a questionnaire to ask ten adults (UCLA undergraduates) to rate the extent to which the movement in the displays seemed “alive” to them (1 = definitely not alive, 7 = definitely alive). Adults rated the chasing displays ($M = 5.73$, $SD = .58$) as more animate than the control displays ($M = 2.37$, $SD = .71$), $t(9) = 10.35$, $p < .001$, $d = 3.28$ (all *t* tests in this report were two-tailed). The questionnaire ended with the question: “For the displays that seemed alive, which of the following words best describes the type of animate motion that you saw (circle one): a. courting, b. fighting, c. chasing, d. guarding, e. following, f. playing.” Six adults categorized the animate motion as chasing, 3 chose following, and 1 courting.

We followed the same procedure with separate groups of adults for the acceleration, high turning rate, and attraction displays. For acceleration, a paired *t*-test indicated that adults rated the displays with accelerations ($M = 4.97$, $SD = .65$) as more animate than the control displays ($M = 3.28$, $SD = .46$), $t(9) = 5.77$, $p < .001$, $d = 1.84$. Three adults categorized the accelerating motion as playing, 2 chose chasing, 2 courting, 1 fighting, 1 guarding, and 1 following. For high turning rates, a paired *t*-test indicated that adults rated the displays with higher turning rates ($M = 5.17$, $SD = .39$) as more animate than the control displays ($M = 3.71$, $SD = 1.10$), $t(9) = 4.50$, $p = .001$, $d = 1.74$. Three adults categorized the motion with higher turning rates as guarding, 2 chose fighting, 2 courting, 2 playing, and 1 following. For attraction, a paired *t*-test indicated that adults did not rate the displays with attraction ($M = 4.58$, $SD = .83$) as more animate than the control displays ($M = 4.81$, $SD = .57$), $t(9) = 1.16$, *ns*. Eight adults categorized the motion with attraction as playing, the other 2 chose courting.

2.2. Results

We present results of our infant studies at three levels: at the *population-level*, indicating whether infants generally discriminated between the animate and the control

motion; at the *group-level*, assessing developmental effects and sex differences; and at the *individual-level*, examining individual behavior by uncovering relationships between dependent measures. Preliminary analyses indicated that the color of the discs did not affect any of the relevant comparisons, so this variable was excluded from further analyses and follow up studies.

2.2.1. Population-level

Total fixation times were longer toward *chasing* than toward the control display, $t(47) = 9.67$, $p < .001$, $d = 1.40$. Infants' longest fixations were also on the chasing display, $t(47) = 4.88$, $p < .001$, $d = .70$, and pupil size was larger when fixating on the chasing display, $t(47) = 2.89$, $p = .006$, $d = .42$.

Total fixation times were longer toward *accelerations* than toward the control display, $t(47) = 7.95$, $p < .001$, $d = 1.15$. Infants' longest fixations were also on the display with accelerations, $t(47) = 5.04$, $p < .001$, $d = .73$, and pupil size was larger when fixating on the display with accelerations, $t(47) = 2.71$, $p = .009$, $d = .39$.

Total fixation times were not longer toward the display with *higher turning rates* than toward the control display, $t(47) = -1.07$, *ns*. Infants' longest fixations were not toward the display with higher turning rates, $t(47) = -1.68$, *ns*, and pupil size was not larger when fixating on higher turning rates, $t(47) = 0.01$, *ns*.

Total fixation times were longer toward *attraction* than toward the control motion, but this effect was only marginally significant, $t(47) = 1.87$, $p = .068$. Infants' longest fixations were on the display with attraction, $t(47) = 2.43$, $p = .019$, $d = .35$. Pupil size was not larger when fixating on attraction, $t(47) = 0.40$, *ns*.

2.2.2. Group-level

2.2.2.1. Total fixation preference. A between subjects 2 (age: 4 vs. 10 months) \times 2 (sex: male vs. female) ANOVA on total fixation preference for *chasing* revealed a main effect of age, $F(1,44) = 11.48$, $p = .001$, $\eta^2_{\text{partial}} = .21$. This main effect was qualified by an interaction between age and sex, $F(1,44) = 4.83$, $p = .033$, $\eta^2_{\text{partial}} = .10$. Post hoc analyses indicated that total fixation preference for chasing was greater in 4-month-old boys ($M = 36$, $SD = 18$) than in 10-month-old boys ($M = 12$, $SD = 12$), $p < .001$ (Bonferroni-corrected), $d = 1.57$; it did not differ, however, between 4-month-old girls ($M = 26$, $SD = 18$) and 10-month-old girls ($M = 21$, $SD = 11$). Post hoc analyses indicated no differences between boys and girls at 4 or 10 months of age (Fig. 1).

A between subjects 2 (age: 4 vs. 10 months) \times 2 (sex: male vs. female) ANOVA on total fixation preference for *accelerations* revealed no significant effects, nor did an equivalent ANOVA for *high turning rates*.

A between subjects 2 (age: 4 vs. 10 months) \times 2 (sex: male vs. female) ANOVA on total fixation preference for *attraction* revealed only a main effect of sex, $F(1,44) = 6.65$, $p = .013$, $\eta^2_{\text{partial}} = .13$. Follow up *t*-tests revealed that boys showed a total fixation preference for attraction, $t(23) = 3.65$, $p = .001$, $d = .74$, but girls did not, $t(23) = 0.40$, *ns*.

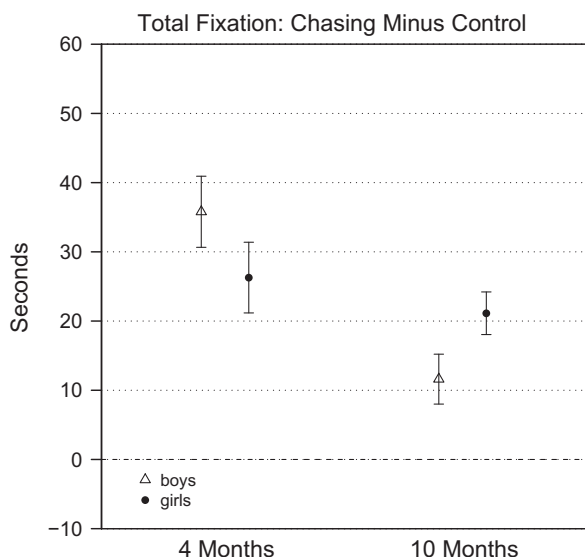


Fig. 1. Difference in total fixation time: chasing minus the control motion. Error bars represent 1 SEM; triangles represent boys, circles represent girls.

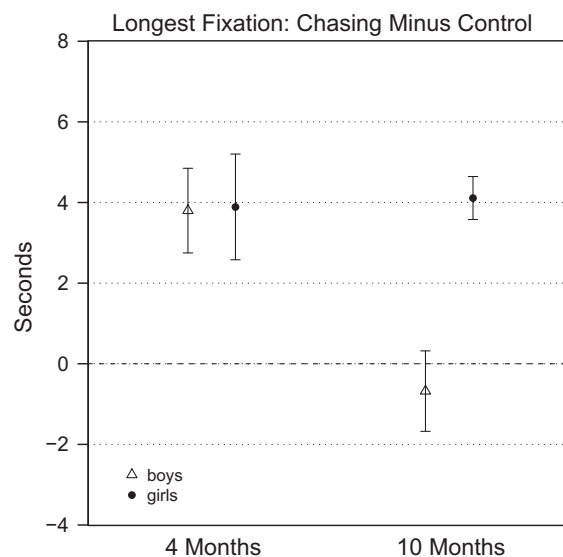


Fig. 2. Difference in longest fixation time: chasing minus the control motion. Error bars represent 1 SEM; triangles represent boys, circles represent girls.

2.2.2.2. Longest fixation preference. A between subjects 2 (age: 4 vs. 10 months) \times 2 (sex: male vs. female) ANOVA on longest fixation preference for *chasing* revealed a main effect of sex, $F(1,44) = 5.80, p = .020, \eta^2_{\text{partial}} = .12$, as well as a main effect of age, $F(1,44) = 4.41, p = .041, \eta^2_{\text{partial}} = .09$. These main effects were qualified by an interaction between age and sex, $F(1,44) = 5.38, p = .025, \eta^2_{\text{partial}} = .11$. Post hoc analyses indicated that longest fixation preference for chasing was greater in 4-month-old boys ($M = 3.80, SD = 3.63$) than in 10-month-old boys ($M = -.68, SD = 3.46$), $p = .003$ (Bonferroni-corrected), $d = 1.26$; it did not differ, however, between 4-month-old girls ($M = 3.89, SD = 4.54$) and 10-month-old girls ($M = 4.11, SD = 1.85$). Post hoc analyses revealed no differences between 4-month-old boys and girls; however, at 10 months girls showed a substantially stronger longest fixation preference for chasing than boys did, $p = .002$ (Bonferroni-corrected), $d = 1.73$ (Fig. 2).

A between subjects 2 (age: 4 vs. 10 months) \times 2 (sex: male vs. female) ANOVA on longest fixation preference for *accelerations* revealed no significant effects, nor did equivalent ANOVAs for *high turning rates* and *attraction*.

2.2.2.3. Pupil dilation. A between-subjects 2 (age: 4 vs. 10 months) \times 2 (sex: male vs. female) ANOVA on pupil dilation on *chasing* revealed only a main effect of sex, $F(1,44) = 6.20, p = .017, \eta^2_{\text{partial}} = .12$, and a main effect of age, $F(1,44) = 6.48, p = .041, \eta^2_{\text{partial}} = .14$. Follow up *t*-tests revealed that girls' pupils were larger on chasing than on the control, $t(23) = 4.01, p = .001, d = .82$, but boys did not show pupillary discrimination, $t(23) = 0.44, ns$ (Fig. 3).

A between subjects 2 (age: 4 vs. 10 months) \times 2 (sex: male vs. female) ANOVA on pupil dilation on *accelerations* revealed only a marginally significant main effect of sex, $F(1,44) = 3.90, p = .055, \eta^2_{\text{partial}} = .08$. Follow up *t*-tests revealed that girls' pupils were larger when viewing

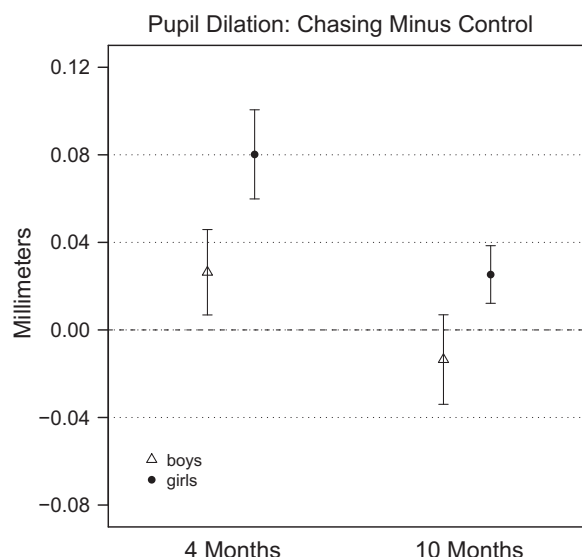


Fig. 3. Difference in pupil size: chasing minus the control motion. Error bars represent 1 SEM; triangles represent boys, circles represent girls.

acceleration than the control display, $t(23) = 3.19, p = .004, d = .65$, but boys did not show pupillary discrimination, $t(23) = 0.95, ns$.

A between subjects 2 (age: 4 vs. 10 months) \times 2 (sex: male vs. female) ANOVA on pupil dilation on *high turning rates* revealed no significant effects, nor did an equivalent ANOVA for *attraction*.

2.2.3. Individual-level

For *chasing*, there was a significant correlation between total fixation preference and longest fixation preference, $r(46) = 0.53, p < .001$. Pupil dilation was significantly correlated with total fixation preference, $r(46) = 0.32, p = .029$,

and also with longest fixation preference, $r(46) = 0.47$, $p = .001$.

For *accelerations*, there was a significant correlation between total fixation preference and longest fixation preference, $r(46) = 0.55$, $p < .001$. Pupil dilation was not correlated with total fixation preference or with longest fixation preference.

For *high turning rates*, there was a significant correlation between total fixation preference and longest fixation preference, $r(46) = 0.55$, $p < .001$. The correlation between pupil dilation and total fixation preference was marginally significant, $r(46) = 0.27$, $p = .059$, and there was no correlation with longest fixation preference, $r(46) = 0.20$, ns .

For *attraction*, the only significant correlation was between total fixation preference and longest fixation preference, $r(46) = 0.56$, $p < .001$. Pupil dilation was not correlated with total fixation preference or with longest fixation preference.

3. Conclusions

3.1. Chasing

Looking preferences for chasing remained stable in girls, but declined in boys with age. We considered the possibility that older boys may have been less motivated to attend, reducing discrimination. However, further analyses revealed no sex differences in overall attention toward the displays, and all differences between groups held up when this variable was included in the design as a covariate. At 10 months, girls exhibited a substantially greater longest fixation preference for chasing than boys did. This finding is consistent with previous work showing that girls may be more attuned to social stimuli than boys in their first year after birth (Lutchmaya & Baron-Cohen, 2002; Lutchmaya et al., 2002).

Girls, but not boys, showed increased pupil dilation when attending to chasing. One possibility is that girls perceived chasing as more animate than boys did, and so were more captivated by it. Fitzgerald (1968) found that pupil dilation was greater for social stimuli than for nonsocial stimuli in 1–4 month olds, so sex differences could reflect differences in how these stimuli were interpreted by infants. We should be cautious with this interpretation, however, as girls may have been more engaged with chasing for reasons other than perceiving it as more animate (or social). Indeed, with accelerations, too, girls showed pupillary discrimination and boys did not. With high turning rates and attraction, in contrast, neither boys nor girls showed increased pupil dilation.

Looking times and pupil dilations were correlated. To our knowledge, we are the first to report such a correlation. This could be because few studies have examined the psychological meaning of pupil dilations in infants. Or, it could be because looking times and pupil dilations correlate only with particular classes of stimuli (e.g., animates)—for instance, Jackson and Sirois (2009) found no such correlation when infants attended to moving inanimate objects (trains). In our experiment, infants who perceived chasing as more animate might have been more engaged with it.

Or, those who were more engaged with chasing may come to perceive it as more animate, increasing differential looking. Possibly, each of these processes might be at work in different subsets of infants.

3.2. Accelerations

Contrary to chasing, accelerations did not result in a correlation between pupil dilations and looking times. One explanation for this difference, consistent with previous findings (Fitzgerald, 1968), is that infants who looked longer at chasing perceived it as more animate, increasing pupil dilations. Lone accelerations, however, may not be perceived as animate; hence looking times might be random with respect to pupil dilations. This explanation requires that infants looking less-than-average at chasing did not perceive it as mere accelerations, since in that case their pupil dilations would be random as well, in which case the overall mean of chasing would be higher than that of acceleration (raised by those infants who perceived chasing as animate). What process could result in a diminished preference for chasing in a subset of infants?

One possibility is that infants who recognized the chase as such became more interested in exploring the control display depicting an unfamiliar motion pattern (for a similar argument, see Rochat et al., 1997). This explanation predicts that correlations between pupil dilation and looking times are greater among older than younger infants, because young infants show no evidence of understanding chasing in goal-directed terms (Csibra et al., 2003; Rochat et al., 2004), and so variation in looking times should be uncorrelated with degrees of understanding; older infants, by contrast, *do* exhibit understanding of chasing (*idem*), so variation in their looking times might be correlated with degrees of understanding. We examined this explanation by testing age-specific correlations, which supported the explanation; for 10-month-old infants, the correlation coefficient of pupil dilation with total fixation preference was $r = .33$ ($p = .13$), and $r = .59$ ($p < .01$) for longest fixation preference. In contrast, for 4-month-olds, these correlation coefficients were only $r = .13$ ($p = .56$) and $r = .30$ ($p = .16$), respectively.

3.3. High turning rates

Analysis yielded null results in this experiment, but we should be cautious not to conclude that infants are incapable of discriminating between different turning rates for two reasons. First, infants may discriminate without having a preference. Second, most preferential looking studies use a fixed trial length and a fixed number of trials; if infants do not show discrimination within these, however, they might still do so if stimuli are presented for longer (Cohen, 1972). Indeed, we found a marginally significant correlation between total fixation preference and pupil dilation, suggesting that those infants who were more engaged while processing higher turning rates may have been able to discriminate. Or, those infants who discriminated first may have been more engaged while processing higher turning rates.

To discriminate between these two possibilities, we initiated a new dependent measure, *duration of the first fixation*,¹ which was computed by subtracting the duration of the first fixation on the control motion from the duration of the first fixation on chasing (Cohen, 1972; Valenza et al., 1996). If infants who discriminated first remained more engaged with turning, this measure might (but need not) correlate with other measures that are computed across all trials; it did, with total fixation preference, $r = .41$ ($p < .01$), with longest fixation preference, $r = .39$ ($p < .01$), and with pupil dilation, $r = .22$ ($p = ns$). Thus, some infants, the attentive ones, detected higher turning rates early on, and remained more attentive to this stimulus throughout the session.

3.4. Attraction

To our knowledge, we provide the first demonstration that infants are sensitive to attraction alone—attraction, of course, is a property of many prior motion studies with infants, but has not previously been isolated from other cues. For instance, previous work has shown that 3-month-old infants attend more to two discs engaging in a chase compared to discs moving independently of each other (Rochat et al., 1997). In this work, however, two kinds of social contingency could have generated preferential looking: the chaser taking the shortest path to the evader (“attraction”); and, the evader accelerating away when the chaser came too close (“fleeing”). Our display showed only attraction, allowing us to tease apart this form of contingency. We found that only boys looked more at attraction than control displays in the 4–10 month age window we tested. Rochat and colleagues found that both boys and girls discriminated with attraction and fleeing combined. Therefore, girls may have been sensitive specifically to the fleeing component of their displays. Future research might investigate whether infants are sensitive to fleeing without attraction: two discs moving independently, but when one comes too close, the other flees.

4. General discussion

4.1. Infants

Two significant questions in cognitive and developmental science are first, whether objects and events are

¹ We do not generally report this measure because it focuses on the first fixation in the first trial alone, thus treating this fixation as special, compared with subsequent fixations in the same trial, and all fixations in subsequent trials. An infant who detects a difference on the second but not the first fixation is thus categorized as not initially having detected the difference. This conclusion would seem unjustified in an experimental design like ours, where infants switched frequently and rapidly between displays (as these were presented very close together on a single monitor). We report first fixation duration in this study, because we found no discrimination at the group level, yet a marginally significant correlation between total fixation preference and pupil dilations. This raises an interesting question: Did those infants who looked longer at turning do so because they discriminated, or by chance. If by chance, there should be no correlation between first fixation duration and the other looking measures, which are computed across all fixations and all trials. If, however, infants did discriminate, they *might* (but need not) have discriminated on the first trial, and in that case, we *might* observe such correlation. And we do, supporting the idea that some infants did discriminate higher turning rates.

selected for attention based on their features or the configuration of their features, and second, how these modes of processing develop. These questions have been addressed in part with experiments focused on infants' perception of faces (Maurer et al., 2002; Tanaka & Farah, 1993; Valenza et al., 1996), human body shapes (Slaughter et al., 2002), and biological motion of individual agents (Bertenthal, 1993; Simion et al., 2008). Here, we examine the properties that draw infants' attention to social motions, such as chasing, and whether this preference depends on featural or configural processing.

If infants' preference for chasing depended on its configuration, the sum of the effect sizes of individual properties should be smaller than their combined effects. That is not what we found. For *total fixation preference*, effect sizes add approximately linearly, with accelerations being responsible for most of the effect size of chasing (about 82%), and the remainder (about 19%) being covered by attraction. However, for *longest fixation preference*, the effect sizes add in a diminishing fashion: the marginal effect of an additional cue is smaller than the effect of this cue by itself. Specifically, even though the effect size of accelerations matches that of chasing, attraction also has a substantial effect—50% of that of chasing. For neither measure, however, do we find evidence that the summed effects of individual properties are smaller than their combined effects (i.e., marginally increasing effects), which we would expect if attention to chasing would be driven by a configuration of its properties. Our findings, therefore, suggest that infants' attention to chasing is driven by its features, not their configuration (this is not to say, of course, that interpretations of chasing by infants and adults do not depend on its configuration).

We hypothesized that configural processing might help discriminating chasing from other types of social interactions. However, for merely drawing attention, featural processing might be better, if particular motion cues reliably correlate with fitness-relevant events. In the case of chasing, our results suggest that infants integrate motion cues in a linear or marginally diminishing fashion. This might be because a featural strategy is more robust to loss of cues, is faster, is easier to develop in early childhood, or some combination of the above (Gigerenzer, Todd, & the ABC Research Group., 1999). Based on these findings, we propose that infants employ a coarse, property-based attentional filter that navigates their attention toward social interactions. This filter could be phylogenetically old, shared with other vertebrates, and respond to general properties of animate (anti-gravitational acceleration) and social motion (attraction), irrespective of their content. The meaning of these social actions might subsequently be inferred using cognitive mechanisms geared toward inferring goals and intentions.

We add three caveats to our interpretations of effect sizes. First, as mentioned in the Introduction, we investigated the effects of isolated cues alone; a full understanding of cue-interactions requires testing two-cue combinations as well. Second, our interpretation depends on there being no interactions between chasing, or its properties, and our control display. If such interactions exist, the effects of properties, when examined individually, may

differ from the effects of these same properties when embedded in chasing. Third, since we designed our stimuli such that the discs never overlapped (in order to prevent violations of infants' intuition that two object cannot inhabit the same place at the same time; Baillargeon, Spelke, & Wasserman, 1985), we could not isolate cues perfectly; our acceleration and turning displays contained some contingency. However, this was true for our control display as well, and to the same extent. And, to the extent that attraction increased turning rates, this was true in the chasing displays as well.

When do organisms benefit from adding cues, and how should cues be added (Frankenhuys & Panchanathan, 2011)? This depends on the extent to which additional cues provide additional information—i.e., uncertainty reduction—in terms of (1) identifying the class to which the stimulus belongs (e.g., animates), and (2) having classified the stimulus, learning about its properties (e.g., motion trajectories; Gigerenzer et al., 1999). For instance, anti-gravitational accelerations might draw attention to animate objects (Szego & Rutherford, 2008), but other objects (e.g., a leaf blown by the wind) may accelerate anti-gravitationally as well. If these objects are unlikely to exhibit attraction, then adding an attraction-cue increases the probability of detecting an animate target, and therefore a combination of acceleration and attraction is more informative, and should draw more attention, than acceleration alone.

4.2. Adults

Replicating existing work, we found that adults judged accelerations and high turning rates as animate (Scholl & Tremoulet, 2000). The latter finding confirms that the turning-cue was perceivable and mimicked properties of animate motion, even though infants, as a group, showed no evidence of discrimination. Correlations between total fixation times and pupil dilation suggested that infants' ability to detect the turning cue depended on their level of engagement. Adults did not rate attraction as more animate than our control motion. This finding is interesting, because adults *did* reach a high degree of convergence in terms of categorizing attraction as “playing”—eight out of 10. Future work might explore why adults consistently categorized attraction as “playing,” without perceiving it to be animate, and whether open-ended questions yield the same categorization as forced-choice. Six out of 10 adults categorized chasing as “chasing,” and three choose “following.” This finding is less surprising, as chasing and following have many properties in common (Barrett, Todd, Miller, & Blythe, 2005). Categorizations were random for higher turning rates and accelerations. That adults categorized chasing as such only when the properties were combined indicates these interpretations depend on its configuration.

In adults' judgments of animacy, the effect size of chasing was about twice as large the effect size ($d = 3.28$) of accelerations ($d = 1.84$) and high turning rates ($d = 1.74$). The latter two effect sizes add up to 3.58, only slightly over the effect size of chasing (9%), suggesting that cue ratings by adults combine approximately linearly to produce their

judgments of animacy. It would be interesting to know whether this result replicates if the animate displays are presented in isolation (i.e., not side-by-side with a control display); and, whether this pattern of results obtains for other kinds of animate and social motions, too (e.g., following, fighting, courting).

In conclusion: we used a cue isolation approach to tease apart the relative contributions of different cues to infants' attentional bias for chasing as well as adults' ratings of perceived animacy, and their categorization of dynamic motion trajectories in terms of their intentions. Our approach can be used broadly to study infants' and adults' responses to other types of animate motion as well. Together, such studies can illuminate the perceptual and inferential machinery that humans, and other animals, use to navigate their attention towards fitness-relevant objects and events, including chasing.

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