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Prior Action Direction of a Novel Agent Cues Spatial Attention in 7-Month-Old Infants

RESEARCH

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ABSTRACT

The present study investigated whether 7-month-old infants attribute directionality to an object after having observed it engage in agentive behavior and whether they maintain this attribution even when the agent is presented statically. Infants were familiarized with an object displaying either agentive behavioral cues (self-propelled, context-sensitive movement) or non-agentive motion (the same movement pattern caused by external factors). In a subsequent spatial-cueing procedure, the agent was displayed statically at the center of the screen. Gaze latencies were assessed for targets appearing at a location congruent or incongruent with the position of the agent's formerly leading end. Only infants that had observed the object move in an agentive manner showed shorter gaze latencies for congruent compared to incongruent targets, suggesting facilitation of attention toward a location congruent with the agent's prior action direction. Results provide evidence that infants attribute directionality to novel agents based on behavioral agency cues, that this directional representation is maintained even when the agent is stationary, and that it guides infants' covert attention.

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KEYWORDS:

agency; self-propelled movement; orienting of attention; infancy; spatial cueing

TO CITE THIS ARTICLE:

Wronski, C., Hernik, M., & Daum, M. M. (2022). Prior Action Direction of a Novel Agent Cues Spatial Attention in 7-Month-Old Infants. *Swiss Psychology Open,* 2(1): 6, pp. 1–15. DOI: https://doi.org/10.5334/spo.38

INTRODUCTION

In our everyday life, we constantly perceive moving entities. Some of them are moving in an *agentive* way: they independently change the direction and velocity of their movements, they interact contingently with other objects, and they change behavior in reaction to and in anticipation of external events. Other objects move solely guided by external forces. Differentiating between agents and non-agentic objects is a prerequisite of successful interactions with our social environment. The present series of studies investigate whether this conceptual differentiation influences attentional processes early in life. We adopt a spatial cueing paradigm to measure how covert shifts of attention are modulated when 7-month-old infants observe agentive behavior. In the following, we briefly discuss the perception of agency in infancy and how we will use infants' covert spatial orienting to assess their perception of a novel agent.

A crucial feature of agents is that they are often *directed* upon something (Lycan, 1999), and infants identify directedness in agentic stimuli from early on. Newborns discriminate biological from non-biological motion (Bardi, Regolin, & Simion, 2011; Simion, Regolin, & Bulf, 2008), and well before one year of age, infants identify agency through the analysis of an object's featural or behavioral cues (Biro, Csibra, & Gergely, 2007). One powerful cue to agency for young infants is self-propulsion. Five-month-olds expect only self-propelled objects to change movement direction spontaneously but not inert objects (i.e., objects that are set into motion by an external force; Luo, Kaufman, & Baillargeon, 2009). Six-month-olds can infer walking direction from point light displays (Kuhlmeier, Troje, & Lee, 2010) and 12-month-olds follow the directional orientation of a biological point light person toward a target (Yoon & Johnson, 2009). Young infants link self-propulsion to goal-directedness (Luo & Baillargeon, 2005; Luo, 2011; Schlottmann & Ray, 2010). Various studies using habituation procedures as in Woodward (1998) have demonstrated infants' sensitivity to goal-directedness in animate and inanimate agents. For example, Luo and Baillargeon (2005) habituated 6-month-olds to a box repeatedly approaching one of two objects. In test events, locations of objects were swapped and the box approached either the same object on a different path or a different object on the same path. Infants showed dishabituation only to events involving a new goal, indicating that they had attributed a goal to the novel, agentive box. Moreover, infants as young as 6 months are sensitive to whether a novel self-propelled and variably moving agent's goal-directed actions fit the environment efficiently (Csibra, Gergely, Biro, Koos, & Brockbank, 1999, Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005, Csibra, 2008). In sum, infants identify principles of agency in novel stimuli well before their first birthday.

A substantial number of studies investigating infants' perception of agency have used habituation or familiarization procedures. With this method, infants' looking times are measured (typically after repeated exposure to events involving behavioral markers of agency and goal-directed actions) to assess their expectations regarding future action goals (e.g., Luo & Baillargeon, 2005; Woodward, 1998). More recently, the assessment of predictive eye movements toward a visible goal during an ongoing action has provided insights into infants' *anticipation* of an agent's goal before the action is completed (e.g., Daum, Gampe, et al., 2016; Falck-Ytter et al., 2006; Kanakogi & Itakura, 2011). A third way in which infants' perception of agency has been studied is through the analysis of *orienting of attention* during the observation of an agentive stimulus. Orienting of attention is the "aligning of attention with a source of sensory input or an internal semantic structure stored in memory" (Posner, 1980; p.4). This can happen *overtly* (i.e., observable by gaze and head shifts), or *covertly* (i.e., without visible orienting behavior). In both cases, stimuli in the area attended to are detected faster than stimuli in non-attended areas, as indicated in faster reaction times to targets appearing at a location congruent with the observer's attention.

Covert orienting of attention is typically assessed in a *cueing paradigm* originally introduced by Posner (1980). Posner demonstrated that reaction times in a target-detection task were faster if the target was cued by a stimulus predictive of its location. This so-called *spatial cueing effect* indicates the previous covert orienting of attention to the cued location. Because the ability for covert orienting of attention develops in the first four months of life, coinciding with the maturation of parietal brain structures (Johnson et al., 1991, 1994), Posner's cueing paradigm can in principle be applied for infancy research. Whereas reaction times in the classic procedure are assessed via button press, infant studies use reactive *gaze latencies* (i.e., the difference between the time the infant's reactive gaze arrives at the target and the time the target was presented), with shorter reactive gaze latencies indicating facilitated reaction to a target appearing at the previously cued location (e.g., Gredebäck & Daum, 2015). In this case, a measure of overt orienting (i.e., the gaze latency) serves as an indicator of the previous covert orienting of attention. Expectations induced by the properties of the cue are therefore captured on a higher temporal resolution than with looking-time paradigms such as the habituation method: While looking-time methods usually capture changes in gaze duration to the display of a completed action, the application of a cueing paradigm allows an "on-line" tracking of reactions to changes in the stimulus. Crucially, in adults, the cueing effect can be evoked by directional cues that are symbolic (e.g., arrows) or social (e.g., eye gaze, pointing or grasping hands; Daum

& Gredebäck, 2011a; Driver et al., 1999; Fischer et al., 2008; Langdon & Smith, 2005). Similar results have been reported in infant studies: Directional cues such as gaze shifts, grasping, and pointing elicit covert orienting of attention to lateral targets in infants well under one year of age (Daum et al., 2013; Daum & Gredebäck, 2011a; Farroni et al., 2004; Hood et al., 1998; Rohlfing et al., 2012; Wronski & Daum, 2014). The cues reported to cause a cueing effect in infants are usually highly familiar behaviors of human actors or human body parts with familiar morphology. In sum, assessing infants' *covert visuospatial orienting of attention* towards the goal of an agent's behavior serves as a mean of understanding how attentional orienting processes are recruited when agents and actions are detected.

Previous research shows that covert orienting of attention can be guided by top-down interpretative processes (see also Ristic & Kingstone, 2005) or bottom-up visuospatial saliency (Jakobsen et al., 2013). Moreover, the covert orienting of attention in infants caused by observed human actions, such as manual grasping, is malleable and can be modified by a brief training in which the laterally grasping hand is either being followed by a consistently congruent or incongruent target (Daum, Wronski, et al., 2016). This suggests that covert orienting of attention can be guided by the information available from preceding events. Taken together, these results suggest that top-down interpretative and learning processes play a role in the infant's covert orienting of attention during the observation of goal-directed actions. Importantly, if the stimulus is presented static and without a visible action goal – for example, a static picture of a grasping hand (Daum & Gredebäck, 2011b), visual attention is oriented purely based on previous experience of observing others grasping and on own grasping actions. In these stimuli, directional information thus guides the observer's attention towards a location outside the stimulus itself, supporting identification and anticipation of action direction and goals (e.g., Gredebäck & Daum, 2015). In the present study, we use this approach to test whether infants infer directional information also from a static, morphologically unfamiliar cue merely based on its previously observed goal-directed actions. This interpretation requires top-down processing because neither familiar morphology (like that of e.g. a human hand; Daum & Gredebäck, 2011b) nor goal-directed movement (as during the observation of an ongoing action; Wronski & Daum, 2014) is available during the spatial-cueing trials.

THE PRESENT STUDY ☻

The rationale of the present study lies in the assumption that one of the potential sources for these interpretative processes may be the concepts of agency and goal-directedness. Support for this hypothesis comes from a spatial cueing study by Wronski and Daum (2014), which suggested that a cue does not necessarily have to include human characteristics to evoke covert orienting of attention in young infants. In this study, a spatial-cueing effect was observed in 7-month-olds in response to a box-shaped object that moved along a nonlinear path, apparently self-propelled, that is, it changed movement direction without any visible external cause. The spatial cueing effect was absent if the box moved on a constant linear path. The agentive movement characteristics seem to play a key role in perceiving the cue as directional and eliciting covert orienting of attention consistent with the perceived direction. It should be noted however, that agency attribution and directional biasing of attention could be driven by self-propulsion and motion direction of the cueing stimulus as it was moving. Here, we aimed at providing a more stringent test for the hypothesis that covert orienting of attention in infants in can be informed top-down by processes of agency attribution and of extracting and encoding direction of the agent's action. Therefore, we investigated whether a spatial cueing effect can be elicited in 7-month-olds by a static novel cue, which previously showed directional agentive behavior.

Hernik, Fearon, and Csibra (2014) provided first evidence that 6-month-old infants quickly detect the direction in which a morphologically unfamiliar yet self-propelled, goal-directed, and contingently reactive agent is acting. Infants encode this perceived action-direction so that it informs their interpretation of the agent, even when it is no longer acting. In the Hernik et al. (2014) study, infants watched brief animations in which a novel faceless box-like agent "chased" another agent across the screen (see Figure 1). In test trials, infants where presented with the now stationary chaser and chasee. If the chaser's formerly leading end (the end at the fore of the chaser when it was moving) was directed towards – rather than away from – the chasee, infants took longer to disengage from the chaser and the chasee (i.e. to move the gaze away from them for the first time), than if the chaser's trailing end (the end at the back of agent when it was moving) was directed towards the chasee. Hernik et al (2014) proposed to interpret this pattern of infant behavior as evidence of *anticipatory waiting* for the box-agent to resume the chase. This interpretation implies that the stationary agent conveyed directional information for the infant observers by virtue of the direction in which its prior chasing actions unfolded and that infants as young as 6 months of age spontaneously engaged in action anticipation upon seeing the stationary agent again. Moreover, infants familiarized with the movement of the box without self-propelled and contingent reactivity did not show this looking pattern, suggesting that infants' interpretation of the events critically depended on the presence of agency cues.

The present series of experiments built further on the rationale of the studies by Wronski and Daum (2014) and by Hernik and colleagues (2014). We assumed that (1) infants'

covert orienting of attention is guided by agency attribution on the basis of behavioral or featural agency cues, and (2) young infants perceive direction of the unfolding action, perceive orientation of an agent exhibiting it, attribute *action direction* (Hernik et al., 2014) to the novel agent, and maintain this attribution even when the dynamic cues are no longer available. Thus, a solitary stationary object can become a directional cue for infants if it has been seen earlier exhibiting directional action and cues of agency.

Accordingly, in Experiment 1, infants were familiarized with "chasing" actions of a 3D animated elongated box-like object bearing distinctive, yet closely matched, features on both its trailing end and its leading end (Figure 1). After familiarization, infants' reactive gaze latencies to laterally appearing targets were assessed in a spatial cueing task. In each cueing trial, the same box-like object, now stationary, was presented at the center of the screen. This central cue was followed by a lateral target (the former chasee) appearing on the sides of the screen congruent or incongruent with the formerly leading feature of the box. In Experiment 2, we tested for possible low-level (i.e., merely motion-based) explanations of the results of Experiment 1. Experiment 3 was designed to provide a baseline by presenting the box-shaped object only in spatial cueing trials without previous movement. This baseline condition also allowed testing whether the shape of the box-like object contributed to perceiving it as directional per se, without ever seeing it in motion. The present study differs from the previous studies in two important ways. Firstly, in Wronski & Daum (2014), cues in spatial cueing trials were either morphologically familiar or moved in a self-propelled way. The present study used static, morphologically unfamiliar cues such that infants could rely on previously observed behavior only. Secondly, Hernik et al (2014) used an anticipatory waiting procedure which did not directly test orienting of attention during test trials. The present study tests more directly the hypothesis that directional information is evaluated and that young infants engage in action anticipation in response to such stimuli, even at an age in which typical anticipation procedures (e.g., Falck-Ytter et al., 2006; Kanakogi & Itakura, 2011) cannot be applied.

EXPERIMENT 1

Experiment 1 was designed to investigate whether directionality attributed to a novel agent on the basis of its prior action direction evokes a spatial cueing effect in 7-month-old infants. This age group was chosen because the present study adopted the same spatial cueing paradigm as Wronski and Daum (2014) who had observed differences in reactive gaze latencies to non-biological objects in 7-month-olds, but not in younger infants. Also, at this age, infants have been shown to consider previous information provided in their orienting of attention (Wronski & Daum, 2014). On the basis of previous findings (Hernik et al., 2014; Wronski & Daum, 2014), we expected that if infants were familiarized to a novel object displaying behavioral cues of agency (specifically: self-propelled, goal-directedness and contingent reactivity), and behaving in a clearly directional manner (e.g., changing movement direction towards the goal-object) while maintaining consistent alignment between its main axis and the vector along which its action unfolds, they could spontaneously identify that object as an agent, encode its orientation with respect to the perceived action direction and later perceive that agent as a directional stimulus in the subsequent spatial cueing paradigm. Thus, we predicted that if the agent was displayed centrally on the screen, infants should fixate faster a peripheral target appearing in the direction of the agent's formerly leading feature (congruent target) compared to a target appearing in the direction of the agent's formerly trailing feature (incongruent target). Gaze latencies were measured as latencies of first fixation of the peripheral target.

METHOD

Participants

In each Experiment, a separate sample of infants participated. In Experiment 1, a sample of 15 7-month-old infants (9 male, mean age: 208.20 days, *SD* = 11.56 days, range: min 183 days, max = 222 days) participated in the study. Additional 8 infants participated but were excluded from further analysis because their being fussy or inattentive resulted in insufficient data quality (n = 3), because of lack of data or valid trials without such obvious behavioral explanation (n = 4), or because individual average gaze latencies in spatial cueing trials deviated from the group mean more than 3 SD (n = 1). Sample sizes in all experiments were planned according to Wronski & Daum (2014), who tested n = 18 participants per condition. However, the final sample turned out to be marginally smaller due to a comparably high drop-out rate in all experiments, suggesting that many infants may have found it more challenging to attend to these unfamiliar stimuli over the long time period they were exposed to them due to the novel combination of familiarization- and spatial cueing trials. All infants in all experiments were healthy, born full term (37–42 weeks' gestation), with normal birth weight (>2,500 g). Their families' addresses were obtained from municipal birth records. Studies were conducted in two middle-sized cities in Germany and Switzerland (two thirds, n = 46 of the total sample for the three experiments was tested in Germany, one third, n = 23 was tested in Switzerland); participating families came from heterogeneous socioeconomic backgrounds. For participation, families received a small gift appropriate to the infant's age

and a certificate. All parents gave informed consent prior to the study. The study was approved by the local ethics committees (the Ethics Committee at the Medical Faculty of the University of Leipzig; 236-10-23082010 and the Ethics Committee of the Faculty of Arts and Social Sciences of the University of Zurich; 2013-03-15) and conducted in accordance with the Declaration of Helsinki.

Materials

Colorful videos of 3D-animated objects were prepared beforehand with the software Blender (www.blender.org, Version 2.63) and presented with the software ClearView (Version 2.7.1; Tobii Technology, Sweden) on a Tobii 1750 near-infrared eye tracker with an infant add-on (precision: 1°, accuracy: 0.5°, sampling rate: 50 Hz). The general layout and design of the stimuli was adapted from Hernik et al. (2014, Experiments 2–3). During familiarization trials, an animated novel box-shaped agent engaged in a contingent goal-directed pursuit-action with a ball-target on a green checkerboard-patterned plane viewed from a 30° angle. The box (length: 4 visual degrees, height: 2 visual degrees) was a yellow elongated shape with two symmetrical trapezoid longer faces and a distinctive feature (a red arch filled with the same yellow texture as the box) attached to each of its two shorter faces (Figure 1). The box was fully symmetrical across – but not along – its main axis, because one end-feature always had n-like orientation and the other u-like orientation with respect to the box. Whether the box had the u-feature at the leading end and the n-feature at the trailing end, or the other way round, was counterbalanced between participants. Four familiarization videos were created by mirroring the scene depicted in Figure 1 horizontally and vertically, resulting in four different movement trajectories.

The box moved at a constant speed of 1.62 visual degrees per second, with its main axis always aligned with the movement path. Two white walls were located on the plane lateral to the movement trajectory of the box. The box passed by the two walls, but never made contact with them. In the beginning of each familiarization trial, the box entered the plane either from its far side (top of the screen) or from its near side (bottom of the screen) and moved on a linear path toward the center of the plane. As the box reached the center, a blue ball entered the scene from a peripheral position on the opposite side of the plane, accompanied by a sound. Contingent with the ball's entrance, the box changed its trajectory orienting towards the ball and moved towards it. Just before the box arrived at it, the ball rolled out of the scene along the same path that it had taken to enter. At this time the box again changed its movement trajectory by orienting towards the exiting ball, and left the scene on the same path as the ball. The movement of the box thus showed clear indications of self-propulsion, goal directedness and contingency upon the behavior of the ball. The total duration of a familiarization trial was 12.5 s.

Test trials were presented according to the procedure used in Wronski and Daum (2014). During test trials, a still image was presented, where the stationary box was at the center of the screen oriented horizontally, with its formerly leading end directed towards either left or right side of the screen. After the presentation of the stationary box for 1,000 ms, the box disappeared and the blue ball was displayed at a horizontal peripheral position congruent or incongruent with the formerly leading feature of the box (Figure 2).

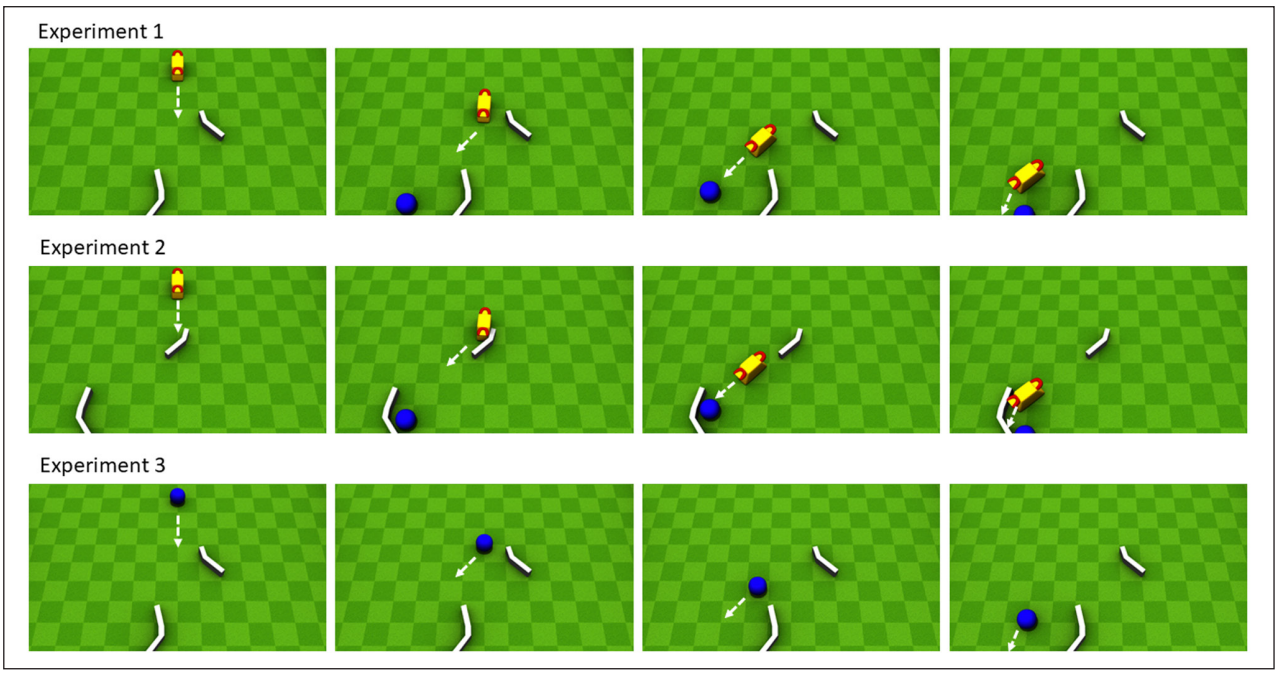

Figure 1 Movement trajectory of box and ball in familiarization videos in the three Experiments.

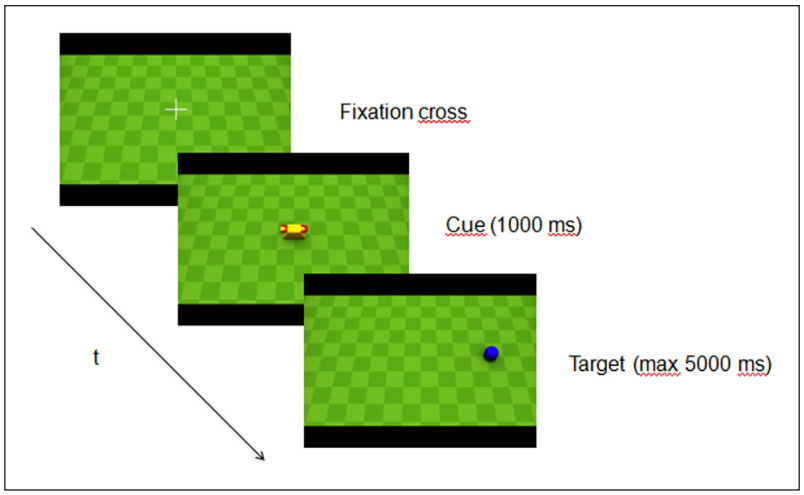

Figure 2 Temporal sequence of stimuli during spatial cueing trials of all three experiments.

Four different orders of familiarization videos were created including all possible four movement trajectories of the box (two films with the box starting position at the top of the display, moving to the bottom right respective left and two films with the box starting from the bottom of the screen, moving to the top right respective left). The order of familiarization trials was counterbalanced across subjects. In the spatial cueing trials, target location as well as the congruence of target location and the shape of the leading feature were pseudorandomized within subjects. The maximum number of trials presented included equal numbers of trials with right and left targets as well as congruent and incongruent targets. In order to avoid adaptation effects, not more than three repetitions of target location or leading feature–target relation (congruence) were allowed. This procedure was adopted from Wronski & Daum (2014). The box and the ball were presented against the same green checkerboard-patterned plane as the chasing events in familiarization trials.

Procedure

Infants were tested at a time of the day when they were likely to be alert and in good mood. Prior to testing, participating families were welcomed in a reception room equipped with infant-friendly toys. While the infant explored the room and got acquainted with the experimenter, parents were informed about the procedure and gave their written consent for the procedure and data collection. The infant and one parent were then escorted to the laboratory. Again, the infant was given several minutes to get familiar with the new environment. The experimenter then helped the parent to seat the infant in a baby car seat (Maxi-Cosi Cabrio), in approximately 60 cm viewing distance from the monitor. During the entire session, the parent remained in the testing room, seated behind the infant. The parent was asked not to talk to or interact with the infant, but to comfort the infant by putting the hands close to the infant whenever necessary. The experimenter was seated behind a screen and was invisible for the infant throughout the session. In the beginning of each session, a 9-point infant calibration of the eye tracker was performed, with looming contracting and expanding spheres accompanied by a sound. After calibration, the presentation of the video clips started. Each trial started with a contracting and expanding cross in the center of the screen, accompanied by a sound. Once the infant fixated the cross, the video demonstration began. Four familiarization trials were shown in the beginning of each session. The entry side of the box (top of the screen left or right/bottom of the screen left or right) was varied in each familiarization trial with the order counterbalanced between subjects. After familiarization, eight cueing trials were presented. From there on, one familiarization trial followed a block of eight cueing trials. Five blocks of test trials were presented such that if they completed the entire session, infants saw a total of 40 cueing trials with a total of eight familiarization trials among them.

Data Analysis

Eye-tracking data (timestamps of gaze location) were extracted and converted to ms using the software MATLAB (MathWorks, 2007) according to the procedure used by Wronski and Daum (2014). Infants had to have watched a minimum of four valid familiarization trials (i.e., 50% of the possible maximum). This number was the same as the number of familiarization trials presented in Hernik et al., (2014, Experiment 3), when the agent had two perceptually matched features on its to ends, as in the current study. Infants also had to contribute a minimum of six valid spatial cueing trials (min. 3 per congruent and incongruent condition; as in Wronski & Daum, 2014) to be included in data analysis. A familiarization trial was declared valid if the infant had looked at the scene for at least 400 ms during the beginning of the agent's movement (during the first 4 s), the change of trajectory towards the ball (the following 3.5 s) and the interaction between agent and ball (during

the last 4 s of the video clip). Familiarization videos were presented in a predefined order as reported above, thus not following a habituation procedure. As in Wronski & Daum (2014), a cueing trial was declared valid if the infant had looked at the cue for a minimum of 100 ms if the latency until gaze arrival on the target was greater than 100 ms to rule out anticipatory saccades (Gredebäck et al., 2009), and if the reactive gaze latency did not deviate more than 2 SD from the individual average gaze latency of all trials were excluded from further analysis. On a group level, infants with gaze latencies congruent or incongruent targets deviating more than 3 SD from the group average gaze latency were excluded from the analysis. Criteria for data exclusion and outliers were defined before data analyses according to the criteria applied in Wronski & Daum (2014). No part of the study procedures and analyses were pre-registered prior to the research being conducted. Statistical analyses were performed using the Software SPSS (Version 27). Cueing data and videos used in familiarization trials can be retrieved from https://osf.io/npgbs/?view_only=73e5e827890a4638bfd84c294c8774c6.

Results and Discussion

Infants in the analyzed sample completed an average number of 6.93 valid familiarization trials (*SD* = 1.39) with an average total looking time of 3.34 s (*SD* = 1.62 s) and an average number of 13.47 valid cueing trials (*SD* = 4.66) of a possible maximum of 40 cueing trials. A repeated measures analysis of variance (ANOVA) with the between-subjects factor feature assignment (leading-end feature: u-like vs. n-like) and the within-factor condition (target location congruent vs. incongruent with the previously leading-end feature) on gaze latencies resulted in a significant main effect for condition, $F(1, 13) = 5.500$, $p = .036$, $\eta^2 = .297$, indicating shorter gaze latencies for congruent test trials ($M = 568.03$ ms, $SD = 271.37$) compared to incongruent test trials ($M = 872.69$ ms, $SD = 371.05$) (Figure 3). No further main effect or interactions were found. On an individual level, 11 of 15 infants showed shorter gaze latencies for congruent compared to incongruent trials.

These results indicated that gaze latencies to targets were faster if the target appeared at the side of the screen congruent with the prior action direction of the box. Low-level saliency features, that is, whether the leading feature was u-like or n-like, had no influence on the spatial cueing effect, further suggesting that the behavior of the box during familiarization, rather than its visual features alone, were the source of directional information for 7-month-olds. An additional Bayesian paired samples T-test was conducted with the free software JASP (2021) using default priors.[1] The Bayes factor indicated evidence for H1; specifically, $BF_{10} = 2.662$, which means that the data are approximately 2.7 times more likely to occur under H1 than under H0. The error percentage is $< 0.001\%$, which indicates great stability of the numerical algorithm that was used to obtain the result.

Experiment 2 was designed to test further whether the spatial cueing effect observed in Experiment 1 was indeed a result of infants' perception of the stimulus as an agentive object with directionality consistent with the perceived direction of its prior actions, and to rule out possible low-level alternative explanations. For instance, instead of attributing directionality on the basis of behavioral cues of agency, infants in Experiment 1 could have treated the

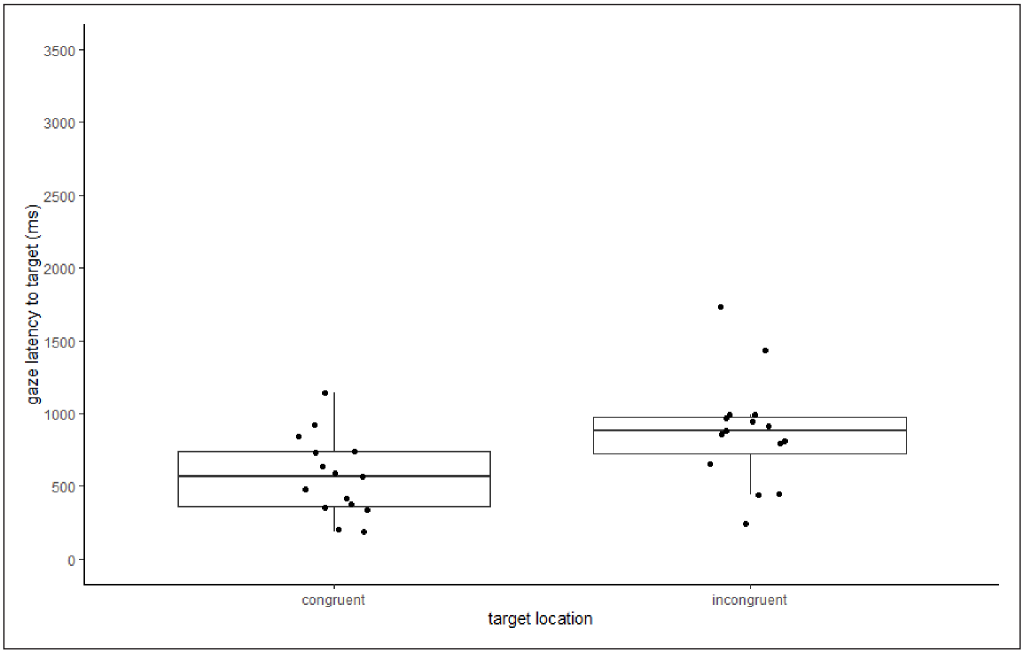

Figure 3 Gaze latencies to congruent and incongruent targets in Experiment 1. Box plots represent Median and first resp. third quartiles; whiskers extend to smallest resp. largest value no further than 1.5 * inter quartile rage (IQR) from the hinge.

leading end of the box as predictive of the target's location merely in virtue of its relative spatial proximity to the target during familiarization, resulting in faster gaze latencies to targets appearing in relative proximity with it (i.e., on the congruent trials). Another possible low-level explanation for the results could be that infants expected the object to continue moving without making an inference of directionality based on agentive goal-directed behavior. In this case, any type of movement behavior would elicit the effects observed in Experiment 1. Experiment 2 therefore employed a similar control condition as in Hernik et al. (2014) to test between these alternative explanations and our hypothesis that encoding the box as an agent in familiarization events was instrumental in eliciting the spatial cueing effect observed in Experiment 1.

EXPERIMENT 2

In Experiment 2, both the box and the ball moved in exactly the same way during the familiarization phase as they did in Experiment 1. The only difference between the two experiments was in the exact location of the two white walls, which in Experiment 1 had been located away from the path of the box. In Experiment 2 they were positioned so that the box's movement trajectory involved contact with both walls, and each change in the movement of the box happened exactly at the time when the box contacted a wall (see Figure 2). The box thus showed the same movement behavior as in Experiment 1, only that the variations in the movement of the box could be now accounted for by the contact with the walls. These familiarization trials were no longer expected to convey unambiguous cues towards the self-propulsion and contingent reactivity of the box. Consequently, familiarization events in Experiment 2 should be less likely than those in Experiment 1 to elicit in infants' perception of the box as an agent with a particular directionality mapped from its actions. Indeed, Hernik et al. (2014) found that 6-months-old infants encoded the boxlike agent's direction and used it for action anticipation only when the box never made any contact with walls, and not when all changes in its behavior happened upon contact with the walls. If the spatial cueing effect in Experiment 1 was caused by the mere proximity of the leading feature and the target in familiarization trials, or by mere expectation of movement in the direction indicated by the formerly leading feature, then we would expect the same pattern of results in Experiment 2, because the motion-paths of the box and ball during familiarization trials was identical in both experiments. If, however, infants in Experiment 2 did not show the same spatial cueing effect, we could reject these alternative explanations and the result would be consistent with our interpretation that the faster gaze latencies to congruent targets observed in Experiment 1 were driven by attribution of agency and directionality to the box.

METHOD

Participants

A sample of 15 7-month-old infants (9 male, mean age: 213.47 days, *SD* = 7.92 days, range: min = 196 days, max = 223 days) participated in Experiment 2. Additional 8 infants participated but were excluded from further analysis due to being fussy or inattentive ($n = 4$), lack of data or valid trials for technical reasons (failure to calibrate, poor quality of signal; $n = 3$), or because individual gaze latencies deviated from the group mean more than 3 SD ($n = 1$).

Materials

Experiment 2 differed from Experiment 1 only in one aspect: The walls in the familiarization trials were now positioned so that at each of its turns the box was making contact with one of the walls. Apart from that, Materials, Procedure, and Data Analysis were identical to Experiment 1.

Results and Discussion

Infants in the analyzed sample completed an average number of 6.87 valid familiarization trials (*SD* = 0.99) with an average total looking time of 4.57 s (*SD* = 1.29 s) and an average number of 12.73 valid spatial cueing trials (*SD* = 4.17). A repeated measures ANOVA with the within-subjects factor condition (test-trial: congruent vs. incongruent) and the between-subject factor feature assignment (leading feature: u-like vs. n-like) on the dependent variable gaze latency revealed no significant main effect for condition, $F(1, 13) = 0.306$, $p = .590$, $\eta^2 = .023$ (Figure 4). Infants who had watched the box with the n-like leading-end feature in familiarization trials showed longer average gaze latencies toward targets ($M = 936.36$ ms, $SD = 393.38$ ms) than infants who had watched the box with the u-like feature at the leading end ($M = 641.67$ ms, $SD = 233.12$ ms). However, this difference was not statistically significant, $F(1, 13) = 3.220$, $p = .096$, $\eta^2 = .199$, and there was no statistically significant interaction between condition and feature assignment, $F(1, 13) = 0.318$, $p = .582$, $\eta^2 = .024$. An additional Bayesian paired samples T-test was performed on the data of this experiment to compare our hypothesis of no difference with the alternative hypothesis that there was in fact a difference but didn't result in statistical significance due to the relatively small sample size. Results showed evidence in favor of the null hypothesis, with a Bayes factor indicating evidence for H0; $BF_{01} = 3.369$, which means that the data are approximately 3.7 times more likely to occur under H0 than under H1 (error percentage = 0.003%).

These results are not consistent with the hypothesis that the spatial cueing effect observed in Experiment 1 was a mere by-product of spatial proximity between the leading-end feature and the target, since if this was the case the same spatial cueing effect should have been evident in Experiment 2 as well. Moreover, these results are consistent with the hypothesis that since

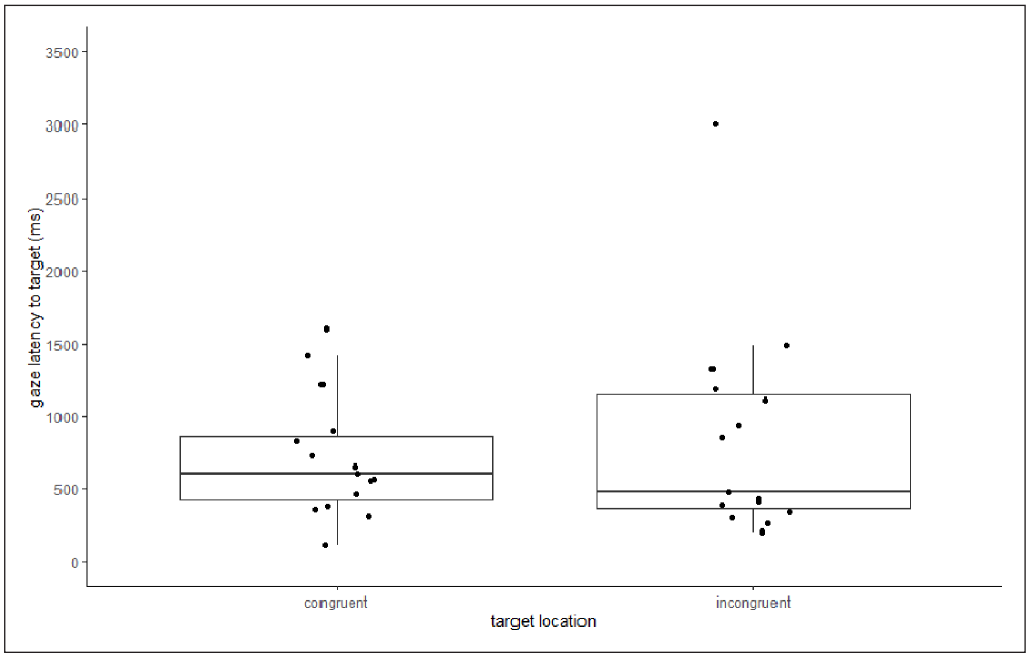

Figure 4 Gaze latencies to congruent and incongruent targets in Experiment 2. Box plots represent Median and first resp. third quartiles; whiskers extend to smallest resp. largest value no further than 1.5 * IQR from the hinge.

familiarization trials in Experiment 2 did not involve clear cues towards the agency of the box, in the following test trials infants did not interpret it in a way that could support covert orienting of attention. However caution is needed when stating these conclusions, given that the additional repeated measures ANOVA on the dependent variable gaze latency with the within-subjects factor condition (test trial: congruent vs. incongruent) and the between factor experiment (Experiment 1, Experiment 2) found no significant main effects for condition, $F(1, 28) = 2.452$, $p = .129$, $\eta^2 = .081$ and experiment, $F(1, 28) = 0.311$, $p = .582$, $\eta^2 = .011$, and also no significant interaction effect, $F(1, 28) = 0.374$, $p = .546$, $\eta^2 = .013$.

In both Experiment 1 and 2 we found no interaction between features assignment (u-feature leading n-feature trailing, or vice versa) and condition (congruent or incongruent test trial). However, the descriptive group-level difference in gaze latencies when the leading feature was u-like rather than n-like, raises the question whether the shape and allocation of the end features themselves might have been nevertheless influencing infants' performance if they were readily perceived as directional. We explored this possibility further in Experiment 3, in which infants were not familiarized with the behavior of the box at all prior to test trials.

EXPERIMENT 3

The aims for Experiment 3 were twofold. First, we wanted to test directly whether the appearance of the box alone and in particular the asymmetry of its end features, could support the directional perception of its shape, independent of behavioral cues. Second, it allowed us to assess the baseline, against which we could test, whether exposure to familiarization trials involving the box facilitated detection of the target at the test. Specifically, we hypothesized that familiarization trials of Experiment 1 could result in such facilitation, because they supported representing the box as an agent with a particular directionality, and potentially also as a goal-directed agent engaged in an action ("chasing") towards the target object.

METHOD

Participants

Data from 14 7-month-old infants (7 male, mean age: 204.29 days, *SD* = 10.32 days, range: min = 191 days, max = 222 days) were analyzed in Experiment 3. Additional 9 infants participated but were excluded from further analysis due to being fussy or inattentive ($n = 4$) or due to a shortage of valid trials for technical reasons (failure to calibrate, poor quality of signal) ($n = 5$).

Materials

To keep the general timing of the procedure as well as visual exposure to the target matched to Experiments 1 and 2, in Experiment 3 infants watched familiarization trials, in which the blue ball moved through the scene along the paths taken by the box in the two previous experiments. However, the box itself was never shown during familiarization. It was only presented during the test trials, identical to those of experiments 1 and 2. Note that given that the box was never seen moving in Experiment 3, none of its ends could be defined as the leading end. In every other aspect, the methods and procedures were identical to Experiments 1 and 2.

Results and Discussion

Infants in the analyzed sample completed an average of 6.86 valid familiarization trials (*SD* = 1.23) with an average total looking time of 4.08 s (*SD* = 1.31 s) and an average of 13.14 valid spatial cueing trials (*SD* = 4.33). A paired samples t-test showed no significant difference between average gaze latencies for test events congruent with the location of the n-feature (*M* = 1099.61 ms, *SD* = 753.82 ms) and test events congruent with the location of the u-feature (*M* = 1246.55 ms, *SD* = 830.82 ms), $t(13) = -0.745$, $p = .470$ (Figure 5). Note that in Experiment 3, the box-like object was only shown in the cueing trials. Therefore, there was no variable "feature assignment" (leading v.s trailing feature) as in Experiment 1 and Experiment 2, which resulted from the box' orientation during movement. Consistent with the assumption that we made when designing the stimuli and consistent with the results of the previous two experiments, we found no evidence that the shapes of the end features of the box alone could sufficiently guide the perception of the box as a directional object. Again, a Bayesian paired samples T-test was performed. The Bayes factor indicated evidence for H0; $BF_{01} = 2.913$, which means that the data are approximately 3 times more likely to occur under H0 than under H1 (error percentage = 0.0010%).

Next, we analyzed whether the average gaze latencies, independent of congruence, differed between the three Experiments. An ANOVA on the average gaze latencies with the between-subjects factor experiment (1, 2, 3) resulted in a significant main effect, $F(2, 41) = 4.068$, $p = .024$, $\eta^2 = .166$. Post hoc tests (α-level Bonferroni-adjusted to .025 for multiple comparisons) revealed that gaze latencies in Experiment 3 (*M* = 1173.08 ms, *SD* = 702.20 ms) were marginally longer than in Experiment 1, where the box chased the ball without making any contact with the walls (*M* = 720.36 ms, *SD* = 224.77 ms; $p = .035$), but not longer than in Experiment 2, where the box made contact with the walls (*M* = 779.19 s, *SD* = 341.54. s, $p = .081$). This pattern suggests that disengagement of attention from the statically presented box and orienting to a peripheral target took longest for the group of infants in Experiment 3.

It should be noted, however, that infants in Experiment 3 were exposed to the box for considerably shorter time than infants in Experiments 1 and 2. Thus, longer gaze latencies of targets in Experiment 3 could be a result of increased attention to the box due to its relative novelty. To exclude this alternative explanation based on the novelty effect on attention, we performed a univariate ANOVA with the between-subjects factor experiment (1, 2, 3) on the average looking times to the AOI of the box (as defined by the boundaries of the object) during the cueing trials. There was no significant difference, $F(2, 41) = 0.890$, $p = .418$, $\eta^2 = .042$, between looking times to the box in Experiment 1 (*M* = 594.71 ms, *SD* = 249.99 ms), Experiment 2 (*M* = 688.30 ms, *SD* = 203.18 ms) and Experiment 3 (*M* = 671.07 ms, *SD* = 139.49 ms). Thus, we found no evidence that the box received more attention in Experiment 3 than in the previous two experiments.

Another, more speculative, reason for the prolonged gaze latencies might be that the exposition to the moving ball in familiarization trials lead infants to expect the ball in cueing trials (now presented as a target) to continue moving. In this case, a property of the target stimulus would have influenced the property of the cue to direct attention. However, studies with adult participants indicate that target identity information is not encoded

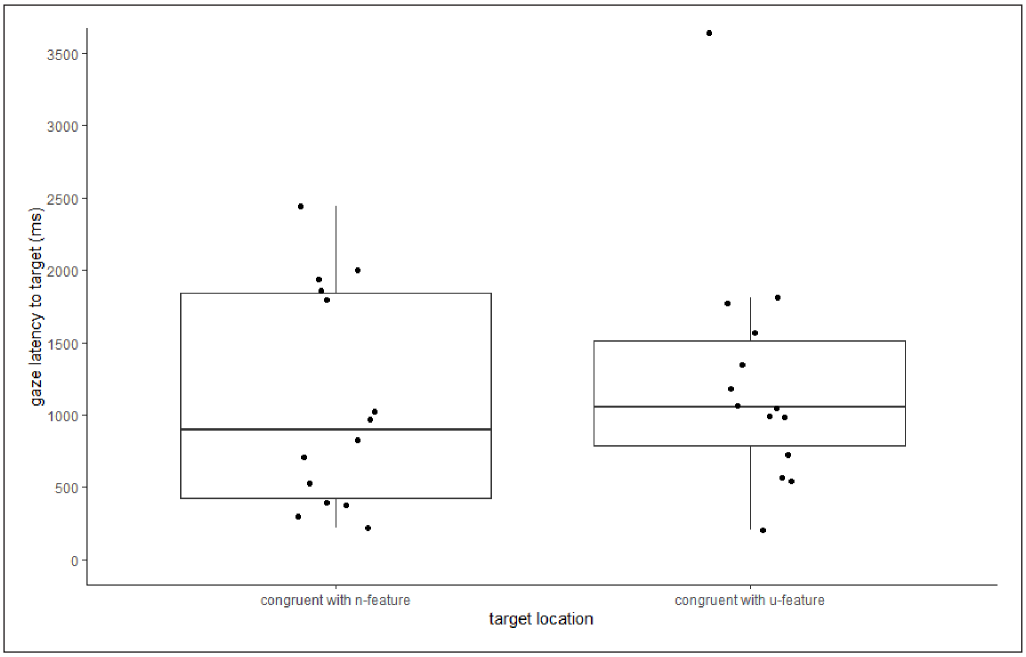

Figure 5 Gaze latencies targets congruent with n-feature or u-feature in Experiment 3. Box plots represent Median and first resp. third quartiles; whiskers extend to the smallest resp. largest value no further than 1.5 * IQR from the hinge.

and retrieved between cueing trials (e.g., Qian et al., 2017), rendering this kind of effect even less plausible for the present infant study. We conclude that covert orienting of attention was facilitated in Experiment 1 (in comparison to Experiment 3) not due to a mere higher amount of prior exposure to the box-cue, but rather due to prior exposure to the cues to the agency of the box and its goal-directed actions towards the ball-target. Consistent with our hypothesis, these allowed infants to treat the box as a source of directional information at test trials, when it was no longer moving.

GENERAL DISCUSSION

The present study provides new evidence that 7-month-olds attribute action-direction to a novel agent with unfamiliar non-human morphology based on behavioral cues and, as a consequence, covertly orient their attention along the perceived directionality of the agent, as indicated by a spatial cueing effect. The spatial cueing effect in this variant of Posner's (1980) cueing paradigm is assessed via gaze latencies (i.e., visual reaction times) to laterally presented targets following a centrally presented cue. A measure of overt visual attention – the gaze latencies to the lateral targets – thereby serves as a measure of the previous covert orienting of attention following the presentation of the cue. Crucially, in the present manipulation the spatial cueing effect was observed in response to a novel, non-biological agent which moved during familiarization (Exp. 1 and 2) but was stationary during the cueing trials in which gaze latencies were measured. Thus, in contrast to prior studies with infants of similar age (Daum & Gredebäck, 2011b; Farroni et al., 2004; Hood et al., 1998; Rohlfing et al., 2012; Wronski & Daum, 2014), infants' covert orienting of attention during cueing trials could not have been supported directly by familiar human morphology or by ongoing dynamic cues to agency and action-direction, as these were absent from the test stimulus.

In Experiment 1, the novel agent showed behavioral cues of goal-directedness, such as self-propelled movement and contingent reactivity with another object. Results from gaze latencies which were measured in a series of spatial cueing trials indicated that this brief familiarization with the stimulus as a self-propelled, contingently reactive, goal-directed agent can elicit a spatial cueing effect in 7-month-olds. Experiment 2 ruled out alternative low-level explanations, such as mere effects of movement. The results of Experiment 3 show that infants had no baseline perception for directionality in the unfamiliar box prior to familiarization.

The current results thus indicate that covert orienting of attention in early infancy can be informed by top-down interpretations – in this case by attributions of directionality elicited by prior agency cues and directional actions. The results are consistent with previous findings that covert orienting in young infants can be guided by dynamic and morphological and agency cues (Wronski & Daum, 2014), that infants' action perception quickly adapts to context-specific observed regularities (Daum, Wronski, et al., 2016), and that infants can spontaneously attribute directionality to a novel agent based on its actions (Hernik et al., 2014).

ATTRIBUTION OF AGENCY

What kind of interpretative processes could underlie the covert orienting of attention by the infants in our study? Overt shifts of gaze in response to orientation changes on novel agents, akin to gaze-following of human models, is often interpreted as evidence that young children and infants attribute attentional orientation to a novel agent on the basis of behavioral cues (e.g., Johnson et al., 2008, 1998). By a similar token it could be argued that infants in our study might have used the agent's orientation as a cue guiding automatic perspective-taking (e.g., Flavell et al., 1981; Phillips, 2019). However, our study provides no evidence that infants attributed perceptual or epistemic capabilities to the novel agent.

We favor instead a leaner interpretation, according to which infants attributed *actional* (Leslie, 1995; Premack, 1990) or *teleological agency* (e.g., Gergely & Csibra, 2003) to the box without necessarily recruiting a more elaborate interpretation of psychological agency. Accordingly, the perceptual input of self-propulsion and the interactive sequence with another object as evident in our stimuli lead to an automatic reading of the observed object as an *internally driven* and *goal-directed agent*. The agent has been observed to act towards the goal and subsequently expected to commence the goal-directed action again. Even before the agent started to move and before the current location of the goal could be observed, infants could anticipate the goal-directed action to unfold in the same direction as before with respect to the agent's orientation. The covert orienting of attention in the direction of the anticipated goal could therefore be a result of action anticipation, similarly to how the latter may be revealed by overt eye movements (e.g., Daum et al., 2012; Falck-Ytter et al., 2006; Kanakogi & Itakura, 2011).

Note that in principle the current results are also consistent with a more parsimonious account. One could argue that the dynamic cues in the familiarization trials were sufficient for attribution of self-propulsion and that at test the agent was expected merely to start *moving* again (rather than producing goal-directed action again) in the same direction as before with respect to orientation of its body. While the current study allows no final decision between these alternative mechanisms, results of Experiment 2 indicate that this lower-level explanation is less likely. Additionally, given the huge body of research documenting young infants' capacity to attribute distal action goals even on the basis of

familiarization trials either comparable or shorter and simpler than those used in our study (Csibra, 2008; Luo & Baillargeon, 2005; Schlottmann & Ray, 2010; Woodward, 1998), we find it implausible that infants in our study would ignore the readily available information about the goal and focus merely on movement direction instead.

CUES TO AGENCY DURING FAMILIARIZATION

What behavioral cues lead infants in our study to construe the unfamiliar box as an agent? Experiment 1 provided infants with several potential cues to agency: the self-propelled movement of the box itself and the interaction scene with another self-propelled object (the ball) which consisted of contingent movement patterns of the box in relation to the ball. Both self-propulsion as well as contingent reactivity have been shown to be basic cues to agency leading young infants to encode action goals of novel agent (Luo, 2011; Schlottmann & Ray, 2010; Shimizu & Johnson, 2004). Dynamic interaction patterns of geometrical shapes similar to those in our interaction sequence result in attributions of animacy and goal-directedness in adults (e.g., Heider & Simmel, 1944; Santos et al., 2008). The sequence presented in the familiarization of Experiment 1 could be seen as a "chasing", potentially involving "reacting" (the box oriented toward the ball when the ball appeared on the screen) and "affecting" (the orienting movement of the box toward the ball was followed by a change in the ball's trajectory) on the part of the box-agent. The external walls in Experiment 2, which guided the movement of the box, provided an alternative explanation for its trajectory changes thus diminishing evidence of both self-propelled and contingent reactivity of the box. Consequently, our design does not allow us to resolve whether the agency attribution in Experiment 1 resulted from a combination of the agency cues present in the familiarization events or one of them played a critical role.

Note also that while infants showed a significant cueing effect only in Experiment 1, infants in both Experiment 1 and 2 showed numerically longer gaze latencies to incongruent targets on a descriptive level. Similarly, Wronski and Daum (2014) found that infants who observed a geometrical object move in a non-agentive fashion still showed a tendency for longer gaze latencies to incongruent targets on a descriptive level. This raises the question how strong the difference in the assumed agency attribution was between the two experiments. Note that in Experiment 2, the box' movement direction changed after contact with the walls, but it was still shown as entering the scene as moving by itself. This could have been interpreted by some infants as a cue to self-propulsion. One possibility is therefore that, despite limited evidence for agency in familiarization trials, some infants in Experiment 2 might have nevertheless attempted to interpret the novel stimulus as agentive and this representation might have been maintained during a number of test trials. Further studies need to disentangle these subtle differences in the amount and quality of agency cues and their role in rapid orienting of attention. Another limitation of our study is the small sample size. Sample sizes were planned according to previous studies using a similar design (Hernik et al., 2014; Wronski & Daum, 2014) but turned out marginally smaller due to higher dropout rates, presumably because of the combination of more difficult stimuli used in the present study (non-biological objects with more complex behavioral patterns) with a visual spatial cueing paradigm. Effects sizes are small and the present results therefore need to be interpreted with caution. However, results conceptually replicate central findings from these studies, permitting us to interpret them with a modest degree of confidence. The aim of this study was to provide a new and more direct test for the hypothesis that covert orienting of attention in young infants may be guided by top-down, interpretative processes, specifically, by attribution of agency to novel stimuli. It extends earlier findings on covert orienting of attention in young infants by showing that directionality can be attributed to static stimuli on the basis on its previously displayed behaviors. Building on the rich literature on agency perception in early childhood, the present study broadens our understanding of how attentional processes are recruited when agents are detected. In contrast to most of the studies on conceptual agency understanding in early childhood using habituation methods, the present study applied a spatial cueing paradigm which can be used to measure attentional processes that occur immediately upon detection of a directional cue. The major contribution to the literature lies in the observation that even quick and involuntary orienting processes are informed by rather abstract agency features early in life. To conclude, the study provides evidence that covert orienting of attention in young infants can be guided by a stationary novel cue with a short history of actions that indicated it as a goal-directed and directional agent.

TRANSPARENCY STATEMENT

We reported how we determined the sample size and the stopping criterion. We reported all experimental conditions and variables. We report all data exclusion criteria and whether these were determined before or during the data analysis. We report all outlier criteria and whether these were determined before or during data analysis.

NOTE

1 Bayesian analyses were performed to help with interpretation of null results predicted for comparisons in Experiment 1 and 2, but for transparency we report them for all three experiments.

COMPETING INTERESTS

The authors have no competing interests to declare.

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TO CITE THIS ARTICLE:
Wronski, C., Hernik, M., & Daum, M. M. (2022). Prior Action Direction of a Novel Agent Cues Spatial Attention in 7-Month-Old Infants. *Swiss Psychology Open,* 2(1): 6, pp. 1–15. DOI: https://doi.org/10.5334/spo.38

Submitted: 22 February 2022 **Accepted:** 21 September 2022 **Published:** 13 October 2022

Swiss Psychology Open is a peer-reviewed open access journal published by Ubiquity Press.