



Walking direction triggers visuo-spatial orienting in 6-month-old infants and adults: An eye tracking study



Lara Bardi ^{a,b,*}, Elisa Di Giorgio ^{c,d}, Marco Lunghi ^c, Nikolaus F. Troje ^e, Francesca Simion ^{c,f}

^a Department of Experimental Psychology, Ghent University, Belgium

^b Department of General Psychology, University of Padova, Italy

^c Department of Developmental and Social Psychology, University of Padova, Italy

^d CIMEC, University of Trento, Italy

^e Queen's University, Canada

^f Center of Cognitive Neuroscience of Padova, Italy

ARTICLE INFO

Article history:

Received 1 August 2013

Revised 16 February 2015

Accepted 24 April 2015

Available online 14 May 2015

Keywords:

Social stimuli

Biological motion

Visuo-spatial orienting

ABSTRACT

The present study investigates whether the walking direction of a biological motion point-light display can trigger visuo-spatial attention in 6-month-old infants. A cueing paradigm and the recording of eye movements in a free viewing condition were employed. A control group of adults took part in the experiment. Participants were presented with a central point-light display depicting a walking human, followed by a single peripheral target. In experiment 1, the central biological motion stimulus depicting a walking human could be upright or upside-down and was facing either left or right. Results revealed that the latency of saccades toward the peripheral target was modulated by the congruency between the facing direction of the cue and the position of the target. In infants, as well as in adults, saccade latencies were shorter when the target appeared in the position signalled by the facing direction of the point-light walker (congruent trials) than when the target appeared in the contralateral position (incongruent trials). This cueing effect was present only when the biological motion cue was presented in the upright condition and not when the display was inverted. In experiment 2, a rolling point-light circle with unambiguous direction was adopted. Here, adults were influenced by the direction of the central cue. However no effect of congruency was found in infants. This result suggests that biological motion has a priority as a cue for spatial attention during development.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Humans are intensely social creatures. Our ability to efficiently interact with others strongly depends on our capacity to recognize and respond to biological signals, such as for example eye gaze and body motion, which

are among the most important source of socially relevant information.

Previous studies demonstrated that social cues can trigger visuo-spatial orienting of attention in adults: averted gaze of another person can automatically induce the observer to shift attention toward the location signalled by the averted gaze (e.g., Driver et al., 1999; Friesen & Kingstone, 1998). The capacity to identify the direction of another person's attention and to orient our own attention accordingly is particularly relevant because it allows humans to draw inferences about the intentions and future

* Corresponding author at: Department of Experimental Psychology, Ghent University, Henri Dunantlaan 2, 9000 Gent, Belgium. Tel.: +32 264 94 27; fax: +32 264 64 96.

E-mail address: lara.bardi@ugent.be (L. Bardi).

behavior of others. Evidence for the idea that social cues can effectively affect orienting comes from studies adopting variants of Posner's cueing paradigm. According to the Posner's theory of costs and benefits, when attention moves to a particular location (such as for example the direction of an arrow), the visual processing of targets present in the cued location is facilitated (Posner, 1978). Consequently, reaction times are faster if the target appears in the cued position (congruent trials) and slower if the target appears in the uncued position (incongruent trials). Spatial cueing studies usually make a distinction between exogenous orienting, which typically occurs when a non symbolic cue, such as a brief flash of light, appears on one side of a computer screen and endogenous orienting, which occurs in response to symbolic cues (such as the words "right" or "left") presented in the center of the screen. Adapting the spatial cueing paradigms, a series of studies has shown that the gaze direction of a centrally presented face can trigger automatic visuo-spatial orienting, even if gaze direction does not predict where a target item may appear and/or the observer is explicitly asked to ignore the cue (e.g., Driver et al., 1999; Friesen & Kingstone, 1998; Langdon & Bruce, 1999). A typical task involves the presentation of a central stimulus depicting a face with averted gaze and the subsequent presentation of a peripheral target. The congruency between the direction of non-predictive gaze cues and target position has been shown to modulate target discrimination (e.g., Driver et al., 1999; Friesen & Kingstone, 1998) saccade's reaction times (e.g., Deaner & Platt, 2003) and latency accuracy of gaze shifts (e.g., Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002). These findings suggest that averted gaze is a socially and biologically relevant signal able to trigger automatic shifts of attention.

Although the special nature of orienting effects induced by social stimuli as compared to orienting attention by non social cues is still under debate, a number of studies suggests that visuo-spatial orienting due to social cues and non-social cues (such as arrows) determines different behavioral effects and relies on different processes (Friesen, Ristic, & Kingstone, 2004; Langdon & Smith, 2005) and distinct neural system (Calleias, Shuman, & Corbetta, 2014; Hietanen, Nummenmaa, Nyman, Parkkola, & Hämäläinen, 2006; Kingstone, Tipper, Ristic, & Ngan, 2004; Lockhofen, Gruppe, Ruprecht, Gallhofer, & Sammer, 2014; but see Greene, Mooshagian, Kaplan, Zaidel, & Iacoboni, 2009). For instance, Friesen et al. (2004) used a counter-predictive spatial cueing task that induces a bias to expect the target to appear at the opposite to gazed-at location in the observer. In this task, nevertheless, the gaze cues resulted in attention shifts to the gazed-at locations. Importantly, this kind of counter-predictive cuing was not observed with arrow cues. Kingstone et al. (2004) investigated brain activation during an attentional orienting task by using an ambiguous figure that could be perceived as a gaze cue (a hat pulled down to the eyes) or as a nonsocial directional cue (a car with eccentric wheels). The standard behavioral cuing effect was observed in both cases. When contrasting orienting by (perceived) gaze and car cues, the results revealed that activity in the area of superior temporal

sulcus (STS), an area known to be involved in face and gaze processing, was increased when the stimulus was perceived as eyes as compared to condition in which it was perceived as a car.

Recently, a similar effect to that obtained for gaze has been discovered for another socially relevant stimulus, namely the motion of the human body. Several studies have demonstrated that the visual system is remarkably adept at recognize the motion of a human body even when it is portrayed by just a few dots moving as placed on the main joints of a person (Johansson, 1973). From such point-light biological motion display, observers can retrieve ample information, such as actions (Dittrich, 1993), emotions (Dittrich, Troscianko, Lea, & Morgan, 1996), and walking direction (Hirai, Saunders & Troje, 2011; Troje & Westhoff, 2006). This is true as long as the display is presented upright. Performance in almost all the tasks drops when the display is presented upside-down, thus revealing a strong inversion effect (e.g., Chang & Troje, 2009; Hirai, Chang, Saunders, & Troje, 2011; Sumi, 1984; Troje & Westhoff, 2006), a phenomenon already known for face perception (Yin, 1969).

Walking direction is an important attribute of biological motion, which provides critical information about another living creature's disposition and intention. By adopting a central cueing paradigm, Shi, Weng, He, & Jiang (2010) demonstrated that the walking direction of an upright point-light biological motion display induced an automatic shift of visuo-spatial attention in the observers. In this study, participants were asked to discriminate the orientation of a laterally presented gabor patch. The target was preceded by a point-light sequence depicting a human walker, an animal walker, a static human point-light figure or a rolling point-light circle. Results revealed that, although participants were explicitly told that the direction of the cue was not predictive of the position of the target, accuracy in a discrimination task was significantly better when the position of the target was congruent with the facing direction of an upright walking human or animal cue than when it did not. This result revealed that automatic orienting of attention can be elicited by upright biological motion. In the study of Hirai, Saunders et al. (2011), the latency to make a saccade to a peripheral target was measured under condition in which the location of the target was congruent or incongruent with the facing direction of a centrally presented point-light walker (upright or inverted). Participants were asked to orient their eyes either toward the right or the left according to the color of the cue. Results revealed that saccade latency and accuracy were affected by the facing direction of the central walker and this was true only when the target was presented upright.

Finally, using a Simon effect task, Bosbach, Prinz, & Kerzel (2004), observed a stimulus–response compatibility effect with point-light walkers. In this task, participants were asked to respond to the color of the dots representing the walker. Although the walking direction of the point-light display was irrelevant for the task, responses were faster and less error prone when the facing direction of the walker and the response position corresponded than when they do not.

Taken together, these outcomes reveal that the walking direction of biological motion can guide automatic shifts of attention in adult observers as was previously demonstrated for eye gaze. In this respect, an intriguing question concerns the developmental origin of the ability to use directional information of biological motion to guide attention.

From a developmental perspective, a first step to enter in our social world is the ability to orient attention to the direction of social signals and to use these as relevant cues. Different studies revealed that infants can use gaze direction to cue their attention (Farroni, Johnson, Brockbank, & Simion, 2000; Hood, Willen, & Driver, 1998). A rudimentary form of gaze following has been found in infants only 2 days old (Farroni, Massaccesi, Povidori, & Johnson, 2004). In the study of Farroni et al. (2000), it has been shown that 4–5 month-old infants were faster to make saccades to peripheral targets cued by the gaze direction of a central real face.

However, the effect of biological motion as a cue for attention was never investigated in infants. In the present study we investigated whether the walking direction of biological motion can guide visuo-spatial attention in 6-month-old infants and in adults.

Sensitivity to biological motion emerges very early in life and some aspects of biological motion processing are present even in neonates, both in humans (Bardi, Regolin, & Simion, 2011; Simion, Regolin, & Bulf, 2008), and in other animals (Vallortigara & Regolin, 2006; Vallortigara, Regolin, & Marconato, 2005). Two-day-old babies, at their first exposure to point-light displays, preferentially attend to biological motion as compared to the motion of an inanimate object (Bardi et al., 2011) and also prefer an upright biological motion display over the same display presented upside-down (Simion et al., 2008). Moreover, infants from 3 to 5 months are able to retrieve the articulated shape of a human body from an array of moving dots (Bertenthal, Proffitt, & Cutting, 1984; Bertenthal, Proffitt, & Kramer, 1987). However, the origin of our ability to retrieve important information, such as direction of locomotion, from such biological motion displays, remains poorly understood. Kuhlmeier, Troje, & Lee (2010) demonstrated that 6-month-old infants are able to extract the directionality of biological motion. Infants could discriminate, as revealed by a visual habituation technique, leftward and rightward motions from a movie depicting the sagittal view of an upright human point-light walker, walking as if on a treadmill. However this study does not tell us anything about the question of whether infants use walking direction as a cue for directing their own attention.

The present study entails two experiments. In experiment 1, we investigated whether the walking direction of biological motion can automatically trigger visuo-spatial attention in infants. To this end, two groups of participants (6-month-old infants and adults) were submitted to a modified version of the cueing paradigm in which eye movements were recorded in a free-viewing condition. The classical cueing paradigm used with adults in previous studies was modified in order to be adapted to infants, who are unable to comprehend written or verbal instructions and to provide manual response. The same paradigm was

also applied to adult participants because, although the cueing effect with biological motion was already shown, only one single study recorded adults' eye movements during the cueing task (Hirai, Saunders, et al., 2011) and so far, no study adopted a free-viewing condition, in which no verbal instructions are given. As a control stimulus, the human walker was inverted by 180°. If infants are able to use the direction of walking in the biological motion stimulus as an attentional cue, the latency to make saccadic eye movements should be faster when the peripheral target appears in a location congruent with the direction of locomotion. This effect is expected to be present when the cue is upright, but not when is inverted. In experiment 2, an inanimate object (a rolling point-light circle) was adopted as a cue. This experiment was design to test whether biological motion cues have an advantage as compared to non-biological cues in directing infants' attention toward a peripheral object. If this is true, we expect no congruency effect to emerge in experiment 2.

2. Experiment 1

2.1. Method

2.1.1. Participants

Sixteen 6-month-old infants (8 girls, mean age = 186.5 days, SD = 13, range = 167–203 days) were included in the final sample. They were Caucasian healthy and full-term infants. Five additional infants were tested but excluded from the final sample for failing to complete testing due to fussiness ($n = 3$) and fewer than 4 correct trials per condition ($n = 2$). Infants were tested only if awake and in an alert state after parents gave their informed consent. A total of 18 undergraduate students were also selected from the Department of Psychology at the University of Padova to participate in the experiment (14 girls, mean age = 22 years, SD = 2, range = 20–28 years). All the adult participants had no previous experience with eye movement studies and were naive to the experimental conditions and hypotheses of the study. All of them had normal or corrected-to-normal vision. The Ethical Committee of the Department of Developmental and Social Psychology of the University of Padova approved all the experimental procedures (Protocol number: 1203).

2.1.2. Stimuli

The stimuli consisted of AVI animations and were derived from point-light sequence of a walking human. The human walker, computed as the average walker from motion-captured data of 50 men and 50 women (Troje, 2002, 2008), was depicted by a set of 11 markers representing the main joints and the head of a person. The translating component of the walk was removed such that the human displayed stationary walking. All walkers were presented in profile, facing leftward or rightward, and were shown with a gait frequency of 0.76 Hz. Stimuli were displayed on a 1024 × 768 pixel monitor. All stimuli appeared as white dots on a black background and the full point-light figure subtended visual angle of 14.9° × 6.2° (16 × 6.5 cm), the target subtended a visual angle of

$5.7^\circ \times 5.7^\circ$ (6×6 cm), and finally the distance between the center of the cue and the center of the target was of 14.5° (15.5 cm).

2.1.3. Apparatus

Adults and infants were placed at a distance of about 60 cm from a 19-in. (1024×768 pixels) computer screen where the stimuli were presented. Adults were seated in a chair, whereas infants were seated in a car seat. Parents were instructed not to interact with their children during testing. A system for the automatic registration of eye movements, made by Applied Science Laboratories (ASL), was employed and consisted of an infrared camera located at the bottom of the computer screen. The eye-tracking system automatically detected the position of the pupil and the corneal reflection of the infrared light-emitting diodes (LEDs) in the eye. Because these signals changed as a function of the observer's gaze direction, the apparatus determined, with a frequency of 50 Hz, the x - y coordinates corresponding to the participant's fixation points during stimulus presentation. Applying the ASL algorithm, a fixation was defined as a period of at least 100 ms during which the fixation point did not change by more than 1 degree of visual angle. Stimulus presentation and data collection were performed using E-Prime 2.0.

2.1.4. Procedure and design

Each participant was tested on a single occasion. Importantly, to directly compare adults' and infants' performance, no instructions were given to adults except that participants needed to watch the images appearing on the computer screen while moving their eyes freely. The experiment started with a three points calibration phase immediately followed by the test phase. During the calibration, a smiley face cartoon was presented in the center of the screen. When the infant started to look at it, the smiley face moved to the top left corner of the screen and remained in this position until the infant fixated on it. Then, it moved to the bottom right corner and remained in this position. These three positions were used to compute the pupil-corneal reflection from three points on the screen, allowing the system to derive gaze direction during test phases. The calibration's accuracy was checked and repeated if necessary. The experimental session began with the presentation of a central fixation point particularly attractive for the infant (i.e., a colored moving cartoon). It was presented at the center of the screen and was accompanied by a brief sound. This central fixation point and sound were used to attract infants' attention toward the computer screen where the stimuli were shown, and to check that the infants' gaze was aligned with the horizontal midline of the screen during the entire experimental session.

As soon as the infant looked at the central fixation point, an upright or an inverted human walker point-light display (the cue) was presented facing either to the right or to the left. The central cue was presented for 1200 ms (the time needed for a full gait cycle). The average luminance of each single dot was 4.45 cd/m^2 . The presentation of the biological motion display was followed by the presentation of a cartoon static picture (the target).

The target was presented at a location that was either congruent with the walker's facing direction (in the same direction as the walking direction of the cue, Fig. 1) or incongruent (in the opposite direction to the walking direction of the cue). The average luminance of the target was 15.3 cd/m^2 . The target remained visible until the participants looked at, and then a new trial began with the centrally presented attention-grabbing stimulus. Congruent and incongruent trials were presented at equal probabilities. The number of trials presented was 64, 32 with an upright human walker display and 32 with an inverted human walker display. In each condition half of the trials were congruent and the other half was incongruent. The order of the trials was randomized. The number of trials was identical for adults and infants.

2.2. Results

For the analysis of gaze, three square-sized areas of interest (AOI) were defined on the screen. The cue AOI covered the human walker at the center of the screen ($15.8^\circ \times 7.2^\circ$), whereas the target AOIs covered each of the targets (right or left) ($6.6^\circ \times 6.6^\circ$). The saccade latency was defined as the time interval between the target onset and the onset of the saccade from the central cue to the lateral target (in milliseconds). Saccade latencies of less than 80 ms were excluded for adults (Hirai, Saunders, et al., 2011), whereas saccade latencies of less than 100 ms were excluded for infants (Daum & Gredebäck, 2010). Trials were also excluded when the endpoint of the first saccade performed after the cue was outside of the target AOI (which was considered an incorrect trial). Infants had to perform a minimum number of four correct trials per condition to be included in the final analysis (that is, at least 16 trials). The mean number of correct trials was 39 ($SD = 11$, range: 20–60) for 6-month-old infants and 52 ($SD = 7$, range: 42–63) for adults.

A repeated-measures ANOVA on saccade latencies with Age (6-month-old infants vs. adults) as between subjects factor and Cue Orientation (upright vs. inverted) and Congruency (congruent vs. incongruent) as within subjects factors was performed. This analysis revealed a main effect of Age ($F(1, 32) = 68.9$, $p = .001$, $\eta^2 = .68$). Overall saccade latencies of infants were slower than those of adults ($M = 305 \text{ ms}$, $SE = 10$ and $M = 182 \text{ ms}$, $SE = 10$, respectively). We also found a main effect of Congruency ($F(1, 32) = 7.8$, $p < .01$, $\eta^2 = .20$). Overall saccade latencies in congruent trials were faster than in incongruent trials ($M = 238 \text{ ms}$, $SE = 7$ and $M = 249 \text{ ms}$, $SE = 8$, respectively). Most importantly, the interaction between Cue Orientation and Congruency was significant ($F(1, 32) = 20.1$, $p < .001$, $\eta^2 = .39$). The congruency effect was present only when the point-light walker was presented upright and not when the cue was presented upside-down. No other main effects or interactions were significant.

Since the main goal of the present study was to answer the question of whether 6-month-old-infants can automatically move attention on the basis of the walking direction of a point-light display, two separate ANOVAs were performed for each age group. Post-hoc comparisons on the

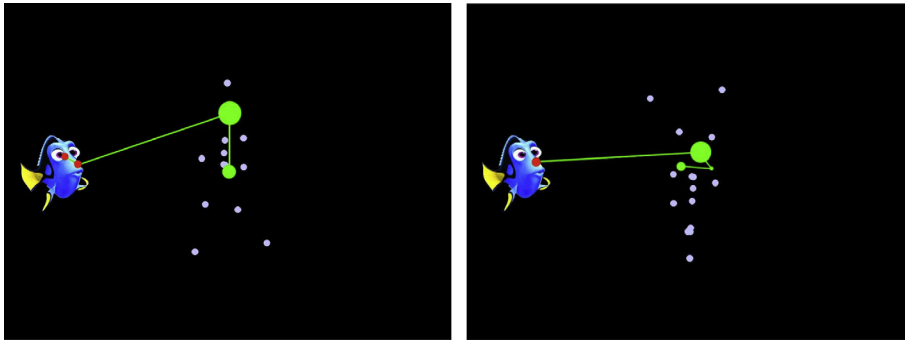


Fig. 1. Trial example from the experiment in adults. The figure represents visual fixations and eye movements from the central cue to the lateral target in one sample frame of an upright-congruent trial (left) and of an inverted-incongruent trial (right).

significant interactions were performed with Bonferroni correction.

For infants, a repeated-measure ANOVA with Cue Orientation (upright vs. inverted) and Congruency (congruent vs. incongruent) as within subjects factors was performed on saccadic latencies. The analysis did not reveal any main effect but a significant interaction between Cue Orientation and Congruency ($F(1,15) = 15.4$, $p < .001$, $\eta^2 = .51$). Post-hoc comparisons showed that when the target position was congruent with the walking direction of the human walker, infants' saccades were faster when the cue was upright ($M = 285$ ms, $SE = 15$) compared to when the cue was inverted ($M = 320$ ms, $SE = 13$), $t(15) = 3.1$, $p < .01$, $d = .76$). Moreover, when the central cue was upright, infants shifted their gaze faster to a congruent target ($M = 285$ ms, $SE = 15$) than to an incongruent target ($M = 309$ ms, $SE = 18$), $t(15) = 2.8$, $p < .014$, $d = .70$). Fourteen out of sixteen participants of our sample showed a positive difference between incongruent and congruent trials (binomial test, $p < .01$). However, this congruency effect disappeared when an inverted biological motion display was presented as a central cue (congruent target, $M = 321$ ms, $SE = 13$, incongruent target, $M = 305$ ms, $SE = 12$, $t(15) = 1.9$, n.s.). Nine subjects out of 16 showed faster saccades toward the incongruent spatial location (binomial test, $p = .80$).

For adults, the same repeated-measure ANOVA was performed. The results revealed a main effect of Congruency ($F(1,17) = 12.4$, $p < .01$, $\eta^2 = .49$) and a significant interaction between Cue Orientation and Congruency ($F(1,17) = 6.8$, $p < .05$, $\eta^2 = .29$). Post-hoc comparisons showed that when the target position was congruent with the walking direction of the human walker display, adults' saccades were faster when the cue was upright ($M = 164$ ms, $SE = 6$) compared to when the cue was inverted ($M = 182$ ms, $SE = 8$, $t(17) = 4.1$, $p < .01$, $d = 1.1$). Moreover, when the central cue was upright, adults shifted their gaze faster to a congruent target ($M = 164$ ms, $SE = 6$) than to an incongruent target ($M = 198$ ms, $SE = 11$, $t(17) = 3.5$, $p < .01$, $d = 1.2$). This was not the case when the central cue was inverted (congruent target, $M = 182$ ms, $SE = 8$, incongruent target, $M = 185$ ms, $SE = 8$, $t(17) = 0.6$, n.s.). These results revealed that a congruency

effect is present in adults when the central biological motion cue is presented upright. The effect disappears when the cue is presented upside-down (see Fig. 2).

Overall, 6-month-old infants, as well as adults, showed a congruency effect: they shifted their gaze 24 ms. faster to a congruent target compared to an incongruent one. This effect of congruency was present for the upright but not for the inverted cue.

Finally, to explore the possibility that the congruency effect obtained for the upright walker was due to asymmetrical starting point of the saccade, we performed additional analyses on the starting point of the saccade within the central cue area. In effect, the presented motion could have induced a shift of eye fixation coherently with the direction of walking that could have influenced our results. In order to discard this possibility, the mean \times coordinate

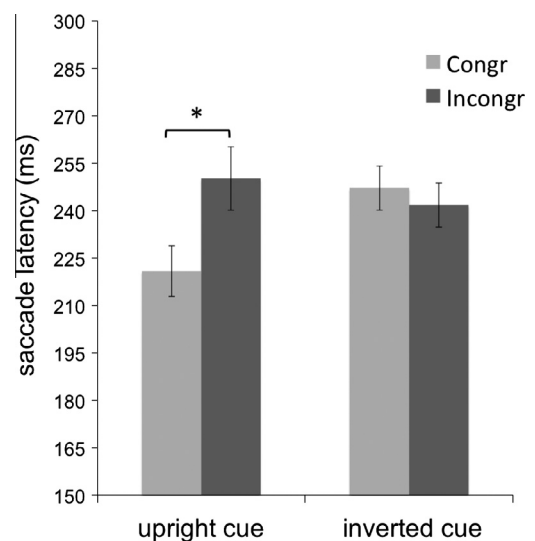


Fig. 2. Saccade latencies. Saccade latencies in congruent and incongruent trials displayed as a function of cue orientation (upright vs. inverted central cue). Data from adults and infants pooled. Saccade latencies were faster in congruent than incongruent trials ($p < 0.05$). This congruency effect was present when the cue was upright but not when the cue was inverted.

of the starting point of the saccade (the point of fixation in the horizontal axis) was submitted to an ANOVA with Cue Orientation (upright, inverted) and Cue direction (walking left, walking right) as within-subjects factors, separately for infants and adults. In adults, results revealed a significant main effect of Cue direction ($F(1,17) = 26.6, p < .05, \eta^2 = .61$) showing that the starting point of the saccade was slightly shifted (of about 3 mm within the central area) congruently with the walking direction (left, right) of the point-light display. Importantly, this effect cannot explain congruency. In effect, the same slight difference in central fixation was observed for the upright and the inverted cue. The interaction of Cue direction and Cue Orientation was far from significance ($F(1,17) = 1.6, p = .22, n.s.$). The same analysis on infants did not show any significant results being both the effect of Cue direction ($F(1,15) = 1.7, p = .21, n.s.$) and the interaction with the Cue orientation ($F(1,15) = 0.0, p = .93, n.s.$) far from significance.

An additional analysis was performed to further explore the starting point of saccades toward the target. We analyzed the starting point of the saccade along the vertical axis of the central cue area by contrasting three Areas of Interest (AOIs): top, center and bottom and we calculated the probability that the starting point of the saccade was located within one of the three AOI, separately for the upright and the inverted cue. For the upright walkers the three AOIs corresponded to the head, center, and feet areas of the body, respectively. For the inverted walker the same AOIs corresponded to the feet, center and head areas respectively.

We performed an ANOVA with AOI and Cue Orientation as within-subjects factors. In adults, results revealed only a main effect of AOI ($F(2,34) = 151.5, p < .001, \eta^2 = .89$) showing that the starting point of the saccade was more often located in the central area (76%) as compared to the top AOI (18%) and the bottom AOI (6%), irrespective of the cue orientation. No other main effects of interactions emerged. In infants, we found a main effect of AOI ($F(2,30) = 23.1, p < .001, \eta^2 = .60$). As well as for adults, the starting point of the saccade was more often located in the central area (67%) as compared to the top AOI (22%) and the bottom AOI (11%). There was also an interaction between AOI and orientation AOI ($F(2,30) = 3.7, p < .05, \eta^2 = .20$) showing that, while in the cue-upright condition, the starting point of the saccades was located significantly more often in the center (72%) as compared to the top (16%) and bottom AOI (12%), in the cue-inverted condition, no statistical difference emerges between the central (62%) and the top AOI (28%) ($t(15) = 2.5, ns$). However, the percentage of saccades starting from the top AOI did not differ from the chance level (33.3%) ($t(15) = .71, ns$). These results seem to reflect a higher variability in cue fixation in the inverted condition.

Overall, results showed that for both groups of infants and adults the upright biological motion display triggers visuo-spatial orienting. To disentangle the question of whether this effect is due to the motion conveyed by a biological agent or by motion direction *per se* a control condition with a non-biological motion of an inanimate object was carried out in Experiment 2.

3. Experiment 2

3.1. Method

3.1.1. Participants

Twelve 6-month-old infants (8 girls, mean age = 176 days, $SD = 9$, range 167–203 days) were included in the final sample. They were Caucasian healthy and full-term infants. Infants were tested only if awake and in an alert state after parents gave their informed consent. A total of 15 undergraduate students were also selected from the Department of Psychology at the University of Padova to participate in the experiment (14 girls, mean age = 22 years, $SD = 3$, range 19–28). All the adult participants had no previous experience with eye movement studies and were naive to the experimental conditions and hypotheses of the study. All of them had normal or corrected-to-normal vision. The Ethical Committee of the Department of Developmental and Social Psychology of the University of Padova approved all the experimental procedures (Protocol number: 1203).

3.1.2. Stimuli

Stimuli consisted of an animation of a rotating point-light circle (rotating clockwise or counter-clockwise). A line was drawn at the bottom or the top of the circle trajectory to depict a flat floor or ceiling that determined the frame of reference. As a result, the circle looked like moving toward the left or right on the floor or the ceiling, similar to the percept of the point-light walker (Shi et al., 2010). The frequency of rotation was controlled so that it was similar to the walking cycle in experiment 1. In experiment 1, the walking cycle, entailing two steps, lasted 1200 ms. Similarly the single dot in this experiment performed two rotations in 1200 ms with a constant speed.

Stimuli were displayed on a 1024×768 pixel monitor. All stimuli appeared as a white dot on a black background and the full dot trajectory subtended a visual angle of $8.5^\circ \times 8.5^\circ$ (9×9 cm), the target subtended a visual angle of $5.7^\circ \times 5.7^\circ$ (6×6 cm), and finally the distance between the center of the cue and the center of the target was of 14.5° (15.5 cm).

3.1.3. Apparatus

The apparatus, procedure and design were identical to that of experiment 1.

3.2. Results

For the analysis of gaze, three square-sized areas of interest (AOI) were defined on the screen. The cue AOI covered rolling point-light circle center of the screen ($8.5^\circ \times 8.5^\circ$) whereas the target AOIs covered each of the targets (right or left) ($6.6^\circ \times 6.6^\circ$). For the analyses of saccade latency, the same criteria adopted in experiment 1, were used for experiment 2. Infants had to perform a minimum number of four correct trials per condition to be included in the final analysis (that is, at least 16 trials). The mean number of correct trials was 49 ($SD = 5$, range:

43–57) for 6-month-old infants and 54 ($SD = 5$, range: 46–62) for adults.

A repeated-measures ANOVA on saccade latencies with Age (6-month-old infants vs. adults) as between subjects factor and Cue Orientation (upright vs. inverted) and Congruency (congruent vs. incongruent) as within subjects factors was performed. The analysis revealed a main effect of Age ($F(1,25) = 26.9$, $p < .001$, $\eta^2 = .52$) being mean saccade latency slower in infants ($M = 254$ ms, $ES = 9$) than in adults ($M = 193$ ms, $ES = 8$). More importantly there was a significant interaction of Age and Congruency ($F(1,25) = 8.2$, $p < .01$, $\eta^2 = .25$). Here, adult participants showed a significant congruency effect ($t(14) = 2.8$, $p < .01$, $d = .71$) being saccade latencies in the congruent condition faster than saccades in the incongruent condition ($M = 188$ ms, $ES = 9$ and $M = 196$ ms, $ES = 7$, respectively). On the contrary, no difference between congruent and incongruent trials ($M = 259$ ms, $ES = 10$ and $M = 250$ ms, $ES = 8$) was found in infants ($t(11) = 1.6$, $p = .13$, ns).

A separate ANOVA conducted on infants confirms no significant main effect of Congruency ($F(1,11) = 2.16$, $p = .13$, ns.). No other main effects or interactions were found. An ANOVA conducted on adults confirmed a significant main effect of Congruency ($F(1,14) = 8.1$, $p < .05$, $\eta^2 = .36$).

Overall the results demonstrate that the motion of an inanimate object triggers visuo-spatial attention in adults. However, the same effect is not present in 6-month-old infants.

4. Discussion

Walking direction is one of the most salient features contained in biological motion. Here we provided evidence that the walking direction of a point-light walker triggers automatic orienting of visuo-spatial attention in adults and 6-month-old infants as well as in adults. Results revealed that both adult and infants shifted their gaze faster toward a target that appeared at the location congruent with the direction of the previously presented point-light walker compared to a target appearing in the opposite, and incongruent, location. Critically, the orienting effect disappeared when the point-light walker was shown upside-down.

These results support the view that the obtained cueing effect is due to the extraction of information about the walking direction of a biological agent, which is disrupted when the display is presented upside-down (Hirai, Saunders, et al., 2011; Kuhlmeier, Troje, & Lee, 2010). Further, our results revealed that the inversion effect in biological motion perception, a phenomenon already shown in newborns and infants younger than 6 months, through spontaneous preference and habituation procedures (Bertenthal et al., 1984, 1987; Fox & McDaniel, 1982; Kuhlmeier et al., 2010; Simion et al., 2008), also emerges in more complex tasks. Specifically, we provide the first evidence that biological motion has a similar effect on overt attention in infants, as visual stimuli based on eye

gaze (Farroni et al., 2000; Hood et al., 1998) and hand grasping (Daum & Gredebäck, 2010).

Experiment 2 revealed that adult observers orient their attention according to the motion of an inanimate object (a rolling point-light circle) when saccade latencies are measured so that they manifest a congruency effect. In contrast, no congruency effect was found in infants. This result suggests that, during development, biological motion may have an advantage as compared to inanimate objects in triggering spatial attention. Our outcome is in line with data from a recent study (Wronski & Daum, 2014). In that study, both 5 and 7 month-old infants were shown to orient their attention according to a hand movement (grasping). However, only older infants showed a similar effect when the hand was replaced by an inanimate object (a square moving along the same motion trajectory performed by the hand). Moreover, no consistent orientation was observed in the group of older infants when a linear translating motion of a square represented the cue. Although more studies are needed to explore whether and how non-social cue can guide infants' attention, these outcomes suggest a different developmental trajectory for social and non-social cues.

The fact that adults can use the rolling point-light circle as cue for attention is not in line with what was found by Shi et al. (2010), who reported increased accuracy in the discrimination of a target when the stimulus was preceded by a human walker but not when the target was preceded by the rolling point-light circle. The inconsistency of the present results with the data from Shi and colleagues can be explained by differences in the task procedure and in the dependent variable selected. In the present study, saccade latencies to the peripheral target have been analyzed, while in the work by Shi and colleagues, participants were instructed to maintain fixation in the center of the screen and accuracy of hand responses to peripheral targets was measured. Second, and perhaps more important, our task entailed a longer presentation time of the cue, which remained on the screen for 1200 ms, rather than 500 ms. It is important to note that the direction of a rolling point-light circle is *per se* ambiguous, unless additional information is presented. In the present study, as in the work of Shi and colleagues, a reference frame was provided to retrieve direction, that is a line representing the floor or the ceiling. It is conceivable that a longer presentation time in our procedure allowed participants to better (unambiguously) interpret the direction of the motion on the basis of the given reference frame. This interpretation might also explain the different results between adults and infants. Adults might be able to process the movement of the rolling point-light circle as unambiguous, whereas infants might be unable to do the same. Further studies should explore this latter interpretation by contrasting biological motion with other types of motion of inanimate objects.

Overall, results of experiment 1 and 2 indicate that infants process biological and non-biological motion in a different way and that the two types of motion differently affect orienting of attention. Only the kinematic present in the biological motion display can trigger automatic orienting in 6 month-old infants. The analyses, carried out in

Experiment 1 on the starting position of the saccade within the central cue area, allow us to discard the hypothesis that the congruency effect was due to the slightly shifted eye position of infants when the target appears.

The results obtained in 6-month-old infants introduce our research into the recent debate concerning the role of local and global information in biological motion perception. Our analysis of the starting point of saccades did not provide sufficient information as to establish which portion of the biological motion stimulus (e.g., the head or the feet area) played a critical role in producing visuo-spatial orienting because of the larger portion of saccades originated from the central area of the display. In addition, it is important to note that the time of presentation of the cue probably precludes a good description of display observation that a different paradigm (e.g., preferential looking) may allow. Future experiments should determine whether infants use local or global information as a directional cue in the biological motion stimulus by presenting them with different cues (e.g., only the feet of the walker) or scrambled biological motion displays

This question has recently been addressed in adults, revealing a superiority of the local motion in direction discrimination and visual orienting (Hirai, Chang, et al., 2011). It has been hypothesized that the visual mechanism that retrieves animacy and walking direction from biological motion primarily responds to local information (Chang & Troje, 2008, 2009a; 2009b), specifically to the motion of the feet. Whether a dot is evaluated in terms of directional cues depends on validating features, which do not themselves contain directional information. Hirai, Saunders, et al. (2011) showed that if the vertical location of the dots representing the feet and their local vertical orientation were consistent with location and trajectory orientation of human feet, then directional information from local motion was sufficient to generate a sense of directionality, which was at least as strong as the directional information that can be obtained from structural information, that is, from the motion-mediated shape of the human body.

Responses to direction in biological motion seem to be present already in infants and it is very likely that they are also based on local information rather than on the ability to retrieve motion-mediated shape (Bardi, Regolin, & Simion, 2014; Bardi et al., 2011). In neonates, the same mechanism might trigger attention toward people and animals, a class of stimuli the developing organism has to learn so much about (Johnson, 2006; Troje & Westhoff, 2006). In order to further explore this idea, we should test whether few month-old infants use local (the motion of single dots) or global (the left–right orientation of the body) to retrieve walking direction from biological motion and whether the same assumptions about location and orientation of local trajectories that control perception in the fully developed visual system are already functional in infants.

References

Bardi, L., Regolin, L., & Simion, F. (2011). Biological motion preference in humans at birth: Role of dynamic and configural properties. *Developmental Science*, 14, 353–359.

- Bardi, L., Regolin, L., & Simion, F. (2014). The first time ever I saw your feet: Inversion effect in newborns' sensitivity to biological motion. *Developmental Psychology*, 50, 986–993.
- Bertenthal, B. L., Proffitt, D. R., & Cutting, J. E. (1984). Infant sensitivity to figural coherence in biomechanical motions. *Journal of Experimental Child Psychology*, 37, 213–230.
- Bertenthal, B. L., Proffitt, D., & Kramer, S. (1987). Perception of biomechanical motions by infants: Implementation of various processing constraints. *Journal of Experimental Psychology: Human Perception and Performance*, 4, 577–585.
- Bosbach, S., Prinz, W., & Kerzel, D. (2004). A Simon effect with stationary moving stimuli. *Journal of Experimental Psychology: Human Perception and Performance*, 30, 39–55.
- Calleias, A., Shuman, G. L., & Corbetta, M. (2014). Dorsal and ventral attention systems underlie social and symbolic cueing. *Journal of Cognitive Neuroscience*, 26, 63–80.
- Chang, D. H. F., & Troje, N. F. (2008). Perception of animacy and direction from local biological motion signals. *Journal of Vision*, 8, 1–10.
- Chang, D. H. F., & Troje, N. F. (2009). Characterizing global and local mechanisms in biological motion perception. *Journal of Vision*, 9, 1–10.
- Daum, M. M., & Gredebäck, G. (2010). The development of grasping comprehension in infancy: Covert shifts of attention caused by referential actions. *Experimental Brain Research*, 208, 297–307.
- Deaner, R. O., & Platt, M. L. (2003). Reflexive social attention in monkeys and humans. *Current Biology*, 13, 1609–1613.
- Dittrich, W. H. (1993). Action categories and recognition of biological motion. *Perception*, 22, 15–23.
- Dittrich, W. H., Troscianko, T., Lea, S. E. G., & Morgan, D. (1996). Perception of emotion from dynamic point-light displays represented in dance. *Perception*, 25, 727–738.
- Driver, J., Davis, G., Ricciardelli, P., Kidd, P., Maxwell, E., & Baron-Cohen, S. (1999). Gaze perception triggers visuospatial orienting by adults in a reflexive manner. *Visual Cognition*, 6, 509–540.
- Farroni, T., Johnson, M. H., Brockbank, M., & Simion, F. (2000). Infants' use of gaze direction to cue attention: The importance of perceived motion. *Visual Cognition*, 7, 705–718.
- Farroni, T., Massaccesi, S., Povidori, D., & Johnson, M. H. (2004). Gaze following in newborns. *Infancy*, 5, 39–60.
- Fox, R., & McDaniel, C. (1982). The perception of biological motion by human infants. *Science*, 218, 486–488.
- Friesen, C. K., & Kingstone, A. (1998). The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. *Psychonomic Bulletin & Review*, 5, 490–495.
- Friesen Ristic & Kingstone (2004). Attentional effects of counter predictive gaze and arrow cues. *Journal of Experimental Psychology: Human Perception and Performance*, 30, 319–329.
- Greene, D. J., Mooshagian, E., Kaplan, J. T., Zaidel, E., & Iacoboni, M. (2009). The neural correlates of social attention: Automatic orienting to social and nonsocial cues. *Psychological Research*, 73, 591–511.
- Hietanen, J. K., Nummenmaa, L., Nyman, M., Parkkola, R., & Hämäläinen, H. (2006). Automatic attention orienting by social and symbolic cues activates neural networks: An fMRI study. *Neuroimage*, 33, 406–413.
- Hirai, M., Chang, D., Saunders, D. R., & Troje, N. (2011). Body configuration modulates the usage of local cues to direction in biological motion perception. *Psychological Science*, 22, 1543–1549.
- Hirai, M., Saunders, D. R., & Troje, N. F. (2011). Allocation of attention to biological motion: Local motion dominates global shape. *Journal of Vision*, 7, 1–11.
- Hood, B. M., Willen, J. D., & Driver, J. (1998). Adult's eyes trigger shifts of visual attention in human infant. *Psychological Science*, 9, 53–56.
- Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception and Psychophysics*, 14, 201–211.
- Johnson, M. H. (2006). Biological motion: A perceptual life detector? *Current Biology*, 16(10), R376–R377.
- Kingstone, A., Tipper, C., Ristic, J., & Ngan, E. (2004). The eyes have it. An fMRI investigation. *Brain and Cognition*, 55, 269–271.
- Kuhlmeier, V. A., Troje, N. F., & Lee, V. (2010). Young infants detect the direction of biological motion in point-light displays. *Infancy*, 15, 83–93.
- Langdon, S. R. H., & Bruce, V. (1999). Spatial cueing by social versus non social directional signals. *Visual Cognition*, 12, 1497–1527.
- Langdon, R., & Smith, P. (2005). Reflexive visual orienting in response to the social attention of others. *Cognition*, 6, 541–567.
- Lockhofen, D. L. F., Gruppe, H., Rupprecht, C., Gallhofer, B., & Sammer, G. (2014). Hemodynamic response pattern of spatial cueing is different for social and symbolic cues. *Frontiers in Human Neuroscience*, 8, 912.
- Posner, M. I. (1978). *Chronometric explorations of mind* (Hillsdale, NJ: Erlbaum).

- Ricciardelli, P., Bricolo, E., Aglioti, S. M., & Chelazzi, L. (2002). My eyes want to look where your eyes are looking: Exploring the tendency to imitate another individual's gaze. *Neuroreport*, 3, 2259–2264.
- Shi, J., Weng, X., He, S., & Jiang, Y. (2010). Biological motion cues trigger reflexive attentional orienting. *Cognition*, 117, 348–354.
- Simion, F., Regolin, L., & Bulf, H. (2008). A predisposition for biological motion in the newborn baby. *Proceedings of the National Academy of Science USA*, 15, 809–813.
- Sumi, S. (1984). Upside-down presentation of the Johansson moving light-spot pattern. *Perception*, 13, 283–286.
- Troje, N. F. (2002). Decomposing biological motion: A framework for analysis and synthesis of human gait patterns. *Journal of Vision*, 2, 371–387.
- Troje, N. F. (2008). Retrieving information from human movement patterns. In T. F. Shipley & J. M. Zacks (Eds.), *Understanding events: How humans see, represent, and act on events* (pp. 308–334). Oxford, England: Oxford University Press.
- Troje, N. F., & Westhoff, C. (2006). The inversion effect in biological motion perception: Evidence for a "life detector". *Current Biology*, 16, 821–824.
- Vallortigara, G., & Regolin, L. (2006). Gravity bias in the interpretation of biological motion by inexperienced chicks. *Current Biology*, 16, 279–280.
- Vallortigara, G., Regolin, L., & Marconato, F. (2005). Visually inexperienced chicks exhibit spontaneous preference for biological motion patterns. *PLoS Biology*, 3, 1312–1316.
- Wronski, C., & Daum, M. M. (2014). Spatial orienting following dynamic cues in infancy: Grasping hands versus inanimate objects. *Developmental Psychology*, 50, 2020–2029.
- Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology*, 81, 141–145.