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Young infants detect the direction of biological motion in point-light displays

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In the present study, we examined if young infants can extract information regarding the directionality of biological motion. We report that 6-month-old infants can differentiate leftward and rightward motion from a movie depicting the sagittal view of an upright human point-light walker, walking as if on a treadmill. Inversion of the stimuli resulted in no detection of directionality. These findings suggest that biological motion displays convey information for young infants beyond that which distinguishes them from non-biological motion; aspects of the action itself are also detected. The potential visual mechanisms underlying biological motion detection, as well as the behavioral interpretations of point-light figures, are discussed.

The movements of animate agents offer an abundance of information to the adult human observer; we can extract information regarding species classification, gender, attractiveness, and emotion from animate motion. Intriguingly, we do so even when the motion is depicted in simple point-light displays conveying the movement of the major joints of the body in the absence of key morphological features (e.g., faces, skin, hair) (e.g., Barclay, Cutting, & Kozlowski, 1978; Bertenthal & Pinto, 1994; Dittrich, Troscianko, Lea, & Morgan, 1996; Johansson, 1973, 1976; Mather & West, 1993; Troje, 2002; Troje & Westhoff, 2006). The perception is robust, surviving heavy masking relatively well (Cutting, Moore, & Morrison, 1988), and so fast that fewer than 200 ms of motion is sufficient to identify a point-light human walker (Johansson, 1976).

The efficiency of this ability, coupled with its ubiquity, has suggested to researchers that the detection of biological motion is a fundamental perceptual process that is part of an early-developing and evolutionarily-endowed mechanism shared across species. As such, there has been an interest in examining biological motion perception from a developmental perspective. Early, seminal work in this area demonstrated that by 4 months of age, infants distinguish upright from inverted human point-light walkers (e.g., Bertenthal, Proffitt, & Cutting, 1984) and show a preference to attend to the former (Fox & McDaniel, 1982), suggesting that infants detect biological motion in upright point-light walkers, and like adults (e.g., Sumi, 1984; Pavlova & Sokolov, 2000), demonstrate an inversion effect with this type of display. A more recent replication and extension of this work has shown that infants as young as 2-days-old differentiate between biological and random motion point-light displays and look longer at biological motion, even when the displays depict non-human animate motion (i.e., that of a chick; Simion, Regolin, & Bulf, 2008). This ability to recognize and preferentially attend to the motion of biological entities, even when presented in its most rudimentary form, has been hypothesized to underlie developing social cognition (e.g., Troje & Westhoff, 2006; Yoon & Johnson, in press).

The majority of research in this field has focused on the visual mechanisms in infants and adults that underlie the perception of biological motion, although to date, their exact nature is not agreed upon. Theories range from those that emphasize the role of local motion (e.g., Mather, Radford, & West, 1992) to those suggesting the importance of global processing (e.g., Bertenthal & Pinto, 1994; Bertenthal, Proffitt, & Kramer, 1987). Others have recently taken a multi-level approach, suggesting that in addition to global form processing, there exists a general detection system that attends to the type of gravity-influenced, ballistic-velocity profile present in the motion of, for example, ankles, effectively signaling terrestrial, articulated animate entities and supporting further learning which may support global form processing (Chang & Troje, 2008; Simion et al., 2008; Troje & Westhoff, 2006).

Little is known, however, about how (or whether) human infants interpret the actual motion within point-light displays of biological motion. That is, biological motion is evidently salient, distinguishable, and possibly privileged compared to other types of motion, but the interpretation of the motion depicted remains relatively unexamined. To be clear, this is not a question of whether infants appreciate the 'meaning' of the entity that is depicted in the point-light display (e.g., as a human or chick; see Proffitt & Bertenthal, 1990, for a summary of relevant work). Instead, this is a question of whether the infant can extract any information about the motion on top of that which sets it apart from nonbiological motion. In one study that has recently taken this approach, Yoon and Johnson (in press) have shown that by 12 months, infants will follow the "gaze" of a point-light actor, suggesting that at this age they may interpret the actions conveyed via point-light display of biological motion within a psychological, social construal, perhaps the same construal engaged by actual human actors or nonhuman entities imbued with cues to animacy and agency such as faces or contingent reactivity (Johnson, Slaughter, & Carey, 1998).

Another existing study that addresses this question examined an action that need not engage a psychological construal, yet also suggests that information regarding the action depicted via biological motion displays is available to infants. Specifically, in a study with the ultimate goal of examining the mechanisms of biological motion perception, it was found that by 3 months, infants distinguish between point-light displays of walking and running (Booth, Pinto, & Bertenthal, 2002). The present study expands this body of research by examining 6-month-old infants' ability to detect information inherent to the direction the walker is moving. Specifically, using a habituation, looking-time paradigm, we tested whether young infants differentiate between leftward and rightward walking of a human point-light figure, even when the figure is not actually horizontally translating (i.e., the walker appears to be on a treadmill). Presumably, the distinction between rightward and leftward walkers in our procedure could be the result of an entirely non-specific novelty effect carried by any kind of low-level difference between the two stimuli. If this were the case, we would expect to observe a similar pattern with inverted point-light displays. In contrast, if the distinction is specific to biological motion and its directionality, we would expect that inversion would eliminate or at least greatly reduce the ability to differentiate. Thus, we tested groups of infants in two conditions, one in which the walkers were upright and one in which they were inverted.

Method

Participants. We tested 40 infants recruited from Kingston, Ontario, Canada, and the surrounding region. Half of the infants participated in the Upright Condition (10 male, 10 female; mean age 6 months 1 day; range 4 months 7 days to 6 months 23 days). In this condition, seven additional infants were tested, but not included in analysis due to fussiness (2), not reaching the habituation criteria described below (1), or experimenter error (4). The other 20 infants were tested in the Inverted Condition (9 male, 11 female; mean age 6 months 2 days; range 5 months 7 days to 6 months 20 days). Thirteen additional infants were tested in this condition, but not included in analysis due to fussiness (9) and failure to reach habituation criteria (4).

Procedure and Stimuli. Infants sat in a baby seat positioned 84cm from a computer monitor (40.6cm x 30.5cm) that displayed video movies. During habituation, infants in the Upright Condition were repeatedly shown a movie depicting a sagittal view of an upright human point-light walker consisting of 11 light points. The walker moved as if on a treadmill; that is, there was no horizontal translation across the ground (Figure 1; also see Troje, 2002, for a description of the creation of the walker). Half of the infants in the Upright Condition (n=10) were habituated to a depiction of an upright, leftward walker, and the other half were habituated to an upright, rightward walker.

On each trial during the habituation phase, a movie sequence with a 3s display of the point-light walker followed by a 1s blank blue screen was played on a loop until the infant looked away from the monitor for 2 consecutive seconds or if 90 s elapsed. A bell ring was used to signal the beginning of a trial, which helped bring the infants' attention back to the screen. Habituation criterion was defined as three consecutive trials with summed looking time less than or equal to 50% of the sum of the looking times on the first 3 trials (e.g., Cohen, 2004). Infants were presented with a minimum of 6 and a maximum of 14 habituation trials.

To test infants' detection of facing direction of the point-light walkers, we presented them with two test movies after habituation, one movie depicted the rightward walker and the other the leftward walker (Figure 1). The two movies were presented with order counterbalanced across participants. If infants are sensitive to the directionality of point-light walkers, then those habituated to one direction of motion should find point-light walkers moving in the opposite direction unexpected, and look longer at the novel movie. In contrast, if infants cannot detect the directionality of the point-light walkers, no looking time difference should be obtained.

For the 20 infants in the Inverted Condition, all procedures remained the same. The movies, however, depicted upside-down rightward and leftward walkers created by simply inverting the upright walker movies within a digital video editing software package (Figure 2). In this way, the four movies used across the two conditions were equal in duration and image size.

Preliminary Data Analyses. To be included in the analysis, infants had to meet the criterion for habituation. Looking time on each trial was measured online by an observer hidden behind a curtain and unaware of the infant's habituation group. A second experimenter, also naïve to the infant's condition and habituation group, measured looking time during the experiment from a live video image. For both conditions, the correlation between the two experimenters was high (Upright Condition: Mean r = .91; Inverted Condition: Mean r = .92). Preliminary analyses of variance (ANOVA's) on looking time revealed no main effects of gender or test trial order (Right Walker first or Left Walker first), and no significant interactions between these variables. For this reason, subsequent analyses collapse data across these variables.

Results

Habituation. Infants participating in the Upright Condition required a mean of 7.00 (SD = 2.13) trials to reach habituation. The mean looking time on the first three trials was 51.29s (SD = 22.45), and decreased to a mean of 14.05s (SD = 9.04) on the last three trials. Looking time patterns were similar in the Inverted Condition; infants required a mean of 6.65 (SD =1.27) trials to reach habituation, and the mean looking time on the first three trials was 34.72s (SD = 23.42), decreasing to a mean of 10.34s (SD = 8.20) on the last three trials.

Test. Infants looking times during test trials were analyzed by a 2 x 2 repeated measures ANOVA with condition (Upright or Inverted) as a between-subjects factor and test trial type (Novel or Familiar) as a within-subjects factor. To create this latter factor, leftward motion movies were considered to be novel and rightward motion movies familiar for infants who were habituated to the rightward walker, with the opposite true for infants who were habituated to the leftward walker. The analysis yielded a significant condition by test trial type interaction, $F(1, 38) = 4.32$, $p = .04$, eta-squared = .10 (Figure 3). Simple effects analyses indicated that in the Upright condition, infants looked longer at the novel test movie (M = 14.07s, SD = 1.92) than the familiar test movie (M = 7.64s, SD = 1.88), $F(1, 19) = 8.40$, $p = .01$. In the Inverted condition, however, infants showed similar looking time to the novel test movie (M = 8.91s, SD = 1.92) and the familiar test movie (M = 9.79, SD = 1.88), $F(1, 19) = .10$, $p = .75$.

Nonparametric, binomial analyses performed for each condition provided converging results. Fifteen of the 20 infants in the Upright Condition showed a looking time preference to the novel movie over the familiar movie in test (p =. 02). In the Inverted Condition, 12 of the 20 infants looked longer at the novel walker in test ($p = .25$).

Thus, the detection of directionality appears to be specific to upright, canonical point-light walkers. However, since previous studies have found increased looking to point-light displays of upright human walkers over inverted walkers at 4 months of age (Fox & McDaniel, 1982) and upright walking point-light chicks over inverted (Simion et al., 2008), there may be concern that infants in the Upright Condition may have simply attended more to the movies, resulting in recognition of a change in novel test displays. Much of this concern can be assuaged by the use of the habituation paradigm. Only infants who habituated, and thus encoded, the stimuli were considered in the analyses in both conditions. To further address this issue, we also considered two other measures. First, as noted above, the number of trials required to reach habituation criteria was similar for both conditions. Second, as a means of examining initial interest in the displays, independent of experience across multiple trials, we examined looking time during the first trial of the habituation phase. The two conditions did not differ, $t(38)=1.67$, $p=.10$ (Upright Condition: $M = 67.60$ s, $SD = 27.00$; Inverted Condition: $M = 52.94$ s, $SD = 28.49$)[2].

Discussion

The present study suggests that young infants detect information regarding the direction a point-light walker is moving from intrinsic cues alone, that is, even when no actual translation is occurring. Furthermore, detection of directionality is subject to an inversion effect; infants did not discriminate the walkers when they were presented upside-down. It is important to note that the lack of a looking time difference to the novel and familiar test movies in the Inverted Condition does not mean that infants would never be able to distinguish between rightward and leftward inverted displays. There are just as many local and configural differences between these displays as between leftward and rightward upright displays, and if these differences were in some way made more obvious to the infant observers during habituation, looking time differences in test may indeed be obtained. What is implied by the present findings is that directional changes are more salient when conveyed with displays of upright, canonical walkers.

How, then, might infants be noticing the change in direction in the upright displays? At least two possibilities exist. By one account, infants may derive from the moving point-light displays the overall global form of the upright walker--but not of the inverted walker (see Proffitt

[2] This finding does not necessarily contradict the earlier results of Fox & McDaniel (1982) because in that study, the upright and inverted stimuli were presented side-by-side, creating a "forced-choice" situation for the infants. In the present study, infants were not presented with such a choice; stimuli were presented individually, with condition as a between subjects factor.

& Bertenthal, 1990)--and *additionally* detect the differences between configurations that are inherent to rightward and leftward walking (e.g., in rightward walkers, the knees point to the right and the elbows to the left). The differences are not detected in inverted walkers because the first step of recognizing a coherent, familiar form of a walker simply does not occur. This distinction between configurations inherent to rightward and leftward walking can alone explain the findings of the present study. Yet, it may also be the case that infants (like adults) derive from these configurations information about the actual "front" or "facing direction" of the walker, such that, for example, infants might expect translation to occur in a particular direction.

By the other account, infants may be using the local motion of individual point-light dots to derive information related to direction. Such a mechanism has been suggested by Troje & Westhoff (2006), and it was shown in their experiments that for adult observers, the local motion of the feet in particular contains salient cues to the direction of a walker. Indeed, recent work with neonates (Simion et al., 2008) has suggested that infants are sensitive to local motion cues such as these, showing increased attention to displays in which they were present. Thus, the pattern of this local motion, given its ballistic, gravity-based velocity characteristics, may also provide information to infants regarding the direction of motion, independent of configural information. The observed inversion effect in the present study would then be due to the specificity of the underlying visual filter for this local motion, which matches the orientation specificity of gravitational forces defining the ballistic movement of the feet (Chang & Troje, 2008).

Separate from questions regarding the possible mechanisms by which infants detect information relative to direction in point-light walkers, a second set of questions remains as to how infants construe the display. The present study cannot directly address whether the display contains psychological information (e.g., goals, intentions, emotion, attention, etc.) for the infant. For example, adults might construe a point-light human walker, or other point-light biological entity as depicting an intentional entity having a goal (e.g., to move to the left or right). By at least 6 months, infants attribute goals to the actions of many types of nonhuman entities including boxes and computer-animated geometric figures that convey one or more behavioural cues such as self-propulsion (Luo & Baillargeon, 2005), the ability to vary an approach path (Csibra, 2008), and contingent reactivity (Shimizu & Johnson, 2004). It is possible that point-light walkers are classified in a similar manner to these types of agents, such that in an appropriate scene, infants at this age may, for example, attribute a goal to the action. Alternatively, 6-month-olds may not yet engage in a psychological construal of point light figures, yet the ability demonstrated here may help to form the foundation for one. In either case, biological motion displays appear to convey more information for infants than that which classifies it as ‘biological’. Our results suggest that aspects of the action itself are being detected.

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Figure Captions

1. Movie stimuli used in the Upright Condition presented as a series of static frames. Infants were habituated to either leftward or rightward walking. In test trials, all infants observed both directions of walking.
2. Movie stimuli used in the Inverted Condition presented as a series of static frames. All procedures remained otherwise identical to the Upright Condition.
3. Looking time (with standard error bars) to test movies (coded as ‘Novel’ or ‘Familiar’) for each condition. An asterisk (*) denotes significance at $p < .05$.

Figure 1

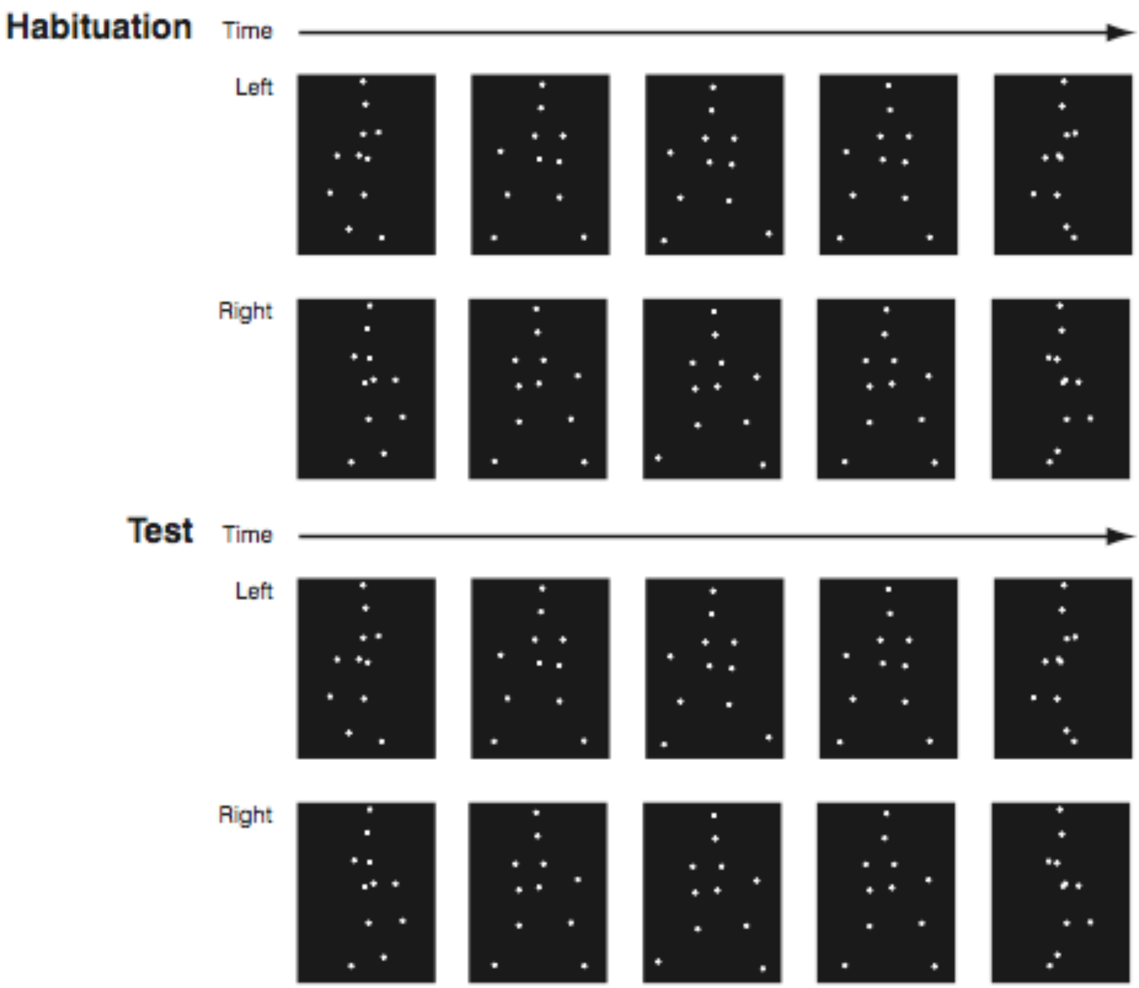


Figure 2

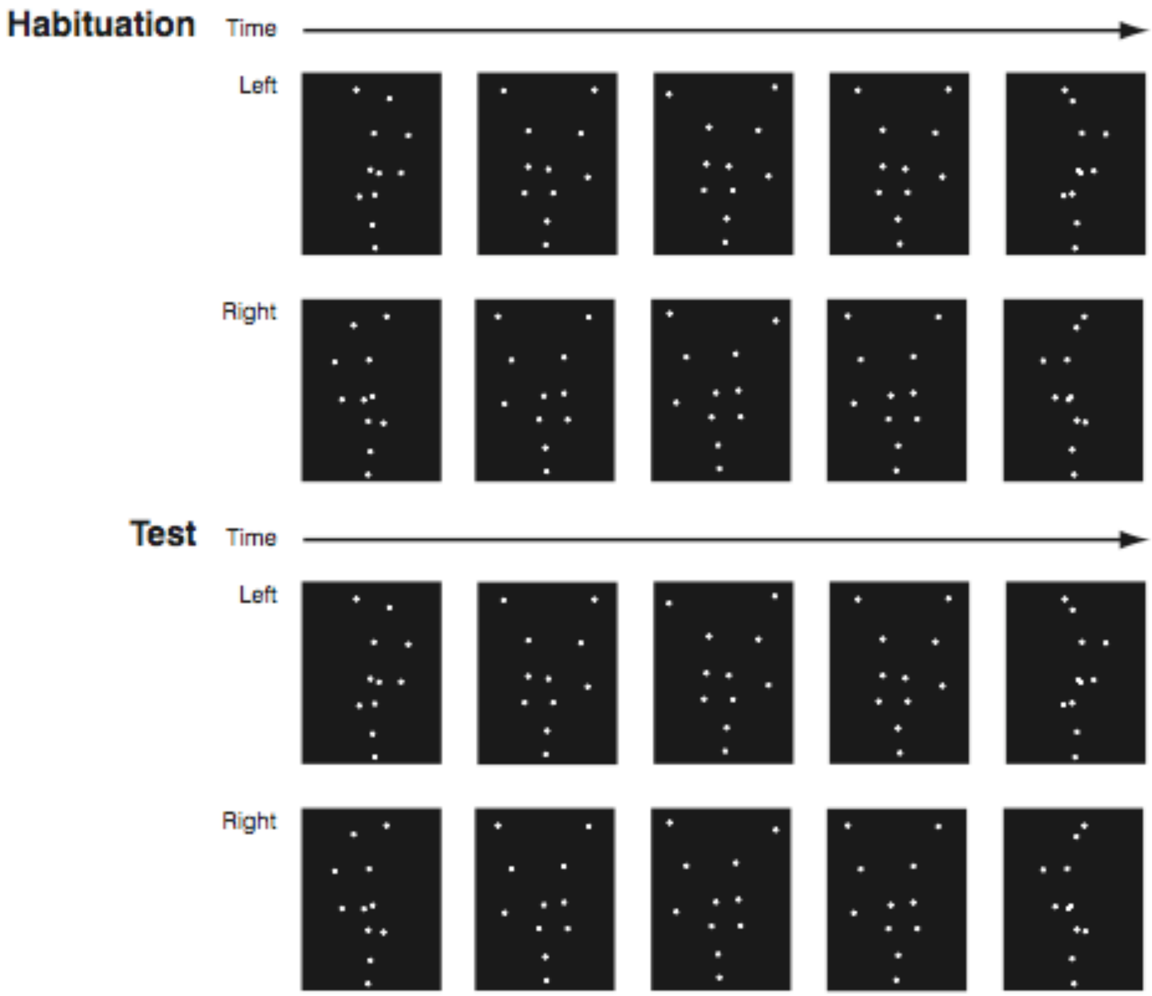
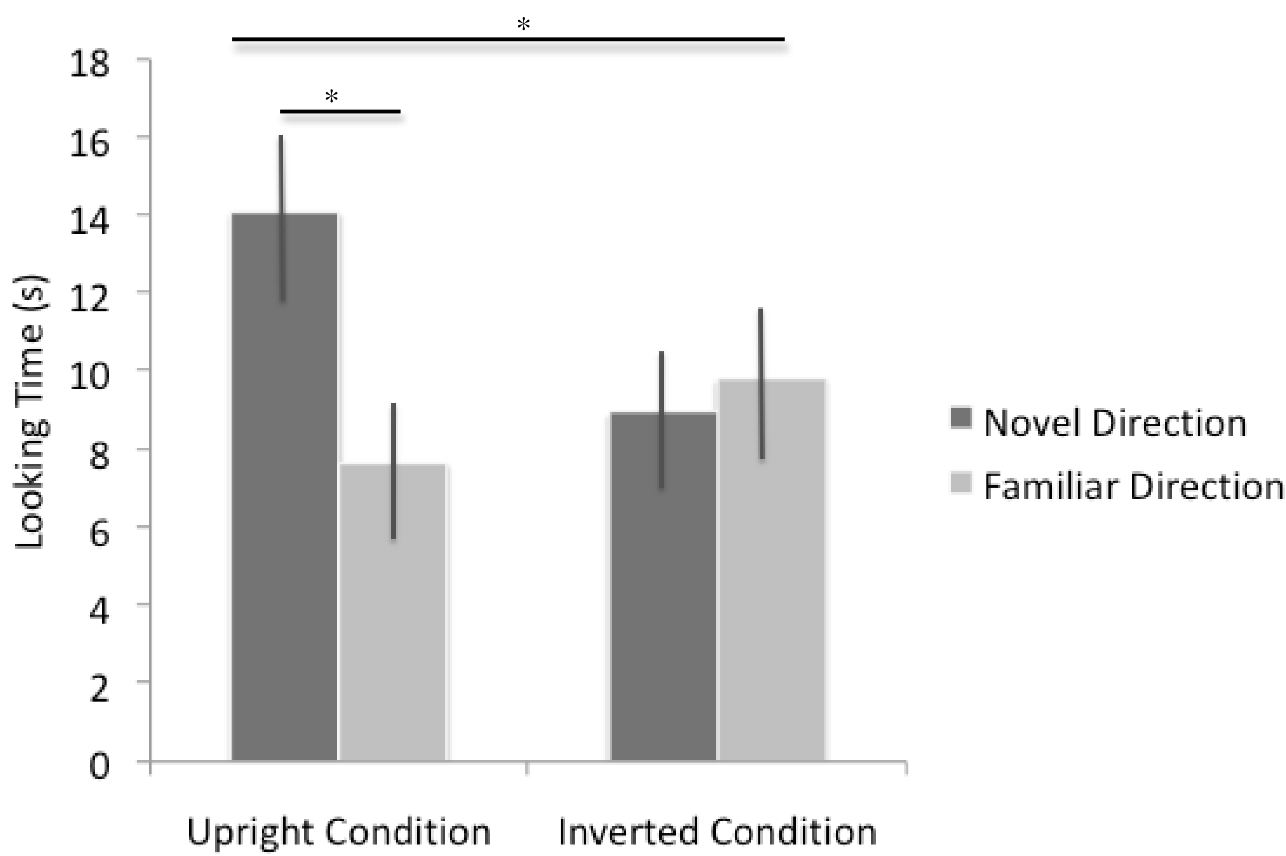


Figure 3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Looking Time (s)
Upright Condition
Inverted Condition
Novel Direction
Familiar Direction