

How social is the chaser? Neural correlates of chasing perception in 9-month-old infants



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ABSTRACT

We investigated the neural correlates of chasing perception in infancy to determine whether animated interactions are processed as social events. By using EEG and an ERP design with animations of simple geometric shapes, we examined whether the positive posterior (P400) component, previously found in response to social stimuli, as well as the attention related negative fronto-central component (Nc), differs when infants observed a chaser versus a non-chaser. In Study 1, the chaser was compared to an inanimate object. In Study 2, the chaser was compared to an animate but not chasing agent (randomly moving agent). Results demonstrate no difference in the Nc component, but statistically higher P400 amplitude when the chasing agent was compared to either an inanimate object or a random object. We also find a difference in the N290 component in both studies and in the P200 component in Study 2, when the chasing agent is compared to the randomly moving agent. The present studies demonstrate for the first time that infants' process correlated motion such as chasing as a social interaction. The perception of the chasing agent elicits stronger time-locked responses, denoting a link between motion perception and social cognition.

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1. Introduction

The human visual system not only detects physical structures in the environment but also their causal and social structures derived from motion information. When observing displays with simple geometrical shapes engaged in a variety of interactions such as fighting, dancing and chasing, adult observers consistently describe seeing animate, interacting entities with distinct goals and intentions (Heider and Simmel, 1944; for review, see Scholl and Tremoulet, 2000). This extraordinary ability of the visual system to derive such socially-rich information from relatively simple visual input reveals the primary and interdependent link between perception and social cognition in adulthood (Schultz et al., 2004). The fact that the discrimination of interacting and randomly moving objects takes place already at 3-months (Rochat et al., 1997), provides evidence that social categorization plays a fundamental role in how humans perceive their environment. However, to date no study has provided direct evidence that infants' social networks are being involved when observing interactions such as chasing,

and the question whether social categorization through motion is present already early in infancy remains unanswered.

In the last decades, neural correlates involved in the perception of interactions have been much researched in adults. These studies find that areas used for perception of social stimuli also correspond when viewing animate interactions such as chasing. Much like the detection of biological motion, chasing elicits activation in the temporoparietal cortex, the posterior superior temporal sulcus (pSTS) and the angular gyrus (Castelli et al., 2000; Lee et al., 2012; Martin and Weisberg, 2003; Schultz et al., 2004) often lateralized to the right hemisphere (Gao et al., 2012; Schultz et al., 2005; Shultz et al., 2011).

Together, adult research on animacy perception suggests that observers, while watching lifeless geometrical shapes move, interpret them in terms of animacy and intentionality while the neurological correspondence of the areas associated with social stimuli support the idea that adults perceive these events as social.

For infants, much like adults, motion informs about the type of observed agents and events. For instance, studies examining infant visual attention have found that 3-month-olds orient and prefer to attend to displays where two discs are chasing compared to displays in which they are moving haphazardly bouncing off the boundaries of the screen (Rochat et al., 1997). Recent evidence (Galazka and Nyström, 2016) further suggests that infant visual

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attention within chasing interactions is largely accounted by the chaser, reflecting the developing sensitivity to kinematic information pertaining to interactions in limited visual displays (Galazka et al., 2014; Galazka and Nyström, 2016). But visual attention alone does not inform about whether infants attend to animated interactions because of their social narrative, or whether perceptual properties of the event alone cause the attentional shifts. One possibility is that areas responsive to social stimuli are elicited when infants observe these types of animated displays, much like in adults. Another possibility, however, is that infants' visual attention toward animated displays is due to lower level perceptual processes. For instance, objects that share the same motion trajectory (known as the classical Gestalt law of 'common fate') (Wertheimer, 1923/1938), objects that come close together, or objects that move contingently might capture visual attention more than randomly moving objects without interpreting them as social. In fact, very young infants attend to the features of chasing, such as goal-directed motion of one object toward another and acceleration more so than when these features are configured in a chasing motion (Frankenhuis et al., 2013). In the present article, we address this theoretical distinction by examining neural activation of social brain processes during chasing perception.

Infant neurological studies have previously used ERP component measures to determine the sensitivity to animacy and social information. One such ERP study found evidence for differential sensitivity to animate and inanimate motion in 9-month-olds (Kaduk et al., 2013). The findings suggested that by 9-months infants allocate more attention to an object moving inanimately than an animate object as evidenced by the increased negativity in the fronto-central Nc component, a mid-latency component that has been found to reflect general attentional arousal (Richards, 2003) as well as orientation to salient stimuli (Courchesne et al., 1981).

The processing of social information in infants, on the other hand, has been measured by the N290 and the P400 component, from now referred to as a N290/P400 complex. This latent component over the lateral posterior region has been argued to index pSTS activity (Gredebäck et al., 2010; Gredebäck and Daum, 2015) and in infants it has almost exclusively been associated with processing socially-valenced information (Gredebäck et al., 2015). For instance, in response to gestures that convey social meaning such as hands turned right side up in a 'give-me' gesture (Bakker et al., 2015), grasping (Bakker et al., 2014, 2016), pointing (Gredebäck et al., 2010; Melinder et al., 2015), gaze direction (Senju et al., 2006) and when observing biological motion (Reid et al., 2006). The infant N290/P400 complex, was found to parallel the N170 component in adults (Gredebäck et al., 2010; Senju et al., 2006) – a component associated in response to social stimuli such as human faces (Csibra et al., 2008). Unlike the infant P400 component, the P400 component in adult population has been associated with a wide range of factors such as visual ambiguity (Kornmeier and Bach, 2009), memory load (Klaver et al., 1999; Beuzeron-Mangina and Mangina, 2000), and attentional control (Falkenstein et al., 1999). Collectively, although no study has previously explored specific neural correlates to chasing, these studies suggest a unique set of ERP components to animated objects and social information in infancy.

The primary goal of the current two studies was to examine the neural correlates of chasing in infants by tapping the N290/P400 complex and the Nc component. In doing so, we gain insight into the underlying processes of social perception through motion.

Based on the two possible accounts of infant preference to animated displays, we hypothesize that if chasing interaction is interpreted as a social event the N290/P400 complex will be larger when chasing motion is compared to inanimate motion (Study 1) and when it is compared to animate but random motion (Study 2). Presence of the P400 component in these comparisons would

speak in support of the social account suggesting that infants, like adults, process chasing as more than a set of motion cues. By contrast, presence of the attentional Nc component alone, would speak for a lower-level perceptual processing account, in which attention to motion parameters alone determines preference for the chasing event.

2. Study 1: chasing versus inanimate motion

2.1. Methods

To address the question of neural correlates underlying perception of a chasing interaction we presented 9-month-old infants with displays depicting two geometrical shapes involved in chasing, where one shape (a triangle or a rectangle) consistently moved toward another, while its partner (a grey circle) consistently moved away. In Study 1, the chasing motion was compared to inanimate motion. The inanimate motion depicted two objects (a rectangle if a triangle was shown during the chasing condition, or triangle otherwise, and a grey circle) moving at a constant speed along linear trajectories, only changing direction by bouncing off the display boundaries or two stationary objects in the display. Using a paradigm previously used for assessing ERP responses in young children (Gredebäck et al., 2015; Kaduk et al., 2013), we first presented the animations and then measured the ERP response to the still images of agents in the animation (a triangle and a rectangle).

2.2. Participants

Eighteen 9-month-old infants (6 female; mean age = 270 days; 8 months 29 days) were included in the final sample. All participants were full-term without known neurological or developmental disabilities. Additional 16 infants were tested but were not included in the final analysis due to failure in meeting the inclusionary criterion of minimum 10 artifact-free trials for each condition (a rectangle and a triangle). Although the exclusion criterion appears to result in a high drop rate, a recent meta-analysis on infant ERPs have determined a drop out rate of about 50% to be the standard in this type of paradigm with such young population (Stets et al., 2012). Participants were recruited from a list of parents who indicated interest in participating in research with their child. The majority of infants were primarily from white middle-class background living in a medium-sized European city. Studies were conducted in accordance with 1964 Declaration of Helsinki and all infants' parents provided written informed consent according to the guidelines specified by the local Ethical Committee. For their participation, parents received a gift voucher worth approximately 10 euro.

2.3. Stimuli and procedure

All infants began the procedure by observing video animations for each condition presented on a 17-in computer screen (Fig. 1). These video displays were directly followed by multiple static test images that were used to extract ERPs. In previous research, this procedure (video and test image) has been found to reliably influence ERPs in infants this age (Gredebäck et al., 2015; Kaduk et al., 2013).

The moving animations consisted of 10-s video presentations at the start of the procedure: 2 times the Chasing interaction and 2 times the Inanimate motion. The animations were created using Anime Studio Debut 10, an animation software (<http://my.smithmicro.com/anime-studio-debut-10.html>). All animations depicted a gray circle and either an orange triangle or a blue rectangle, where the triangle and the rectangle always belonged to one condition each (counterbalanced between subjects). All shapes were matched for luminosity and size, and all geometrical shapes

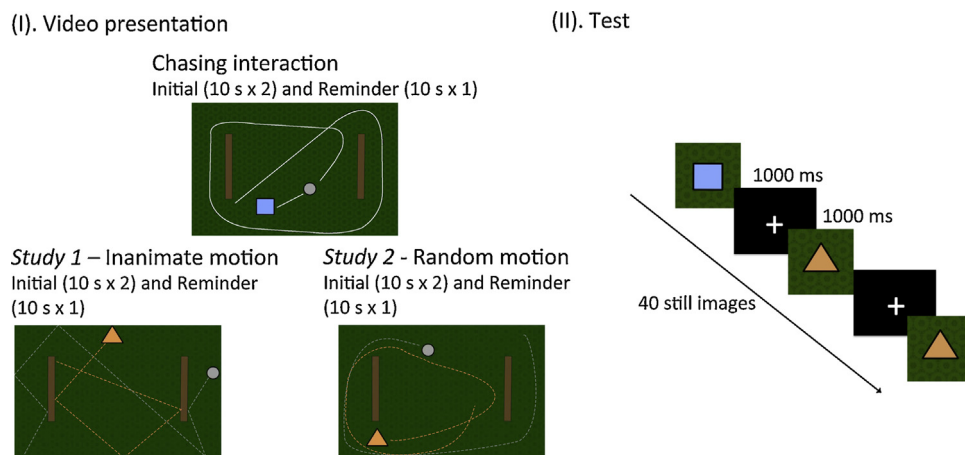


Fig. 1. Stimuli used during the initial video presentation (initial and reminder) and test images. The identity of the chaser (here a blue rectangle) and the inanimate object (here an orange triangle) in Study 1 and random object in Study 2 was counterbalanced across participants. The trajectory represented here reflects the first 4 s of the video. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

moved against textured green background with two brown rectangular shapes placed on each side of the screen to provide context for the interaction (barriers behind which objects could move or bounce off of). Examples of each animation are provided in the Supplementary materials.

2.3.1. Chasing interaction

The chasing interaction began with the chaser (orange triangle or blue rectangle) moving at constant velocity of 0.4 visual degrees/frame (12 pix/frame) toward the target (gray circle), while the target moved at the baseline velocity of 0.19 visual degrees/frame (6 pix/frame). When the chaser got within 2.5 visual degrees (80 pixels) from the target, the target accelerated to 4 times its initial velocity to 0.8 visual degrees/frame (24 pix/frame) for the duration of 24 frames. After this it decelerated to its initial speed. The acceleration and the eventual deceleration of the target occurred 4 times in 10 s trial duration. A specific 4-note high-pitched sound accompanied the chasing animation and it corresponded to the increasing proximity of the chaser to its target.

2.3.2. Inanimate motion

The inanimate motion animation depicted the main shape (orange triangle/blue rectangle) and the gray circle moving at a constant speed of 0.4 visual degrees/frame (12 pix/frame). Each shape moved randomly, with no apparent relation to each other. As they moved, both shapes occasionally bumped into the borders of the screen as well as the brown rectangles. When that happened, the shapes simply bounced off and continued to move randomly. The inanimate motion also included a specific bouncing sound that was contingent on when the main shape bounced off the surfaces.

The study was within-subject design, meaning that each infant saw both chasing interaction and inanimate motion. The static ERP test images that followed the initial video presentation consisted of randomly altered still images depicting the geometric shape associated with chasing (orange triangle or blue rectangle; 20 trials), or the geometric shape associated with inanimate motion (blue rectangle or orange triangle; 20 trials) but never with more than three consecutive images of the same shape. The object was shown against the same background as the previously seen animations but without any other objects present. The shape was also slightly zoomed in in order to make it stand out from the background and enhance the infant's attention exclusively to the shape involved in the motion rather than any other shapes (such as the grey circle or background barriers presented in the animation). The rectangle was 2.5 (80 pixels) × 2.4 visual degrees (71 pixels). The triangle had

a base of 3.1 (98 pixels) and height of 2.4 (77 pixels) visual degrees. To make sure that any differences between the groups were not due to low-level visual differences, we double-checked that there were equal number of subjects in the counterbalanced groups (as many subjects saw chasing triangles, $n=9$, as chasing rectangles, $n=9$). Each trial consisted of a black image with a white fixation-cross (1000 ms in duration) followed by a still image of the orange triangle or a blue rectangle (1000 ms in duration) with the corresponding sound (800 ms in duration). The still image was then followed by another fixation cross, followed by the next image, etc.

After approximately 40 test trials, or when an infant stopped paying attention to the screen, each child was presented with a reminder animation set. This set consisted of one presentation of each animation seen previously at the start of the stimulus presentation. This was done in order to remind infants of the previously seen motions. In Study 1, each child observed between 3–6 reminder video presentations ($M=4.1$). After the reminder video, infants saw another test set of static images until the infant stopped attending completely. Infants attended on average to 56 trials in each condition (range: 39–74) of which 56 were chaser trials and 55.9 inanimate object trials. On average, the entire stimulus presentation was 5 min and 58 s. This included the initial video presentation, still test images and the reminder videos.

2.4. EEG recording and analysis

Age appropriate 128-channel Geodesic Sensor Nets (HCGSN 130; EGI, Eugene, OR) were used to record EEG signals. The signal relative to the vertex referenced was sampled at 250 Hz, amplified by EGI Net amplifier (GES 300 Amp; EGI, Eugene, OR) and stored for off-line analysis. Continuous EEG data were digitally filtered (0.3–30 Hz) and segmented from 300 ms prior to the appearance of the still image to 1000 ms after the image's appearance.

Similar to prior research with infant population (Greddebäck et al., 2015; Rosander et al., 2007) the most anterior and posterior electrodes (37 electrodes) were not included in the final analysis due to high noise and artifact frequency caused by poor contact with the infant scalp. The data were manually checked for artifacts (such as channel glitches and strong drifts within individual channels). Subjects with less than 10 valid trials in each condition were excluded from further analysis, which is comparable with other EEG studies using visual stimuli in infant population (Kaduk et al., 2013; Stets and Reid, 2011; Stets et al., 2012). As a consequence, on average 13.3 (range: 10–23) chase trials and 14.2 (range: 10–23) inanimate trials per infant were included in the final anal-

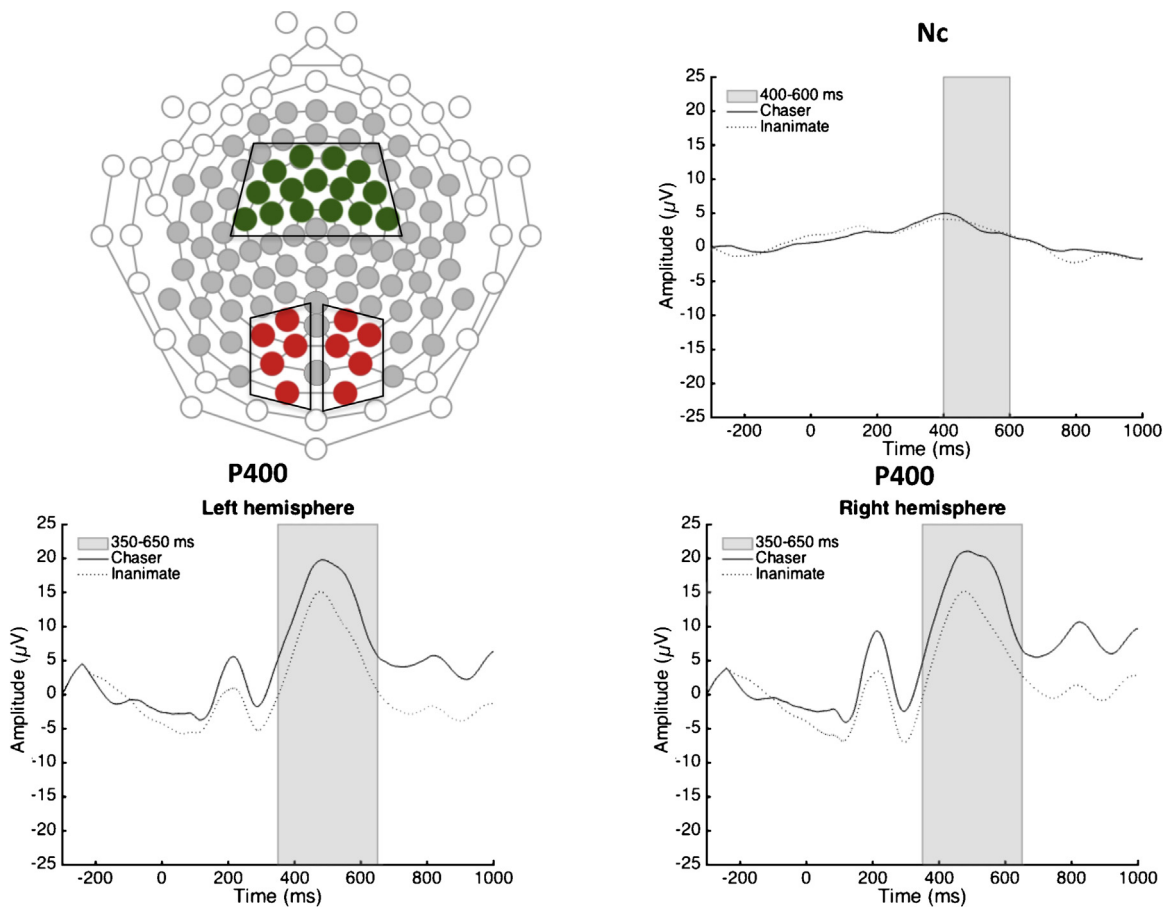


Fig. 2. Grand average ERP data for selected channels for the Nc component (in green; top graph) and P400 (in red) component of the Left (bottom left graph) and Right (bottom right graph) hemisphere with time of interest shaded in gray. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

ysis (Paired sample t -test $t(17) = -1.25$, $p = 0.23$). Segments were then re-referenced to average reference and all trials were baseline corrected with the average amplitude between 0 and 300 ms prior to appearance of the image. Finally, the data were aggregated to individual averages for each trial type (chase/inanimate). A figure with all channels and conditions in the sensor layout is found in the Supplementary information.

Regions of interest were chosen to cover areas in the low occipital-temporal region previously found to elicit P400 component to social information (Bakker et al., 2015). Based on the visual inspection of the individual averages we selected 13 channels over posterior area (all channel numbers: 62, 66, 67, 70 [O1], 71, 72, 74, 75 [Oz], 76, 77, 82, 83 [O2], 84; of which left channels were: 66, 67, 70, 71, 74; and right channels were: 76, 77, 82, 83, 84).¹ Analyses of the P400 component were based on the average amplitude of these channels and a time interval ranging from 350 to 650 ms after the object appearance. As a dependent variable, the aggregate amplitude value was entered in a General Linear Model (GLM) with the agent (chaser, inanimate object) and hemisphere (left, right) as within subject factors.

In addition, ERP Nc component (channel numbers: 5, 6, 7, 12, 13, 20, 29, 36, 104, 105 [C4], 106, 111, 112, 118) was examined, as it was previously identified to measure attentional sensitivity to inanimate over animate motion (Kaduk et al., 2013). The Nc component was investigated using the average amplitude of the designated

channels during a time range from 400 to 600 ms after the appearance of the image. Amplitude data for the Nc was measured in a Paired sample t -test with agent as an independent variable. All data sets were checked for outliers (± 3 z-score) but none were found.

2.5. Results

Based on previously set hypotheses, two components of interest were examined: P400 component in the lateral posterior region encompassing low occipital and post temporal electrodes as well as the Nc component over central frontal electrodes.

2.5.1. P400

A $2(\text{chaser, inanimate agent}) \times 2(\text{hemisphere: left, right})$ repeated measures analysis of variance revealed a significant main effect of agent type $F(1, 17) = 5.05$, $p = 0.038$, $\eta^2 = 0.229$ with a significantly higher amplitude for the chaser ($9.45 \mu\text{V}$, $\text{SE} = 2.25$) than the inanimate agent ($4.32 \mu\text{V}$, $\text{SE} = 1.86$) (Fig. 2).

The analysis also indicated a significant main effect of hemisphere, $F(1, 17) = 48.39$, $p < 0.001$, $\eta^2 = 0.740$, with a higher amplitude in the right ($12.48 \mu\text{V}$, $\text{SE} = 1.92$) than left ($1.28 \mu\text{V}$, $\text{SE} = 1.88$) channels. There was no significant hemisphere by agent interaction $F(1, 17) = 0.944$, $p = 0.345$, $\eta^2 = 0.053$.

2.5.2. Nc

For the Nc component, a Paired sampled t -test demonstrated no significant differences between agent types, $t(17) = 1.79$, $p = 0.091$ with a positive amplitude for the chaser ($3.38 \mu\text{V}$, $\text{SE} = 4.45$) and the inanimate agent ($0.28 \mu\text{V}$, $\text{SE} = 4.75$).

¹ Channels in the central midline (62, 72 and 75) were not included in the left nor right analysis for the P400 component.

Visual inspection of the data further indicated test of the N290 component in the P400-region as well as an earlier positive component peaking at around 200 ms following stimulus onset (P200). The N290 component demonstrated significantly higher positive amplitude for the chaser (1.67 μ V, SE=9.27) than the inanimate agent (-2.87 μ V, SE=9.38), $t(17)=2.30$, $p=0.034$. At the P200 component, the amplitude for the chaser was slightly more positive (4.87 μ V, SE=2.42) than the amplitude for the inanimate agent (1.19 μ V, SE=2.45), but the difference was only marginally significant $t(17)=1.99$, $p=0.062$.

Finally, for all the components tested, none correlated significantly with the number of reminder videos (all $ps > 0.05$).

2.6. Discussion

The results from Study 1 show that when presented with still images of two geometrical shapes, 9-month-old infants are able to differentiate between them based on whether they saw them previously engaged in a chasing interaction or as part of an inanimate motion. Specifically, findings demonstrate a significantly positive P400 ERP component around 400 ms for the chasing agent compared to the inanimate agent. Based on prior findings demonstrating that the P400 is considered a measure of social perception (Bakker et al., 2014, 2015, 2016; Gredebäck et al., 2010, 2015; Melinder et al., 2015; Senju et al., 2006) the current findings suggest that chasing is perceived as a social event already early in infancy.

In addition to the P400 component, present findings indicate a negative deflection around N290. As mentioned previously, the infant N290, along with the P400, has been found to be the precursor of the adult N170 component, which most studies find in response to social stimuli such as human faces (Csibra et al., 2008; de Haan et al., 2002; Halit et al., 2003). Thus, the N290 component found in infants toward the end of the first year can also be used as a marker of social stimuli processing. The P200, which was marginally significant, may also be related to social processing in infants and merits further investigation.

The lack of difference in the Nc component over central frontal area was unexpected, since it has been previously found in response to inanimate versus animate motion of a single agent (Kaduk et al., 2013). A potential reason for the differential findings might have to do with the methodological differences between the two studies – here we present two objects engaged in an interaction, while the previous study presented infants with a single object either following or violating universal laws of physics. It is also important to point out that in the present study we did not find any significant differences between the two objects across conditions within the Nc component, which typically reflects attention or general arousal, suggesting both objects to be equally interesting. Given that the significant differences between conditions within the P400 component is not typically reflective of attentional or perceptual processing, and the lack of the significant Nc component which typically is, suggests that attentional or perceptual processing alone is not responsible in explaining the difference between the two motion types. Rather, the present findings are compatible with the idea that it is the social nature of the chasing interaction that drives the distinction.

While the results in Study 1 are novel and important for understanding the development of chasing perception, it may be argued that the socialness of the stimuli is related to the *individual* agents, and not to the *interaction* between them. In Study 2 we again presented infants with a chasing motion but compared it to an animation where the goal-directedness of the chaser was replaced with random animate motion, which effectively eliminates the perception of interactivity between the two agents. We hypothesize that if the contingency between the two agents is the main factor eliciting the P400 component, we expect the same P400 component

in the second comparison. Given findings in Study 1, we also expect a significant N290 component when chasing motion is compared to random. Finally, we do not expect a significant difference in the Nc component.

3. Study 2: chasing versus random

3.1. Methods

In order to examine whether the results in Study 1 are due to 9-month-olds' sensitivity to the interaction between the two agents, rather than animacy of individual agents, here we examine interaction through correlated motion as a source of socialness. Unlike in Study 1, here both types of animations depicted objects that moved of their own energy source rather than as a mechanical result of collision with stationary objects within the display or its boundaries. In Study 2, keeping animacy constant, we varied the motion contingency. While in the chasing interaction the chasing agent moved in a goal-directed way toward the target, as the target moved away in response, in the random motion both objects moved in no relation to each other. In this case, the motion of one object had no consequence on the motion of the second object.

3.2. Participants

Eighteen 9-month-old infants (6 female; mean age = 280 days; 9 months 7 days) were included in the final sample. All participants were full-term without known neurological or developmental disabilities. Additional 15 infants were tested but were not included in the analysis due to failure to meet the inclusionary criterion of minimum 10 artifact free trials for each stimulus set. None of the infants who participated in Study 1 participated in Study 2.

3.3. Stimuli and procedure

The procedure was identical to the one in Study 1, in that all children saw blocks with video animations followed by the static ERP images. The main difference between the two procedures was that the stimuli presented were the chasing interaction from Study 1 and a new random motion animation.

3.3.1. Random motion animation

The Random motion animation was created on the base of the Chasing interaction. As in the Chasing interaction animation, the Random motion animation depicted the main shape (orange triangle/blue rectangle) move continuously at a constant velocity of 0.4 visual degrees/frame (12 pix/frame). The motion of the gray circle in the random motion animation was similar to its motion in the chasing interaction. That is, the gray circle moved at a baseline velocity of 0.2 visual degrees/frame (6 pix/frame). Just like in the chasing interaction, the gray circle accelerated to 0.8 visual degrees/frame (24 pix/frame) for 24 frames and returned to its original velocity 4 times during the trial. But, unlike in the chasing interaction, here both shapes moved independently of each other following different trajectories, never overlapping. Just like the chasing motion, a 4-note sound was used. The sound was the same as the one used in chasing motion but with a lower pitch. Here, rather than being dependent on a proximity of the chaser to the target (since they moved independently from each other) the sound occurred at the same time as in the chasing motion, moments before the target's acceleration bouts. Thus, in both conditions the sound was contingent on the target's acceleration profile.

3.4. EEG recording and analysis

The recording and analysis procedure was identical to Study 1. On average, infants attended to 58.5 trials (range: 40–74 of which 58.6 were chaser trials and 58.4 were random agent trials). The same criteria were used for channel and trial rejection as in Study 1. As a consequence, on average 13.4 chaser trials (range: 10–24) and 13.4 random agent trials (range: 10–26) per infant were included in the final analysis, Paired sample t -test $t(17) = 0.039$, $p = 0.970$. Again, the aggregated ERP amplitude for the P400 was within the interval 350–650 ms after onset of the image and within 400–600 ms for the Nc component.

Each child observed between 2–5 reminder video presentations ($M = 3.5$, $SD = 0.90$) and on average total stimuli presentation lasted approximately 6 min 9 s.

3.5. Results

3.5.1. P400

As in Study 1 for the P400 component, a 2(chaser, inanimate agent) \times 2(hemisphere: left, right) repeated measures analysis of variance revealed a significant main effect of agent type $F(1, 17) = 12.20$, $p = 0.003$, $\eta^2 = 0.418$ with a significantly higher amplitude for the chaser (8.48 μV , $SE = 2.70$) than the random animate agent ($-0.221 \mu\text{V}$, $SE = 2.69$) (Fig. 3). The analysis also indicated a significant main effect of hemisphere, $F(1, 17) = 44.47$, $p < 0.001$, $\eta^2 = 0.723$, with a higher amplitude in the right (13.26 μV , $SE = 3.05$) than left ($-5.0 \mu\text{V}$, $SE = 2.44$) channels. There was no significant hemisphere by agent interaction $F(1, 17) = 0.472$, $p = 0.501$, $\eta^2 = 0.027$.

3.5.2. Nc

For the Nc component, a Paired samples t -test further indicated no significant differences between agent types, $t(17) = 0.586$, $p = 0.566$ with positive amplitudes for the chaser (1.26 μV , $SE = 0.88$) and the randomly moving agent (.87 μV , $SE = 0.75$).

3.5.3. P200 and N290

As in Study 1, there was a positive inflection at around 200 ms followed by a negative deflection at around 300 ms post stimulus onset. Here, as in Study 1, the N290 component demonstrated significantly higher positive amplitude for the chaser (3.38 μV , $SE = 3.21$), and a negative amplitude for the random agent ($-6.56 \mu\text{V}$, $SE = 3.33$), $t(17) = 3.60$, $p = 0.002$. Unlike in Study 1, at the P200 component, the difference between the random agent ($-6.85 \mu\text{V}$, $SE = 2.64$) and the chaser (0.59 μV , $SE = 2.42$), was significant $t(17) = 2.88$, $p = 0.010$.

Finally, as in Study 1, for all the components tested, none correlated significantly with the number of reminder videos (all $ps > 0.05$).

3.6. Discussion

The results from Study 2 show that 9-month-old infants are able to differentiate between an agent previously engaged in a chasing interaction and an animate agent that previously moved randomly in relation to another agent. As in Study 1, findings demonstrate a significantly positive ERP component around 400 ms for the chasing agent compared to the random agent and a significant difference characterized by a negative deflection in both agents around 290 ms (N290). These findings suggest that chasing is perceived as a social event involving two (or possibly more) interacting agents early in infancy. Just like in Study 1, there was no significant difference in the Nc component in Study 2, again indicating that the objects in both conditions were equally attention grabbing.

The difference in findings between the two studies is that here unlike in Study 1, the P200 shows lower amplitude for the random agent compared to the chaser. This finding is interesting as it signifies that the chaser is identified and processed as an *interacting entity* very rapidly. Such strong and fast reaction in response to the agent whose motion is correlated with another agent suggest that social interactions and/or relations are involved in very basic perceptual processes that may influence later processing stages- an important question for future research.

4. General discussion

The primary purpose of the present studies was to test two theoretical perspectives on animacy perception in infancy. One explanation claims that animated interactions are conceptualized as social events based on a combination of motion cues such as self-propulsion, goal-directedness and interactivity (motion contingency) between agents. Another claim suggests that preference for the social motions involves a low-level perceptual processing of individual motion parameters causing the attentional shift toward the features of the motion. In addressing this theoretical distinction, we examined whether by 9-months infants are able to differentiate between an agent that was previously engaged in a chasing interaction from an object that engaged in a different type of motion. Across two studies we presented infants with short videos depicting two geometrical shapes either being involved in a chasing interaction (Study 1 and 2), moving inanimately (Study 1) or moving randomly (Study 2). With these comparisons we varied the object's animacy (Study 1) and interactivity between the agents while keeping animacy the same (Study 2). In doing so, we have provided the first evidence for the neural correlates of chasing perception in young infants, which provided support for the involvement of the social network during observation of chasing.

Both studies postulate evidence of a strong positive amplitude for the chasing agent in the low occipital and post temporal areas 400 ms post stimulus onset. Given that prior research examining early perception to social information in infancy found a similar P400 component (Bakker et al., 2015, 2016; Gredebäck et al., 2010; Melinder et al., 2015; Senju et al., 2006), present findings are compatible with the notion that the chasing geometrical shape is processed as a social agent compared to an inanimate object or a randomly moving object. This highlights that animacy alone may not fully explain the effect but rather the socialness of the chasing event that drives the effect. Furthermore, given that the P400 component has been found to be an index for adult pSTS activity which in turn has been shown in response to interacting animated interactions of which chasing may be considered the hallmark (Gao et al., 2009), it is likely that the infant P400 found here has its main sources in the pSTS.

In both studies, we find a main effect of hemisphere with higher P400 amplitude in the right than left channels. This finding corroborates with previous adult research that has found higher engagement of the right pSTS when observing correlated motion such as chasing (Schultz et al., 2005). In other studies, the engagement of the right pSTS has been especially sensitive to goals and intentions behind motion (Gao et al., 2012) as well as in response to unsuccessful compared to successful outcomes of goal-directed actions (Shultz et al., 2011).

In addition to the P400 component, here we find a negative deflection around 290 ms. For both the random and the inanimate agent, the N290 was larger (more negative) followed by a lower (less positive) P400 amplitude in comparison to the chasing agent. Previous research suggests that this amplitude pattern may appear for novel rather than familiar stimuli in 9-month-olds (Key et al., 2009 but see also Key and Stone, 2012; Scott et al., 2006), suggesting

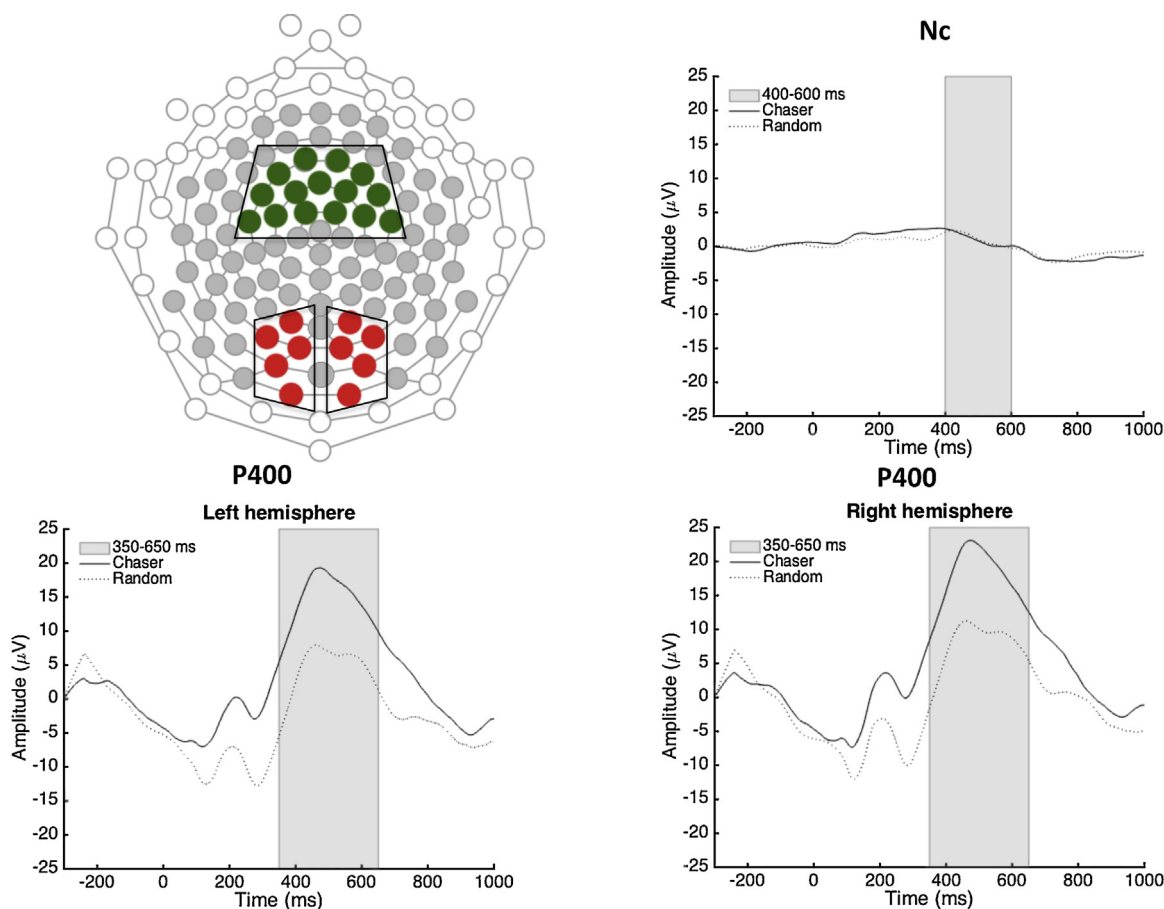


Fig. 3. Grand average ERP data for selected channels for the Nc component (in green; top graph) and P400 component (in red) of the Left (bottom left graph) and Right (bottom right graph) hemisphere with time of interest shaded in gray. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

it to be involved in longer processing and greater visual attention. It is thus possible that the inanimate agent and the random animate agent required more visual processing, while the chasing agent was more easily recognized as such. Increased visual attention to randomly moving shapes has also been previously found in 5-month-old infants when presented with a display showing discs chase next to a displays with inanimately moving discs (Rochat et al., 1997).

The infant N290/P400 complex has been suggested to be the precursor to the adult N170 (de Haan et al., 2003, 2002; Halit et al., 2003), which in adults has been localized to the fusiform gyrus and the superior temporal sulcus (Itier and Taylor, 2002, 2004) activated during perception of social stimuli, biological motion and animate motion. Here we find similar components, suggesting that the amplitude difference during chasing perception may be related to the social aspects of interactions rather than the presence of motion cues pertaining to animacy as defined by the violation of the Newtonian laws of mechanics. However, which aspects of the chasing interactions may be responsible for the emergence of the N290/P400 complex is an important question for future research and one that is beyond the scope of the present paper. Good candidates for further assessment may be correlated motion between the chaser and the target, such as the goal-directedness of the chaser and the contingent reaction of the target. Since the processing responses are so rapid, visual pop-out paradigms could possibly be used in parallel with neurophysiological measures.

Study 1 did not find any differences in the Nc component between animate and inanimate objects, as Kaduk et al. (2013) did. The different findings might have to do with the way animacy was

measured in both studies. In Kaduk et al. (2013) a single object was moving through an obstacle course continuously either violating or abiding by the Newtonian laws of physics from a side view. In contrast, in the present study, infants were presented with two objects from a top view, and they had to process not only how the objects move in their environment but also how they move in relation to each other. Given the finding that inanimate motion engages increased attention (Kaduk et al., 2013), it is possible that motion cues pertaining to a socially contingent interaction between agents required similar attentional effort as the inanimate motion, rendering the effect null. It could also be that we have a “ceiling effect” since the infants had to track multiple objects. In all cases, it seems like all conditions in our studies were equally engaging for the infants.

In addition to the N290/P400 complex, in both studies there was a positive peak around 200 ms following the stimulus onset to the chasing agent compared to inanimate and random agent. But, the difference in amplitudes was only significant when the chasing agent was compared to the randomly moving agent in Study 2, where the amplitude for the random agent was negative. Previous research in adult population found that the visual P200 component in the posterior area is involved in cognitive processes such as feature detection and retrieval (Luck and Hillyard, 1994), memory load performance (Klaver et al., 1999), and semantic processing as well as higher-order perceptual processing (Freunberger et al., 2007). In one study, Yorio et al. (2008) suggest that the early positive wave has to do with the formation of perceptual categories between first and second objects as well as a visual discrimination and recollection of previously seen items. Other studies found the amplitude

around the P200 to increase following visual discrimination training (Ding et al., 2003), proposing that the P200 might be in part responsible for stimulus encoding and later recall. In our case, the higher positive amplitude for the chasing could therefore indicate categorization of the still images based on previous differences in motion as well as visual discrimination of the chaser from the others. Furthermore, given that the only difference between the two studies was in the presence of a significant difference in the P200 when chasing was compared to random motion, it may have to do with the presence of motion contingency between the objects. It would be striking if the P200 we found in infancy is indicative of early perception of social relationships forming a foundation for higher cognitive processing. To us, this is an important finding, which merits future research to investigate this issue in detail.

A potential confound in the present study has to do with the auditory differences between the conditions. While the sounds may have aided in differentiating between the shapes, they do not account for the seen effects. Current literature on auditory processing suggests that a detection of a mismatch to pitch changes, such as those in Study 2 results in a slow positive wave between 100 and 400 ms at the frontal and central regions, with a reversed polarity at the parietal, occipital and temporal regions in infants (He et al., 2007). Other studies, depending on the experimental design, find the presence of a P300 (peak between 250 and 350 ms) component over central and parietal areas in infants when passively listening to varying tones (Mclsaac and Polich, 1992), while others find the same component over frontal and central electrode sites (Kushnerenko et al., 2002; Leppänen et al., 1997). In the present study, we do not find the P300 component. In the posterior sites we find a negative deflection at around 300 ms, while in the frontal central areas as measured by the Nc component, we find slightly more positive amplitude, but no significant differences between conditions. Thus, the specific effect is unlikely attributed to the auditory differences.

In conclusion, the present findings demonstrate for the first time that neural components responsible for the chasing perception is different from inanimate and random motion processing. We show that similar to adults, chasing is evaluated as a social interaction in infants as young as 9 months, which was indexed by the differences in the socially valenced N290/P400 complex. We also show that the P200 is modulated, which indicates that the social properties of objects are involved very early in visual processing.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.dcn.2016.05.005>.

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