**Seeing the world from others' perspective:
14-month-olds show altercentric modulation effects by others' beliefs**

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Research highlights

- The present research asked whether 14-month-old infants are influenced by another person's belief in their own behavior: whether they are *altercentric*
- We found altercentric effects in an active behavioral paradigm: infants searched longer in a box when another person believed it contained an object
- This was found regardless of whether the other's belief was true or false (whether the box actually contained an object)
- Infants encoded the other's belief that required tracking multiple objects, object features, or also involved a sensitivity to the aspectuality of beliefs

Abstract

Humans have a propensity to readily adopt others' perspective, which often influences their behavior even when it seemingly should not. This altercentric influence has been widely studied in adults, yet we lack an understanding of its ontogenetic origins. The current studies investigated whether 14-month-olds' search in a box for potential objects is modulated by another person's belief about the box's content. We varied the person's potential belief such that in her presence/absence an object was removed, added, or exchanged for another, leading to her true/false belief about the object's presence (Experiment 1, $n=96$); or transformed into another object, leading to her true/false belief about the object's identity (i.e., the objects represented under a specific aspect, Experiment 2, $n=32$). Infants searched longer if the other person believed that an object remained in the box, showing an altercentric influence early in development. These results suggest that infants spontaneously represent others' beliefs involving multiple objects, and raise the possibility that infants can appreciate that others encode the world under a unique aspect.

The highly social nature of human existence requires us to be equipped with cognitive mechanisms that allow proficient navigation in the social world. As individuals tend to differ in their knowledge, intentions, and abilities, we often have to rapidly infer others' unique perspective. Various abilities may support human sociality, some of which, for example sensitivity to others' beliefs, may be present early in ontogeny (Baillargeon, Scott, & He, 2010). Uncovering the nature and development of these cognitive mechanisms is still one of the liveliest domains in research on social cognition (Baillargeon, Buttelmann, & Southgate, 2018; Carruthers, 2013; Perner & Ruffman, 2005; Poulin-Dubois et al., 2018; Rakoczy, 2011). It is uncontroversial that humans eventually arrive to the ability to consider others' mental states when they are prompted to, for example in communicative or collaborative contexts (Hanna, Tanenhaus, & Trueswell, 2003; Schober, 1993). In line with humans' pronounced sociality (Herrmann, Call, Hernández-Lloreda, Hare, & Tomasello, 2007), however, it has been argued that humans have a stronger tendency to attend to others (Kovács, Téglás, & Endress, 2010). In fact, people seem to readily compute others' perspective and mental states even when this is not required by the situation or task they are performing, or it is even disadvantageous. Humans are thus inclined to spontaneously focus on the perspective of others: they are altercentric (Kampis & Southgate, 2020; Samson, Apperly, Braithwaite, Andrews, & Bodley Scott, 2010).

Altercentrism in human cognition reflects that people's behavior is spontaneously influenced by the presence, and perspective, of others, even when their task requires them to focus on their own point of view (Elekes, Varga, & Király, 2017; Kovács et al., 2010; Samson et al., 2010). The sensitivity to the other's perspective appears for example in joint tasks where participants act together (Elekes, Bródy, Halász, & Király, 2016; Freundlieb, Kovács, & Sebanz, 2016). While one possible role of altercentrism is facilitating interactions, others'

perspective can have an effect on people's behavior even when there is no obvious or immediate interactive context. Even if the other is not engaged in any task, adults' reactions are affected by the belief of another agent (Kovács et al., 2010; Van Der Wel, Sebanz, & Knoblich, 2014), or by a mismatch between their own and someone else's perspective (Samson et al., 2010). Thus, altercentrism may enable rapid availability of others' mental states (Kovács et al., 2010), supporting social behavior in general. However, we may attend to others not only to coordinate with them but also to identify what information they possess when we aim to seek or transmit information, potentially giving altercentrism a broader, epistemic function.

From a developmental perspective it could be particularly advantageous to have a disposition to attend to others' point of view from early on (Southgate, 2020). Infants face a crucial learning task when discovering the world, and the social environment can help with identifying relevant sources of information and guide their leaning. Thus, attention to others' perspective may enable infants to learn about the material world via the perspective of others around them. For instance, studies have suggested that infants may learn about the valence of objects through the preferences of others (Egyed, Király, & Gergely, 2013; Kamps, Somogyi, Itakura, & Király, 2013), and map a new word to an object that was in the speaker's center of attention, and not what they themselves were attending to (Baldwin, 1991).

Thus, one might wonder whether infants, similarly to adults, may also have a strong disposition for altercentrism, and spontaneously attend to other's perspectives and mental states. Evidence seems consistent with this possibility. A large body of studies points towards infants' sensitivity to others' visual and mental perspective, though the underlying abilities are debated (Apperly & Butterfill, 2009; Baillargeon et al., 2010; Carruthers, 2013;

Leslie, 2000; Perner & Ruffman, 2005). Neuroimaging evidence suggests that infants' own representations and those used to encode others' perspective are handled at least in part by the same system (Kampis, Parise, Csibra, & Kovács, 2015; Southgate & Vernetti, 2014), potentially increasing commensurability between the two and allowing for the other's perspective to influence infants' behavior. Crucially, while there are studies documenting altercentric effects in school-aged children (Buttelmann & Buttelmann, 2017; Elekes et al., 2017), to our knowledge there is only one study that speaks to altercentric modulation in infants, where infants' looking times were influenced by another agent's belief (Kovács et al., 2010).

The current studies asked whether altercentric modulation can be found in 14-month-old infants in an active behavioral task. We adapted a task in which infants search longer in a box if they think an object is still inside, compared to when the box is empty (Feigenson & Carey, 2003). The target age group was chosen as it is from this age onwards when the effects of conceptual and social information on infants' behavior have been reliably probed with this paradigm (Feigenson & Carey, 2003; Feigenson & Halberda, 2008; Stahl & Feigenson, 2014, 2018). Our main goal was to establish the existence of altercentric effect in preverbal infants in a task involving a behavioral response. We modified the manual search paradigm to assess how long infants would search depending *on another person's belief* (i.e., the belief infants ascribe to this person). Specifically, we asked whether infants search longer in a box if the other person believes that it contains an object, compared to when she believes it is empty, while infants' own belief was kept constant. In Experiment 1, to track the other's belief, infants had to keep in mind how many objects she believed to be in the box. In Experiment 2, tracking the other's belief required identifying the unique perspective or aspect (Perner, Mauer, & Hildenbrand, 2011) under which she represented these objects.

Experiment 1

Method

In the three conditions of Experiment 1 we assessed whether 14-month-old infants' (n=32/condition) track events involving multiple objects and ascribe to others beliefs based on spatiotemporal or feature-based tracking; and whether representing others' beliefs may modulate infants' own search behavior. The conditions differed in the events that led to the Actor's belief: whether in her presence or absence an object was (i) removed from-, (ii) added to-, (iii) or exchanged in the box, corresponding to the three conditions. All studies received full ethical approval from the United Ethical Review Committee for Research in Psychology in [country – blinded for review] and were conducted according to the principles of the Declaration of Helsinki. Participants' caregivers gave written informed consent prior to participation. Datasets of the studies will be made available in a data repository upon acceptance of manuscript, and are available from the authors upon request during review. Video recordings cannot be made publicly available due to privacy restrictions, sample videos are provided as supplementary materials.

Participants

Ninety-six healthy full-term 14-month-old infants participated (age range from 14;0 [Months; Days] to 15;1, mean age = 14;17) in the study, randomly assigned to one of the three conditions (N=32/condition). The number of infants per condition was based on the study of Feigenson & Carey (2003) who included n=32 infants, and a power analysis for the main analysis (one-sample t-test on the difference scores) with medium effect size of Cohen's

$d = 0.5$, a power of 0.8 and alpha of 0.05, yielding $n = 34$. We therefore included $n = 32$ per condition, yielding a total of $n = 96$. Thirty-seven additional infants were tested but not included in the analyses because they did not search in any of the trials (22), the study was not completed because the baby fussed out (10), or due to parental interference or experimental error in the procedure or error in the recording (5).

Procedure

We adapted a manual search task that was previously developed to study how infants track objects and perform simple arithmetic operations on them from their own, first person perspective (Van de Walle, Carey, & Prevor, 2000). In such a task (Feigenson & Carey, 2003) 14-month-olds witnessed a certain amount (2, 3 or 4) of objects placed inside an opaque box. Next, infants were allowed to retrieve some of the objects, and then were allowed to search further. Measuring the duration of infants' manual search in the box showed in such studies that infants searched more persistently in the box if one of the objects was still inside, compared to when all objects were already retrieved.

In the present experiments, in each condition infants first received three familiarization trials that introduced them to the objects and the setup, followed by two test trials where the other person's belief was varied between trials. Within each condition infants received two trials, one trial where the Actor (depending on condition, correctly or falsely) believed an object to be in the box [Actor believes: object present (A_{obj_pres}) trials] and one where she (correctly or falsely) believed it was absent [Actor believes: object absent (A_{obj_abs}) trials]; while the infant's belief was constant across the two trials.

At the end of each test trial, infants were given the opportunity to search in the box during a 15 second period, after which the experimenter retrieved any remaining objects from the box before the next trial. Crucially, in order to avoid the confound of some infants finding the object faster by chance, in all cases when an object had remained in the box, this object was in fact surreptitiously put into a hidden compartment. Therefore, infants did not find an object in any of the test trials in Experiment 1 or 2, thus search durations reflect their persistence to search for a (potential) remaining object.

Figure 1. Schematic depiction of events in test trials of a) Experiment 1: Object Absent condition, and b) Experiment 2. In Experiment 1 the other two conditions differed from the Object Absent condition in the following ways. In the Object Present condition the Actor (A) added initially only one object, and in A's presence/absence the Confederate (C) added one more object. In the Object Exchanged-Absent condition A initially added one object, and in her presence/absence C exchanged this object to an object of a different kind. All three conditions ended with A removing one object, followed by a 15 second period during which

infants were allowed to search in the box. For further details on the procedure see text and supplementary material.

In the *Object Absent condition* initially there were two objects in the box, then both were sequentially removed, therefore at the end of the trials infants knew the box was empty. In one of two trials the Actor (A) did not witness that the second object was removed by a Confederate (C), and therefore believed that it remained in the box (Actor believes object present (A_{obj_pres}); false belief trial). In the other test trial both A and the infant knew that all objects had been retrieved (Actor believes object absent (A_{obj_abs}); true belief trial), see Figure 1.

In the *Object Present condition* there was initially only one object in the box, then a second (identical) one was added by C. Finally, one of the two objects were removed, thus in the end one object remained in the box. Infants in this condition therefore expected an object to remain in the box. In one of two trials A did not see that a second one was added and therefore in the end believed the box was empty (Actor believes object absent (A_{obj_abs}); false belief trial). In the other trial A knew the second object was added and thus also expected an object to remain in the box (Actor believes object present (A_{obj_pres}); true belief trial).

In the *Object Exchanged-Absent condition* initially there was one object in the box, which was then exchanged to another (differently looking) one by C. Finally, this second object was removed, therefore at the end of the trials infants knew the box was empty. In one of two trials A did not witness that the first object was exchanged to the second, and therefore believed that the first object remained in the box by the end of the trial (Actor believes object present (A_{obj_pres}); false belief trial). In the other test trial both A and the infant

knew that when the second object was removed the box remained empty (Actor believes object absent ($A_{\text{obj_abs}}$); true belief trial).

Materials

We used a white cardboard box (29*29*15 cm) with a 14*8 cm opening that was covered by an elastic cloth that prevented infants from seeing inside the box but enabled reaching into it. The box had a hidden compartment in its back where objects could be hidden and which was inaccessible to the infants. In familiarization we used colorful whistles with a ball inside that made a rattling sound. In test there were whistles of different colors (red, green, or blue) that did not rattle, and an additional toy rattle in the Object exchange condition (see Supplementary Materials Figure S1a-c).

Coding

We coded the duration of infants' searching during the 15s period when the box was in front of them. Infants were scored as searching whenever one or both hands were in the box, with their knuckles passing the entrance cloth of the box. If infants reached into the box opening but clearly just manipulated/played with the cloth we did not count it as searching. Half of the participants ($n=16$) of each condition (Object Absent, Object Present, and Object Exchanged-Absent) were coded on both trials by a second coder who was blind to the purpose of the study and the trial type ($A_{\text{obj_abs}}$ vs. $A_{\text{obj_pres}}$); inter-rater agreement was $r(96)=.972, p<.001$.

We calculated an altercentric modulation score via subtracting from the search durations on the A_{obj_pres} trials the search durations on A_{obj_abs} trials. Such a difference score is commonly used in this type of task, as absolute search times may vary across infants (Feigenson & Carey, 2003; Stahl & Feigenson, 2018). A modulation score above 0 would reflect that infants search longer when the other believes an object to be present, compared to when she believes the box is empty.

Results

We first compared the altercentric modulation scores in Experiment 1 to chance level (0) (for mean search values on individual trials, see Supplementary Materials Figure 4). Infants on average searched longer on A_{obj_pres} trials than on A_{obj_abs} trials, as reflected by a positive altercentric modulation score ($M_{diff} = 0.924$ s, $SD = 3.529$, see Figure 2a) significantly above chance ($t(95) = 2.565$, $p = .012$; Cohen's $d = 0.262$, 95% CI = [0.208, 1.639]; all statistical tests two-tailed). Thus, infants overall searched significantly longer when the Actor believed an object remained in the box, compared to when she believed there is no object left.

Subsequently the altercentric modulation scores were entered into a univariate ANOVA with condition (Object Absent / Object Present / Object Exchanged-Absent) and Order of Test (A_{obj_pres} first or A_{obj_abs} first) as between-subject factors, yielding a significant effect of Order of Test ($F(1,90) = 15.59$, $p < .001$, $\eta_p^2 = 0.148$), no effect of condition ($F(2, 90) = 0.099$, $p = .906$, $\eta_p^2 = .002$), and no interaction between condition and order ($F(2,90) = 0.032$, $p = .969$, $\eta_p^2 = 0.001$). The altercentric modulation score was different from chance in the A_{obj_pres} first order ($t(47) = 4.581$, $p < .001$; Cohen's $d = 0.661$, $M_{diff_A_obj_pres_first} = 2.271$ s, $SD = 3.434$, 95% CI =

[1.274, 3.268]) but not in the A_{obj_abs} first order ($t(47)=.943$, $p=.35$; Cohen's $d= 0.136$, 95%, $M_{diff_A_obj_abs_first}= -0.423$ s, $SD=3.109$, $CI= [-1.326, 0.479]$).

Figure 2. Average altercentric modulation scores (difference in search durations between A_{obj_pres} : Actor believes object is present and A_{obj_abs} : Actor believes no object remained trials) in a) Experiment 1 (N=96); and Experiment 2 (N=64) split by whether infants passed the criterion in baseline trials, and in b) Experiment 1 split by order of test trial. Solid and dashed black lines depict the median and mean respectively, boxes indicate interquartile range, whiskers show 1.5 times the interquartile range and circles show outliers that fall outside this range. Asterisks indicate significant difference from zero.

The effect of order on the altercentric modulation scores (i.e., on the difference between trials) indicates that the two belief trials were significantly different from each other in one order and not in another. To check whether the data pattern holds even when trial order

cannot play a role, we analyzed the log-transformed search scores* on the first trials only, in a univariate ANOVA with trial type (A_{obj_pres} vs. A_{obj_abs}) and condition (Object Absent / Object Present / Object Exchanged-Absent) as between-subject variables. This revealed a significant difference in search duration between the two trial types ($F(1,90)= 4.844, p=.030, \eta_p^2=.051$), and no effect that on the very first trial infants who received an A_{obj_pres} trial (Actor believes object present) searched significantly longer than those receiving an A_{obj_abs} trial (Actor believes object absent), with mean raw scores of $M_{A_{obj_pres}}= 6.490$ s, $SD=3.026$ and $M_{A_{obj_abs}}= 5.042$ s, $SD=3.374$.

Discussion

Infants searched longer when according to the Actor's belief an object remained in the box, compared to when she believed all have been retrieved. As infants' belief about the box's contents was constant within the trial pairs, this difference arguably reflects the effect of the actor's belief on infants' behavior. The difference in modulation scores in the two presentation orders could arise from the first trial being more sensitive to factors increasing search times (e.g. the Actor's belief in A_{obj_pres}), combined with children being less easily motivated to search later on. Thus two different effects may be working against each other: a decrease across trials in motivation to search (Van de Walle et al., 2000) and an effect of

* As some trials included a zero value, a constant of 1 was added to every value before log-transformation. However, the same analyses with excluding those infants ($n=5$) who had a value of 0s on the first trial (resulting in $n=91$ infants included in the analysis) on the log-transformed values of the search times lead essentially to the same results (see Supplementary Material).

the other's belief on infants' search. The influence of the other's belief on infants' search times also holds between-subjects in the first trial, confirming that the main effect stems from our conceptual manipulation even when trial order cannot play a role.

Overall, these results show that infants tracked another person's beliefs involving individuation and tracking of multiple objects based on spatiotemporal and feature information. Experiment 2 was set out to investigate whether infants ascribe to others beliefs involving aspectuality (Perner et al., 2011) and thus are sensitive to the unique aspect under which the other represents the objects.

Experiment 2

While at least by 18 months of age infants successfully track belief scenarios involving some forms of aspectuality (F. Buttelmann, Suhrke, & Buttelmann, 2015; Scott & Baillargeon, 2009; but see Fizke, Butterfill, van de Loo, Reindl, & Rakoczy, 2017), it is an open question whether infants grasp the fundamental inferential requirement of understanding aspectuality: that another person's partial information about an object can lead her to mistakenly posit the existence of the two objects instead of one. We tested whether 14-month-old infants understand beliefs relying on the person's mistaken individuation of a single object as two (thus holding a false belief about its identity), based on the aspect (here: visual appearance) under which she perceives them. In first-person computations a majority of 14-month-old infants could override their default assumption that different appearances signal distinct objects, if they were shown that objects could have dual appearances (Cacchione, Schaub, & Rakoczy, 2013). Experiment 2 asked whether infants can use such inferences to represent another person's belief about object identity. Considering that

infants' limitation to inferentially individuate objects from their own perspective may constrain them in attributing such contents to others (in Cacchione *et al.* 2013, approximately 70% of infants showed the predicted behavior), we introduced two baseline trials to assess whether infants individuate objects on the basis of their knowledge about the two appearances, and predicted that only infants who show this understanding would successfully track similar events from the other person's perspective, and show altercentric modulation in belief trials.

Methods

Infants were first presented with two belief trials in counterbalanced order: true belief (A_{obj_abs}) and false belief (A_{obj_pres}) trials. Following this, they received two baseline trials in fixed order: an unknown-transform ($B:I_{obj_pres}$) trial, then a known-transform ($B:I_{obj_abs}$) trial. The fixed order of baseline trials was implemented in order to avoid carry-over from 'known-transform' ($B:I_{obj_abs}$) trials (i.e. that infants would assume that all objects may transform).

Participants

Sixty-four 14-month-old infants participated (age range from 14;2 to 15;3 mean age = 14;16). Thirty-five additional infants were tested but not included in the analyses because they did not search in either of the belief test trials (13), they fussed out (15), or due to parental interference or experimental error in the procedure (7). Sample size was determined as for Study 1. We aimed to have $n=32$ infants who passed the baseline criterion

as we expected specifically those infants to track the other's belief and thus show an effect in the belief trials.

Materials

We used a white cardboard box as in Experiment 1, but slightly larger in order to have a large enough opening for the new objects (that were slightly bigger than in Experiment 1). As experimental objects we used plush figures that could change their appearance via turning them inside out. We used toys of somewhat different size, color and material in baseline and test trials (for details see Supplementary Materials).

Procedure

Familiarization trials

The first two familiarization trials were identical to Experiment 1, but the third familiarization came after the two belief trials and served to re-engage infants.

Test trials

In test trials it was always the confederate (C) who took out the objects from her bag, to avoid any suspicion children might have that the actor (A) has knowledge of the transforming feature of the objects. C took out an object, put it on the top of the box, and named it. Then A repeated the label and put the object into the box. In A_{obj_pres} trials A left at this point. Then C retrieved the toy and demonstrated the transformation (while labeling both appearances), and then put the object in its new form back into the box. In A_{obj_abs} trials

A left at this point. Then in both trials A came back, sat down and retrieved the toy in its new form, and put the toy away into a bag, followed by a measurement period. In the end of the trial C always demonstrated the reverse transformation when A was present. After this the second test trial followed. Thus in A_{obj_abs} trials A knew there was only one object which was now retrieved leaving the box empty; while in A_{obj_pres} trials A must have thought there were two objects, one of which likely still remained in the box.

Baseline trials

Unknown Transform ($B:I_{obj_pres}$) trial

In baseline trials C sat passively at the table. A took out an object from her bag, named it, then put in the object to the box, and then immediately retrieved it in its changed form (as transformation was done invisibly to the child, inside the box), and then put it away. Then a measurement period followed. If infants individuated two different objects from the two appearances, they should search longer for the second, “remaining” one (while, in fact, the box was empty). Afterwards A took out the toy from her bag and showed the transformation to the infant to reveal that in fact there was only one object, just as it was done in the belief trials for A.

Known Transform ($B:I_{obj_abs}$) trial

In these trials A did not do the transformation surreptitiously inside the box, but retrieved the toy, showed the transformation, and put it back. Thus if infants followed the transformation indicating that the two appearances belong to the same object, when she later retrieved it in the new form, they knew that the box was emptied.

Coding

Search durations were coded as in Experiment 1. Twenty-five percent of infants ($n=16$) were coded on all four trials (unknown transform vs. known transform baseline trials, and A_{obj_abs} vs. A_{obj_pres} test trials) by a second coder who was blind to the purpose of the study; inter-rater agreement was $r(64) = .951, p < .001$.

To determine whether infants made the predicted first-person inferences in baseline, we set a criterion that aimed to grasp a meaningful difference between search durations in the two baseline trials. Infants were considered to have ‘passed’ the baseline criterion if search duration on the ‘unknown transform’ trials was equal or higher than the search duration on the ‘known transform’ trial multiplied by the constant of 1.2, which was based on the average ratio between search times in the two types of trials in Experiment 1. If infants did not search at all in the ‘known-transform’ baseline trial (which is considered a valid response), since a value of zero cannot be multiplied to produce a meaningful minimum value for the ‘unknown transform’ trial, a minimum of 500ms search duration in the unknown-transform baseline was set to categorize an infant as ‘passer’ (see details in Supplementary Materials)[†].

[†] The minimum difference of 500ms was a pre-set value aimed to approximate the shortest meaningful duration. Since search duration was coded from the moment when the child’s hand was inserted halfway into the box, until the moment when it was halfway taken out, this duration arguably reflects an initiated reaching/searching action. Importantly,

Results

We aimed at 32 infants who qualify as passing this baseline criterion, and 32 additional infants finished the experiment but did not pass baseline. In accordance with our criterion, in the ‘passing’ group infants searched longer on B:Iobj_pres trials than in B:Iobj_abs trials ($M_{B:Iobj_pres} = 5.224$ s, $SD = 4.056$; $M_{B:Iobj_abs} = 1.577$ s, $SD = 1.904$). This was not the case in the ‘non-passing’ group, where infants in fact searched longer on B:Iobj_abs trials than on B:Iobj_pres trials ($M_{B:Iobj_pres} = 2.419$ s, $SD = 3.843$; $M_{B:Iobj_abs} = 3.361$ s, $SD = 4.207$).

To test the prediction that particularly those infants who individuate objects on the basis of their knowledge about the two appearances in the baseline trials, would represent the actor’s beliefs in test trials; we split infants into two groups based on whether they have passed the baseline criterion. In the group who passed baseline ($n = 32$) infants searched on average longer on Aobj_pres trials than on Aobj_abs trials ($M_{diff_passing} = 1.345$ s, $SD = 3.208$, see Figure 2); and a one-sample t-test showed that this score was significantly different from chance ($t(31) = 2.371$, $p = .024$; Cohen’s $d = 0.419$, 95% CI = [0.188, 2.501]). An independent-samples t-test with order of test trial (Aobj_pres first vs. Aobj_abs first) as between-subject variable showed no significant effect of order $t(30) = 1.914$, $p = .065$; Cohen’s $d = 0.676$, 95%, $M_{Aobj_pres_first} = 2.386$, $SD = 2.76$, $M_{Aobj_abs_first} = .303$, $SD = 3.363$, 95% CI = [-0.139, 4.305]. In the non-passing group the altercentric modulation score was not significantly different from

however, the results are independent of whether we use the above-defined criteria that are derived from Experiment 1, or conceptually similar criteria derived from earlier studies (see Supplementary materials).

chance ($M_{diff_nonpassing} = -0.428$ s, $SD = 3.927$, $t(31) = 0.617$, $p = .542$; Cohen's $d = 0.109$, 95% CI = [-1.844, 0.987]), and an independent-samples t-test with order of test trial (A_{obj_pres} first vs. A_{obj_abs} first) as between-subject variable showed no significant effect of order $t(30) = 1.160$, $p = .255$; Cohen's $d = 0.402$, $M_{A_obj_pres_first} = .424$, $SD = 4.889$, $M_{A_obj_abs_first} = -.1181$, $SD = 2.77$, 95% CI = [-1.221, 4.429].

Additionally, we correlated difference scores from baseline trials with the altercentric modulation scores from test trials, which revealed a significant positive correlation between the two ($r = .258$, $n = 64$, $p = .04$).

In sum, the 'baseline-passing' infants searched longer in the box when according to the other person's (false) belief there were two separate objects, and after the removal of an object she believed that one object remained in the box (A_{obj_pres} trials); compared to when she knew that there is only one object with two appearances, and therefore believed that in the end all objects have been retrieved (A_{obj_abs} trials). Crucially, it was the 'baseline passing' infants - who varied their searching behavior depending on their own knowledge about the object's identity in the respective baseline trials - who showed a pattern consistent with representing the other person's different beliefs in the test trials.

Discussion

Experiment 2 showed that 14-month-old infants who are sensitive to the dual identity of objects in first-person representations also spontaneously tracked others' beliefs about object identity, which modulated their duration of search in the box. Therefore, in contrast with recent proposals (Apperly & Butterfill, 2009), we provide evidence suggesting that

computing others' beliefs involving aspectuality may occur spontaneously, and emerge early in development. Another study using an interactive helping task did not find evidence in toddlers for understanding false beliefs involving aspectuality (Fizke et al., 2017). However, the helping task differs in many aspects from the current task. For example, the continuous measure in our task may be more sensitive to capture these phenomena than the binary assessment in the helping task. Additionally, in our study infants who failed to grasp aspectuality from a first-person perspective also showed no evidence of belief attribution, and such factors may overshadow children's socio-cognitive abilities in other tasks too. Infants' limitations in belief attribution may therefore at least in part come from limitations of their developing cognitive systems used in first-person reasoning - a possibility also supported by the correlation between infants' behavior on the baseline and belief trials.

The intuitive prediction is that when it comes to complex third-person inferences, giving infants training in a specific first-person inference would also have an effect on infants' understanding of others' beliefs involving the same domain. For instance, while infants younger than 11.5 month usually pay little attention to the objects' color compared to their shape (Wilcox, 1999), training them with the importance of color information in object individuation may also facilitate their understanding that others may use color information for individuation. Whether such effects are indeed observable in various domains and how fast such transfers may occur is a matter for future studies.

General discussion

Two experiments asked whether 14-month-old infants show altercentric modulation in an active behavioral task. Results showed that infants searched longer in a box when another

person believed it contains an object, compared to when she believed that all had been retrieved. Infants' own knowledge was identical in the two trials, therefore the observed differences should be due to the other person's belief about the content of the box.

This altercentric modulation is consistent with other studies showing that infants' (Kovács et al., 2010) and adults' (Freundlieb et al., 2016; Samson et al., 2010) behavior can be influenced by another agent's belief or visual perspective. However, it also extends previous findings in two significant ways. First, the present scenarios are novel in that successful belief attribution required individuating and tracking multiple objects, and their appearance or identity. The current results therefore support the possibility that from early on infants can entertain various types of belief contents, including beliefs that involve appreciating the aspectuality of mental representations. Second, we found altercentric modulation in an active everyday behavior (searching) in early infancy, at an age at which, to our knowledge, there are no published reports documenting such effects.

While these results suggest that infants encoded the other person's belief, at the same time they also open up questions regarding the relation between infants' own representations and those of the actor. While there was an effect of the other person's belief (infants searched longer in $A_{\text{obj_pres}}$ trials when the actor believed an object remained in the box than in $A_{\text{obj_abs}}$ trials when she believed it to be empty), there were seemingly no effects of the infants' own beliefs in Experiment 1, as there was no overall difference between the conditions where an object was present and where no objects were present. Infants may be particularly prone to attend another person's perspective to facilitate social learning (Kampis et al., 2013), and as a consequence the other's belief might even outweigh their own representation (Southgate, 2020).

In adults, altercentric effects are typically considered akin to a by-product of our generic heightened sociality or an indication of spontaneous perspective taking, likely facilitating interpersonal coordination (Gallotti & Frith, 2013). From a developmental perspective, however, it could be advantageous to have a disposition to attend to others' point of view from early on (Kampis et al., 2013; Southgate, 2020). Infants face a crucial learning problem, and the social environment is a useful source to select the most relevant sources of information. On one hand, attention to others' perspective and beliefs would allow infants to learn *about* others, enabling infants to take part in social interactions with increasing success, via action coordination, action interpretation, and action prediction. On the other hand, such a sensitivity would also allow infants to learn about the material world *through the lenses of others* (Kampis et al., 2013). Kampis et al. (2013) found that 10-month-olds readily applied a preference they learned about one agent (preferring one object over another) also to another, novel agent; and argued that infants have treated the content of the other's preference as universally applicable, generic information attached to the object. Thus, sensitivity to others' mental states may serve a dual function early in human ontogeny, enabling infants both to learn about others, as well as to learn about the world via the perspective of others around them.

In the current study, however, infants' representations were not directly pitted against that of the other person's, rather, we intended to keep infants' beliefs constant across trials in each condition. As such, the current data do not speak to the relative strength of infants' own representations vs. those they form based on the other's perspective (Southgate, 2020). A critical question to be addressed by future work remains how first-person and third-person (attributed) representations are separated, whether altercentric modulation may

change over development, and under what circumstances representations attributed to others spontaneously modulate one's own action planning.

Further questions for future work remain whether altercentric effects would generalize to a variety of different populations (e.g., non-WEIRD societies, Henrich, Heine, & Norenzayan, 2010). Relatedly, the phylogenetic origins of altercentrism have yet to be uncovered. Recent evidence indicates that non-human apes and monkeys predict others' actions based on their beliefs (Hayashi et al., 2020; Krupenye, Kano, Hirata, Call, & Tomasello, 2016), and consequently some proposals have drawn strong parallels between apes' and human infants' socio-cognitive abilities (Apperly & Butterfill, 2009; Tomasello, 2018). Yet, at least two aspects of the current findings suggest that such conclusions may be premature, as to our knowledge no altercentric effects have been demonstrated in non-human animals, and there is no evidence for the understanding of aspectuality of beliefs in any other species. The fact that human infants adopt the other's perspective so readily points to a strong tendency to spontaneously focus on the other's mental states and raises the crucial question whether the altercentric tendency of humans may be a species-unique phenomenon.

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