



PAPER

Visual cues of motion that trigger animacy perception at birth: the case of self-propulsion

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Abstract

Self-propelled motion is a powerful cue that conveys information that an object is animate. In this case, animate refers to an entity's capacity to initiate motion without an applied external force. Sensitivity to this motion cue is present in infants that are a few months old, but whether this sensitivity is experience-dependent or is already present at birth is unknown. Here, we tested newborns to examine whether predispositions to process self-produced motion cues underlying animacy perception were present soon after birth. We systematically manipulated the onset of motion by self-propulsion (Experiment 1) and the change in trajectory direction in the presence or absence of direct contact with an external object (Experiments 2 and 3) to investigate how these motion cues determine preference in newborns. Overall, data demonstrated that, at least at birth, the self-propelled onset of motion is a crucial visual cue that allowed newborns to differentiate between self- and non-self-propelled objects (Experiment 1) because when this cue was removed, newborns did not manifest any visual preference (Experiment 2), even if they were able to discriminate between the stimuli (Experiment 3). To our knowledge, this is the first study aimed at identifying sensitivity in human newborns to the most basic and rudimentary motion cues that reliably trigger perceptions of animacy in adults. Our findings are compatible with the hypothesis of the existence of inborn predispositions to visual cues of motion that trigger animacy perception in adults.

Research highlights

- Because animacy perception in adults relies on fast and automatic visual processing that is mainly constrained by a collection of visual motion cues, we hypothesized that this faculty has an early ontogenetic origin.
- Self-propelled motion – the capacity to initiate motion without the application of an external force – is among the most powerful low-level perceptual cues that convey animacy.
- Our results demonstrated that at birth, the self-propelled motion onset of an object is a crucial visual cue that allows newborns to differentiate between self- and non-self-propelled objects.

- Our findings are compatible with the hypothesis that predispositions to attend to certain visual cues of motion that trigger animacy perception in adults are present at birth.

Introduction

The visual world that we experience is immensely complex and rich with objects but, despite this complexity, adults, infants, and even newborns can organize and structure it. The first and most important way of making sense of the world is to identify and differentiate animate entities from inanimate ones. Due to its adaptive relevance, some authors have claimed that the animate

vs. inanimate dichotomy represents evolutionarily adapted domain-specific knowledge systems that are subserved by distinct neural mechanisms in the adult brain (Caramazza & Shelton, 1998; Mahon & Caramazza, 2009; Schultz, Friston, O'Doherty, Wolpert & Frith, 2005; Vallortigara, 2012a). In the same vein, some authors suggest that adults possess an ancestrally derived domain-specific subsystem for visual attention, that is automatic, independent from beliefs, goals and acquired experience, for detecting the presence of animate beings and monitoring them (New, Cosmides & Tooby, 2007; Pratt, Radulescu, Guo & Abrams, 2010).

Understanding how humans identify and separate social agents from other objects and how this ability develops are open and intriguing questions. The aim of this paper was to investigate sensitivity in human newborns to the most basic and rudimentary motion cues that reliably trigger perception of animacy in adults.

In addition to structural perceptual features such as those of faces (Kanwisher, 2000), eyes (Puce, Allison, Gore & McCarthy, 1995) and overall body structure (Downing, Jiang, Shuman & Kanwisher, 2001), the perception of biological motion, through movement, can also be used to identify animate entities (Troje, 2013; Vallortigara, Regolin & Marconato, 2005; Vallortigara & Regolin, 2006). Even more interesting, simple geometric figures can be perceived as animate by virtue of their motion, a phenomenon known as perceptual animacy (Heider & Simmel, 1944; Michotte, 1963; Rutherford, 2013; Santos, David, Bente & Vogeley, 2008; Scholl & Gao, 2013; Scholl & Tremoulet, 2000). Here, we are concerned with this perceptual level, which can be considered consistent with the more basic level of 'animacy' conceptualized by Leslie (1994, 1995) and later adopted and developed by Carey (2009) and also termed 'mechanical agency'. Thus, the terms animacy and mechanical agency refer to objects that are capable of self-propelled motion (i.e. without the application of an external force), can act as a mechanical cause and can resist forces that may act upon them.

Heider and Simmel (1944) were the first to demonstrate that animations of simple geometric shapes interacting with one another can elicit the perception of animacy solely based on how these shapes move together. Since that study, several researchers have tried to reveal which visual cues of motion promote the perception of animacy in adults, such as speed and trajectory direction changes (Dittrich & Lea, 1994; Scholl & Tremoulet, 2000; Szego & Rutherford, 2008; Tremoulet & Feldman, 2000), discontinuity in motion trajectory (Gelman, Durgin & Kaufman, 1995; Santos *et al.*, 2008), motion contingency (i.e. spatial and temporal synchrony; Bassili, 1976; Blakemore, Boyer, Pachot-Clouard, Meltzoff, Segebarth *et al.*, 2003; John-

son, 2003; Johnson, Booth & O'Hearn, 2001; Santos *et al.*, 2008) and violation of Newtonian laws of motion (Kaduk, Elsner & Reid, 2013). However, one of the most powerful defining attributes of animate motion is that it involves movement that appears to be self-produced, as animate objects move without requiring external forces (Leslie, 1994; Stewart, 1984).

It is plausible to hypothesize that the perceptual animacy phenomenon has an early ontogenetic origin because in adults, it is based on fast and automatic visual processing, which is mainly constrained by a collection of low-level visual motion cues. Developmental research has demonstrated that preverbal human infants make a fundamental distinction between animate and inanimate entities, with motion cues providing a decisive role in their classification of objects into these categories both behaviourally (Baker, Pettigrew & Poulin-Dubois, 2014; Gelman, 1990; Mandler, 1992; Poulin-Dubois, Crivello & Wright, 2015; Premack, 1990; Saxe, Tzelnic & Carey, 2007; Spelke, Phillips & Woodward, 1995; Surian & Caldi, 2010; Träuble, Pauen & Poulin-Dubois, 2014) and neurally (Kaduk *et al.*, 2013). Empirical evidence showed that infants as young as 9 months were surprised when familiar and unfamiliar inanimate objects (i.e. chairs) moved on their own, demonstrating that they discriminate between them (Golinkoff, Harding, Carlson & Sexton, 1984). Similarly, 9-month-old infants were surprised when an inanimate object (i.e. a robot) moved autonomously (Poulin-Dubois, Lepage & Ferland, 1996). Other studies suggest that infants recognize and distinguish self-moving objects from inert ones by at least 6 or 7 months of age (Leslie & Keeble, 1987; Pauen & Träuble, 2009; Woodward, 1998). A more recent finding showed that even 3- and 5-month-old infants know that stationary objects start to move only if they are contacted by another moving object, or if they are provided with an inner mechanism that permits self-produced motion (Luo & Baillargeon, 2005). Further, these infants perceived the self-propelled nature of a movement and held different expectations for physical events involving inert or self-propelled objects when such events possessed an internal source of energy (Luo, 2011; Luo, Kaufman & Baillargeon, 2009).

From a domain-specific viewpoint, it has been suggested that this precocious sensitivity to self-produced motion as a critical cue to differentiate animate from inanimate objects is due to the existence of an innate, domain-specific visual module present from birth (Leslie, 1984; Premack, 1990). The primacy of motion as a cue for identifying animate entities has also been acknowledged by Mandler (2003), who proposed that infants develop knowledge about the motion of animate and inanimate entities through an innate process (i.e. perceptual analysis). In the same vein, other authors have

hypothesized that at birth, infants possess separate core knowledge systems for animate and inanimate objects, and that they understand that constraints on motion that apply to physical objects may not hold true for animate beings (Spelke, 2004; Spelke & Kinzler, 2007). In contrast, according to a more domain-general view, as in associative learning, infants use learning mechanisms that operate across all domains of knowledge to encode statistical regularities in their environments. Therefore, infants learn about identities and properties of the objects that appear in self-propelled events through their experiences with specific kinds of entities that engage in these motions (Rakison, Lupyán, Oakes & Walker-Andrews, 2008; Rakison & Poulin-Dubois, 2001).

Since studies on animacy perception have never involved infants younger than 3 months of age, we cannot exclude the possibility that experience during the first 3 months of life may shape the responses of infants towards animate objects.

To our knowledge, only one study has investigated directly the ontogeny of animacy perception in subjects that have had no visual experience. Mascalzoni, Regolin and Vallortigara (2010) demonstrated that newly hatched chicks possess an innate sensitivity to self-produced motion. On their first day of life, visually naïve chicks were exposed to an animation sequence depicting two oval-shaped objects, and each object was a different color. In the animation sequence, a given object was set in motion either by self-propulsion (i.e. it started moving on its own) or by the application of an external force (i.e. by direct contact with a second object) or in a third case, motion onset was ambiguous, that is, at the time of motion onset the object was hidden behind occluding screens and therefore, no cues were provided about the nature of motion onset. After exposure to the animation sequences, the spontaneous preference of chicks for these scenarios was tested and chicks preferred the self-propelled object. These results demonstrated that the domestic chick, a highly precocial bird species, showed an innate sensitivity to self-propulsion and this may be because self-propulsion is a crucial cue to animacy. The visual preference found in newborn visually naïve chicks for self-produced motion seems to be at the basis of the predisposition for identifying animate creatures and, more importantly, for approaching conspecifics. Therefore, the ability to detect and to prefer an object that starts to move without any external force with a self-initiated movement, might be a sort of jumpstart to the development of animacy perception that is crucial to survive in a social environment.

What about human newborns? Does the ability to discriminate between inert and self-propelled objects, described in chicks, also hold true in human newborns?

Some authors would suggest that this is the case, such as those who support the notion of the existence of separate core knowledge systems, present since birth, devoted specifically to detect and process objects and social agents, respectively (Spelke & Kinzler, 2007; Vallortigara, 2012b). However, to date, no studies have investigated whether human newborns are sensitive to motion cues that trigger animacy perception in humans. The idea of the existence of innate predispositions towards animate beings in humans is not new. This idea is based mainly on two sources of evidence in humans. First, at birth, motion triggers attention (Valenza, Simion & Umiltà, 1994) and, second, from the time of birth, infants pay attention either to specific features belonging to animate entities, such as the face, eyes, and gaze (Batki, Baron-Cohen, Wheelwright, Connellan & Ahluwalia, 2000; Farroni, Csibra, Simion & Johnson, 2002; Morton & Johnson, 1991; Valenza, Simion, Macchi Cassia & Umiltà, 1996), or to the presence of biological motion (Simion, Regolin & Bulf, 2008). This predisposition to orient towards both motion and animate beings at birth has been attributed to the activation of a subcortical orienting mechanism (i.e. the superior colliculus), which precociously biases humans towards socially relevant stimuli (Johnson, 2005; Morton & Johnson, 1991; Simion, Valenza, Umiltà & Dalla Barba, 1998). Even more interesting, the ability to perceive and discriminate at birth certain well-defined perceptual spatio-temporal cues present in a physical causal event has recently been demonstrated (Mascalzoni, Regolin, Vallortigara & Simion, 2013). Specifically, to test newborns' sensitivity to spatio-temporal cues which tightly correlate with adults' causal perception, newborns were presented with two bilaterally computer animation events (i.e. a launching and a delay event). In the launching event (i.e. causal event), object A started to move towards object B, which was stationary. Immediately after contact between the two objects, object B started to move along the same direction as A, while object A became stationary. In this sort of display, adult subjects perceive object A as 'launching' object B and causing its movement. The delay event (i.e. non-causal event) was identical to the launching one except for the presence of a 1-s delay between the time of contact and the motion of B. In adult subjects the presence of a delay abolished any impression of physical causality: object B appeared in this case to be self-propelled and moving independently from object A (Michotte, 1963).

In that scenario, newborns showed a clear preference for the launching event (i.e. causal event), demonstrating that they are sensitive to the additive effects of a set of patterns of motion and of spatio-temporal perceptual cues. Indeed, the temporal continuity between the motion

of two objects involved in the event, the continuity of trajectory between the motion of two objects, and the sequence of the displacements of two objects are present all together in the visual display and, therefore, that study can tell us nothing about which single pattern of motion might drive newborns' visual preferences.

Here we sought to go beyond this limit by asking the question whether newborns are sensitive and manifest a preference toward the most basic and rudimentary motion cues that reliably trigger perception of animacy in adults. We carried out a series of experiments to test sensitivity in newborns to self-propulsion (Experiment 1) and to the change in trajectory of an object with and without contact (Experiments 2 and 3) as motion cues that elicit animacy perception in adults. Indeed, these patterns of motion have been extensively studied in adults who were asked to decide whether a moving object was animate, and results demonstrated that they consistently produce animate perception (Scholl & Tremoulet 2000; Tremoulet & Feldman, 2000).

Experiment 1

The aim of Experiment 1 was to test the presence of an inborn sensitivity to a visual cue of motion that in adults triggers animacy perception such as self-propelled motion onset of an object when the object starts from rest on its own without any external force.

Newborns were presented with two computer-generated events in which the visibility of the self-propelled motion onset of an object was manipulated (i.e. self-propelled vs. ambiguous). In the self-propelled motion event, the object started from rest with a self-initiated visible movement; therefore its initial starting motion was clearly visible and available to the baby. In contrast, in the ambiguous event the object appeared on the screen already in movement, so no cues about the onset of motion were available to newborns. In this manner, contrary to Mascalzoni *et al.*'s study (2013), our two stimuli are totally equated (i.e. low-level variables, quantity of motion, speed, trajectory), except for the visibility of the onset motion of the object. If newborns are sensitive to the motion cues that trigger animacy perception in adults, then they should prefer the event in which the onset motion of the object by self-propulsion is visible and not ambiguous.

Method

Participants

Eighteen full-term newborns were selected from the maternity ward of the Paediatric Clinic of the University

of Padova. Data from six newborns were discarded because they became too tired or started crying during testing ($n = 3$) or showed a position bias (newborns looked in one direction more than 80% of the time, $n = 3$). Therefore, the final sample consisted of 12 newborns (seven males). Their postnatal age ranged from 13 to 98 h ($M_{age} = 40$ h, $SD = 27$). All subjects met the normal delivery screening criteria, had a birth weight between 2380 and 4140 g ($M = 3245$ g, $SD = 476$), and had an Apgar score of 10 at 5 min. Newborns were tested only if awake and in an alert state, and after the parents had provided informed consent. All experimental procedures have been licensed by the Paediatric Clinic of the University of Padova.

Apparatus and procedure

An infant-control preferential looking technique was used. Stimuli consisted of two animation events presented on an Apple LED Cinema Display (Flat Panel 30") computer monitor (refresh rate = 60 Hz, 2560 × 1600). The baby sat on an experimenter's lap at a distance of approximately 30 cm from the monitor and white curtains were drawn on both sides of the newborn to prevent interference from irrelevant distractors. Eye movements were recorded with a video camera placed above the monitor, and the direction and duration of the first fixations, the total number of orienting responses and the total fixation time towards the stimuli were coded off-line. In accordance with Cohen (1972), we assumed that the number of orienting responses indexed an orienting mechanism, whereas duration of the first fixations, as well as the total fixation time, indexed a detection mechanism. At the beginning of each preference test trial, a red disc on a black background appeared to attract the infant's gaze to the centre of the monitor. In a continuous fashion, the disc changed in size from small (1.8 cm) to large (2.5 cm) until the newborn's gaze was properly aligned with the red disc. The sequence of trials was then started by a second experimenter who watched the newborn's eyes through the video camera. When the newborn's gaze was aligned with the red disk, the second experimenter pressed a keyboard key that automatically turned off the central disc and activated the onset of the stimuli, thereby initiating the sequence of trials. Because stimuli were presented bilaterally on the left and the right side of the monitor with a convergent motion pattern (from peripheral to the central visual field), each newborn was given two paired presentations (trials 1 and 2) of the test stimuli. In each trial, the position of the stimuli was reversed (the initial left-right order of presentation was counterbalanced across subjects).

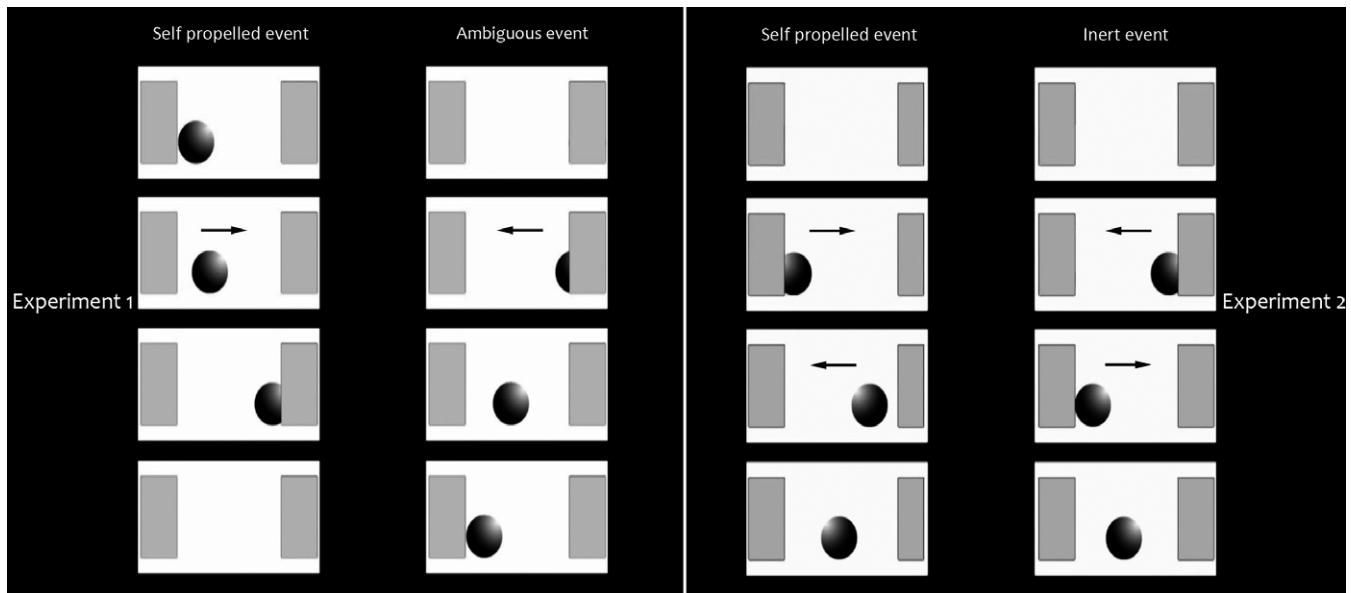


Figure 1 Schematic representation of the events used in: Experiment 1 (left-most sequence: the Self-propelled event; right-most sequence: the Ambiguous event); Experiment 2 (left-most sequence: Self-Propelled event; right-most sequence: the Inert event).

A trial ended when the newborn did not fixate on the display for at least 10 s. Videotapes of the newborn's eye movements were coded off-line by a different observer, unaware of the stimuli presented. The mean estimated reliability between observers was Pearson's $r = .98$, $p < .001$.

Stimuli

Stimuli consisted of two animation events presented on a computer screen: a self-propelled motion event and a non-self-propelled motion event. Each event featured two occluders (grey rectangles with an area of $4 \times 8.5 \text{ cm}$, $7.6^\circ \times 15.8^\circ$), placed on the left and right, respectively, and one object (grey disc of 3 cm in diameter). In the self-propelled motion event, the object was already present on the screen near the first occluder and after 0.5 s it started to move on its own towards the second occluder, until it completely disappeared behind it. In this event, there were cues about the self-propelled nature of the object in motion. In contrast, in the non-self-propelled motion event, the entrance of the object was ambiguous (i.e. masked), because it appeared already in motion emerging from behind the first occluder; therefore no cues about whether motion onset was driven by self-propulsion or external force were available. After emerging from the first occluder, the object continued moving towards the second occluder (as occurred in the self-propelled event) but then it stopped in front of the second occluder for 0.5 s. We chose to

include this 0.5-s stop to ensure that in both animation events, the two stimuli remained the same amount of time in a static position (i.e. 0.5 s at the beginning of the self-propelled motion event and 0.5 s at the end in the ambiguous display). Importantly, both objects moved with identical speed and covered the same distance; Figure 1). In this type of display, adult subjects perceive the object already present on the screen that started to move as a self-propelled object, compared to the object in the ambiguous display.

Both events described lasted 4.5 s (84 frames, 25 frames/s). Each object covered a distance of 11 cm at 4 cm/s and maintained both its starting and final position for 0.5 s. Videos were produced by looping the animations. Each set of elements occupied an overall 10 cm window in width (20° visual angle at a viewing distance of 30 cm).

Results

The Kolmogorov-Smirnov goodness-of-fit test showed that the data were normally distributed. To establish whether the newborns showed a spontaneous visual preference for one of the two stimuli, separate two-tailed dependent samples t -tests were performed. When tested for their preference for a self-propelled motion event vs. an ambiguous motion event, newborns looked significantly longer at the self-propelled event ($M = 41.6$ s, $SD = 18$) than at the ambiguous one ($M = 33.8$ s, $SD = 20.2$), $t_{(11)} = 2.3$, $p = .039$ (Cohen's $d = .68$) (Fig-

ure 2). Ten out of 12 newborns preferred the self-propelled motion event compared to the other event (binomial test, $p = .039$). The percentage of total fixation time newborns spent looking at the self-propelled motion event was significantly above chance level of 50% ($M = 58.2\%$, $SD = 10$), $t_{(11)} = 2.9$, $p = .014$ ($d = .84$). As regards the number of orientations, newborns did not look significantly more frequently to self-propelled motion event ($M = 12.1$, $SD = 4.3$) compared to the ambiguous one ($M = 10$, $SD = 4.7$), $t_{(11)} = 1.4$, $p = .17$, ns.

With respect to the duration of the first orientation, babies looked longer at the self-propelled motion event first ($M = 7.3$ s, $SD = 4$) compared to the ambiguous event ($M = 5$ s, $SD = 3.2$), $t_{(11)} = 2.6$, $p = .025$ ($d = .75$). In addition, in test phase 1, 7 out of 12 newborns oriented first at the self-propelled motion event (binomial test, $p = .77$, ns), and in test phase 2, 6 out of 12 newborns oriented first to the self-propelled motion event (binomial test, $p = .26$, ns).

Of note, in the self-propelled motion event, the first look measure does not begin at the exact time when the object starts to move. This is because at the beginning of each loop event, there is a 0.5-s time in which the object remains present on the screen. For this reason, we decided to conduct further analyses in order to investigate whether the sudden onset motion per se attracted newborns' attention. We analysed the location where newborns were looking at the exact time when the object started to move. To do so, we calculated the total number of orientations towards the object that started to move on its own and divided this number by the total number of orientations towards both stimuli at the same exact time, $\times 100$. If the sudden onset motion per se triggers newborns' attention, then we should find that newborns

look more frequently at the sudden onset motion in the self-propelled motion event. But this was not the case. The percentage of the number of orientations toward the onset motion of the object vs. motion in ambiguous display at the time when the object started to move was not above the chance level of 50% ($M = 54.2\%$, $SD = 11.7$, one sample t -test $t_{(11)} = 1.2$, $p = .24$, ns).

Finally, we carried out a further analysis by examining the looking behaviour of newborns when the object started to disappear in the self-propelled motion event, in order to investigate an alternative explanation for the significant results obtained here, that is a possible preference for a disappearance event. Specifically, we analysed the location where newborns were looking at the exact time when the object started to disappear behind the occluder in the self-propelled display (end of the event). We decided to concentrate our analyses on the exact time when the object started to disappear behind the occluder because all newborns, once their attention is captured by that exact time, continued to look at the disappearance event throughout its duration. If the disappearance event per se triggers newborns' attention, then we should find that newborns look more frequently (i.e. made more orientations) at the object that disappeared. However, the percentage of the number of orientations toward the disappearing object, calculated as the total number of orientations towards the disappearing object divided by the total number of orientations towards both stimuli at the same exact time, $\times 100$, is not above the chance level of 50% ($M = 51\%$, $SD = 12$, one sample t -test $t_{(11)} = .23$, $p = .82$, ns). We can conclude that the results in Experiment 1 are not due to a preference for a disappearance event (self-propelled) over an object appearance event.

Overall, Experiment 1 showed that newborns prefer the self-propelled motion event, where an object starts to move on its own without an external force, in contrast to an event in which the entrance of the object is ambiguous, where no visual cues about the onset of its motion are available.

Experiment 2

As well as the onset of motion by self-propulsion, changes in trajectory direction by self-propulsion are important visual cues in triggering animacy perception in both adults (Tremoulet & Feldman, 2000) and infants (Luo, 2011; Luo & Baillargeon, 2005). In Experiment 2, the entrance of the object was masked as in the ambiguous event of Experiment 1; for this reason, it appeared on the screen already in movement. In the case

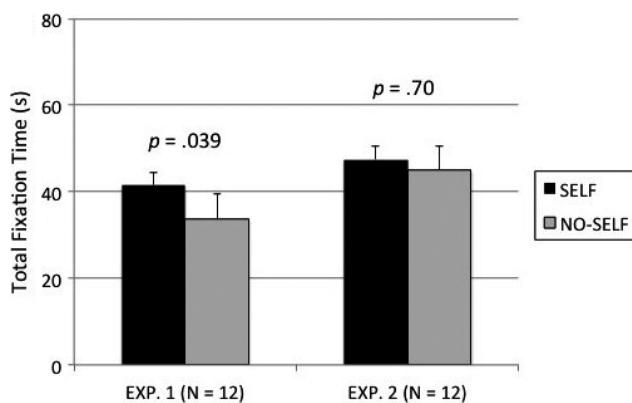


Figure 2 Average total fixation time (s) for the self-propelled motion and the non-self-propelled events in Experiments 1 and 2, respectively.

of the self-propelled motion event, the object changed its trajectory, to move in the opposite direction, and stopped at the centre of the screen (without coming in contact with either occluder). In contrast, in the inert event, the object changed its trajectory towards the opposite direction after contacting an occluder, and then stopped at the centre of the screen. In this experiment, the perceptual cue that revealed self-propelled motion was the change of direction with and without an external force (the occluder). As in Experiment 1, the stimuli were kept equivalent for all the low-level variables.

Method

Participants

The final sample comprised 12 healthy, full-term newborns (five males). Their postnatal age ranged from 14 to 175 h ($M_{(age)} = 44$ h, $SD = 42$). All of them met the screening criteria of normal delivery, had a birth weight between 2185 and 3970 g ($M = 3087.9$ g, $SD = 508$), and had an Apgar score of 10 at 5 min. Two babies were excluded from the final analyses because they changed their state during testing.

Apparatus and procedure

The apparatus and the procedure were identical to that used in Experiment 1. The mean estimated reliability between coders was Pearson's $r = .87$, $p < .01$.

Stimuli

Stimuli consisted of two animation events presented on a computer screen (a self-propelled motion event and non-self-propelled motion event) and, as in Experiment 1, each event featured two occluders on the left and right (grey rectangles with an area of 3×8.5 cm) and one object (grey disc of 3 cm in diameter). Unlike the previous experiment, in this case the entrance of the object was masked (or ambiguous) in both events, because it appeared from behind the occluder already in motion, so no cues about the onset (by self-propulsion or by external force) of its motion were available. Therefore, the two events were equivalent with regard to the nature of the onset motion of the object. However, in the self-propelled motion event, the object changed its trajectory direction and went back and stopped at the centre of the animation event without any contact with the occluder (the distance between the object and the occluder was 1 cm). In contrast, in the inert event, the object changed its trajectory direction by contacting the occluder and

then went back and stopped at the centre. In both events, the object remained at the centre of the animation event for 0.5 s; thereafter the animated sequence restarted. Therefore, contrary to Experiment 1, here the visual cue that revealed self-propelled motion was a change of direction with and without an external force (the occluder).

Results

Since data were normally distributed as indicated by the Kolmogorov-Smirnov goodness-of-fit test, separate two-tailed dependent samples t -tests were performed. Newborns did not look significantly longer at the self-propelled motion event ($M = 47.5$ s, $SD = 15.3$) compared to the inert event ($M = 45$ s, $SD = 24$), $t_{(11)} = .39$, $p = .70$, ns (Figure 2). Eight out of 12 newborns preferred to look at the self-propelled motion event compared to the inert event; the binomial test did not reveal any statistically significant effect (binomial test, $p = .39$, ns). The percentage of total fixation time newborns spent looking at the self-propelled motion event was not significantly above chance level of 50% ($M = 54\%$, $SD = 12$), $t_{(11)} = 1$, $p = .31$). With regard to the number of orientations, newborns did not look more frequently at the self-propelled motion event ($M = 14.3$, $SD = 3.6$) compared to the inert one ($M = 14$, $SD = 6.3$), $t_{(11)} = .25$, $p = .81$, ns.

Finally, with regard to the duration of the first orientation, newborns did not look longer at the self-propelled motion event ($M = 6.4$ s, $SD = 3.6$) compared to the inert event ($M = 6.4$ s, $SD = 4.2$), $t_{(11)} = .03$, $p = .97$, ns. In both test phases, 9 out of 12 newborns oriented first towards the self-propelled motion event, and the binomial test did not reveal any statistically significant effect (binomial tests, $p = .15$, ns).

Experiment 3

Data from Experiment 2 showed that newborns did not prefer an object that changed its trajectory direction on its own, without contact with an external force. This result seems to suggest that when visual cues about the onset of motion of an object by self-produced motion were no longer available, newborns did not show any visual preference. However, this null result should be interpreted with caution, because it could be the case that the newborns simply were not able to discriminate between the two stimuli. Experiment 3 aimed at testing whether newborns were capable of discriminating, after habituation, the two stimuli presented in Experiment 2.

Method

Participants

Seventeen healthy, full-term newborns took part in the experiment. Data from four babies were discarded because they changed their state during testing ($n = 3$) or because of position bias ($n = 1$); therefore the final sample consisted of 13 newborns (10 males). Their postnatal age ranged from 12 to 120 h ($M_{age} = 57.9$ h, $SD = 38.6$). All of them met the screening criteria of normal delivery, had a birth weight between 2510 and 4150 g ($M = 3245$ g, $SD = 630$), and had an Apgar score of 10 at 5 min.

Apparatus and procedure

The apparatus was the same as in the two previous experiments. With regard to the procedure, the experiment was carried out using an infant-control habituation setup (Horowitz, Paden, Bhana & Self, 1972). Infants were judged to have habituated when, from the fourth fixation onward, the sum of any three consecutive fixations was 50% or less of the total of the first three fixations (Slater, Earle, Morison & Rose, 1985). Half of the newborns habituated to the self-propelled motion event (i.e. the object that changed its trajectory direction without contact with an occluder), whereas the other half habituated to the inert event (i.e. the object that changed its trajectory direction after contacting an occluder). During the habituation phase, the same stimuli were presented side-by-side. The stimuli remained on the screen until the habituation criterion was reached. The habituation phase was followed by two preference tests in which a familiar event and a novel one were presented side-by-side. The left-right position of the stimuli was reversed from the first to the second presentation. Looking at one stimulus, generally the novel one, for a longer period of time indicated discrimination and recognition. During the preference test phase, the experimenter recorded the duration of the infant's fixation on each stimulus. The presentation lasted until the infant had fixated on each stimulus on least once and a total of 20 s of looking had been accumulated.

Results

All newborns reached the habituation criterion. A one-way analysis of variance was run to compare the total fixation times to reach the habituation criterion for the two groups of subjects that had habituated to the self-propelled motion event ($M = 51.2$ s, $SD = 13$) or the

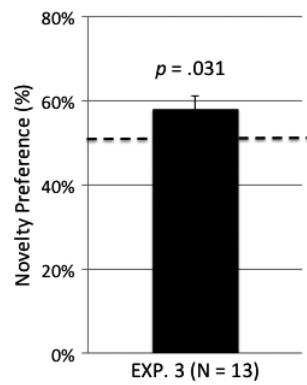


Figure 3 Average novelty preference in Experiment 3.

inert event ($M = 43.7$ s, $SD = 14.8$). The results of the comparison were not significant, $F_{(1,12)} = .93$, $p = .36$, ns.

To test whether newborns were able to recognize and discriminate between the novel stimulus and the familiar one, a novelty preference score (percentage) was computed. The time that each infant spent looking at the novel stimulus during the two test presentations was divided by the total time spent looking at both test stimuli during the two presentations, and subsequently converted into a percentage score. Hence, only scores that were significantly above 50% indicated a preference for the novel stimulus. The mean novelty preference score was 58% ($SD = 11.3$), which differed significantly from the chance level of 50%, $t_{(13)} = 2.4$, $p = .031$ (Cohen's $d = .68$) (Figure 3).

Overall, these results do not support the assumption that the lack of preference found in Experiment 2 was due to an inability to discriminate between the two stimuli. Newborns were sensitive to differences between the two stimuli and, therefore, were able to discriminate and recognize the familiarized stimulus.

General discussion

The animate vs. inanimate dichotomy represents probably the broadest level at which objects in the world can be grouped and, as such, is one of the cornerstones of conceptual knowledge (Gelman, 1990; Spelke & Kinzler, 2007). Motion, and in particular self-propelled motion, which implies that an object starts to move on its own, provides one of the most powerful cues about what makes an object be perceived as animate, both in adults (Scholl & Gao, 2013) and in infants a few months old (Luo, 2011; Luo *et al.*, 2009). In the same vein, Mascalzoni *et al.* (2010) demonstrated that sensitivity to self-propulsion is

also a critical motion cue for animacy perception in visually naïve chicks.

This paper addresses questions concerning the origin of this sensitivity in human newborns. Specifically, we examined whether sensitivity to the most basic and rudimentary motion cues, such as the onset motion and trajectory change by self-propulsion that consistently trigger animacy perception in adults and older infants, is present at birth. To this end, three experiments were carried out in which both the motion onset of an object (Experiment 1) and its trajectory direction change by self-propulsion (Experiments 2 and 3) were manipulated.

Experiment 1 demonstrated that newborns preferred a self-propelled motion event compared to an ambiguous event in which no explicit visual cues about the motion onset of the object were available (i.e. the entrance of the object on the screen was masked or ambiguous due to the presence of an occluder). This result seems to suggest that an object that starts to move on its own attracts newborns' visual attention. However, one might argue that the preference for a self-propelled motion event is a novelty response that comes from the sudden onset of motion and not from an appreciation of self-propulsion per se. Indeed, the possibility that sudden onset of motion per se is a more interesting display for newborns makes sense. However, newborns did not look more frequently at the exact time when the object started to move in the self-propelled motion event, demonstrating that the sudden onset motion per se did not grab newborns' attention. Moreover, a second alternative explanation for the significant effect of Experiment 1 might be that newborns manifest a preference for a disappearance event over an object appearance event. This possible explanation can be discarded because newborns did not look more frequently at the object that disappeared behind the occluder in the self-propelled display during the end of the event, as documented by the percentage of the number of orientations toward the disappearing object that was not above chance level.

In Experiment 2, the entrance of the object on the screen was masked in both events, so no cues for the onset of motion were available, but only in the self-propelled motion event did the object changed its trajectory direction on its own without external force and external contact. The results from Experiment 2 demonstrated that newborns, even if they were able to discriminate between the two events, as shown in Experiment 3, did not manifest any preference for the event in which the object changed its trajectory direction without external contact (i.e. self-propelled motion event) compared to an event where the object changed its trajectory direction only after an external contact with

the obstacle (i.e. inert condition). It is worth pointing out that by 7 months of age, infants already associate change in direction and speed with animals (Träuble *et al.*, 2014). However, in that study 7-month-old infants, that are older than newborns and with more visual experience of animate and inanimate objects, were presented with stimuli that changed both their direction and speed, while in our study newborns were presented with only one specific visual cue of motion, which is trajectory direction change. It is plausible that different visual cues of motion together could have additive effects on animacy perception at birth. Specifically, it is plausible to hypothesize that an object that changes its trajectory direction and its speed without external forces can elicit visual preference already at birth. This is an interesting point that future studies will explore.

Overall, the data seem to suggest that self-propelled motion onset is a crucial visual cue in eliciting newborns' visual preference, because when this cue is eliminated, the preference for the event that contained it disappeared. This is also in agreement with work of Mascalzoni *et al.* (2010), who reported that chicks do not show a preference for a self-propelled object compared to an inert one if no cues about the nature of the motion onset of such objects has been provided.

To our knowledge, this is the first study that has attempted to determine the existence of the sensitivity to the basic and rudimentary motion cues of self-propelled motion onset and trajectory direction changes in human newborns. Our findings are compatible with the hypothesis that certain inborn sensitivities to visual cues of motion that trigger animacy perception in adults are present at birth. This also supports the idea that vertebrates, comprising phylogenetically distant species such as domestic fowls and humans, have primitive neural pathways that ensure a bias to preferentially attend to and process sensory information about other living entities, as in the case of face and biological motion perception (Rosa Salva, Farroni, Regolin, Vallortigara & Johnson, 2011; Rosa Salva, Mayer & Vallortigara, 2015; Rosa Salva, Regolin & Vallortigara, 2012; Simion, Di Giorgio, Leo & Bardi, 2011). This sensitivity to detect self-propulsion as a motion cue that belongs to animate entities and not to inanimate things, does not imply of course that newborns possess abstract concepts such as intentional agency (i.e. the precocious capacity to interpret the behaviour of animate objects in terms of goals and motivational states) and mentalistic agency (i.e. mental states such as desires and beliefs) (Carey, 2009), but there is no doubt that the sensitivity to this cue that drives newborns' preference might be a sort of bootstrapping point to the development of animacy perception found later.

To conclude, future work should investigate in greater detail whether newborns are also innately endowed with the sensitivity to other movement properties that trigger animacy perception, such as changes in speed (Szego & Rutherford, 2008) or violation of Newtonian laws of motion (Kaduk *et al.*, 2013); whether these visual motion cues have additive effects on animacy perception at birth; and, finally, whether and to what extent visual experience modulates the perception of these motion cues to animacy perception. In light of this, our work has demonstrated that self-propelled motion sensitivity is present at birth and it might be the first step to developing the concepts of animacy and agency that will appear later during development (Csibra, 2003; Csibra & Gergely, 1998).

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