Prepared to learn about human bodies' goals and intentions

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Human beings are one of the first and one of the most frequent “objects” in infants’ environment. Infants’ interactions with their caregivers are extremely diverse and socially rich. Caregivers provide care, affection and knowledge. It therefore seems trivial to assume that one of the first things human infants will learn is how to identify their conspecifics. The first section of this chapter reviews a series of studies that contradict the above intuition. Experimental research presented in this section has shown that infants, prodigiously good at learning about faces, are slow at learning about the human body appearance. A few explanations have been put forward to integrate these conflicting findings. Faces and bodies are similar in many respects (e.g. they have component parts whose relative position is species-specific; minor variations in the distance between these components occur between individuals) but also different in others (e.g. body parts movement leads to ampler structural changes than face component movements and these movements are often object-oriented). Thus, because movement changes the outline of bodies it may be more difficult to build a prototype of the human body than of the human face. Alternatively it could be that body movement, particularly the goals of human action, grab infant’s attention, at the expense of learning about body structure. It has been proposed that infants’ learning about the structure of the human face is secondary to their learning about facial communicative cues like eye-contact and eye-gaze (Gliga & Csibra, 2007). In the second section we will review evidence in support of a similar developmental story for acquiring knowledge about body structure. We will show that, before acquiring precise knowledge on humans’ appearance, infants are proficient at understanding and anticipating human (body) action. This attentional bias is driven by their need to learn from others, which requires understanding other people’s goals and intentions. The final section will attempt to integrate these two lines of research. We will propose that the principles infants use to understand the goals of human actions can also be used to learn about which bodily actions are possible and which are not, and eventually about human body structure. We will bring arguments to support this view from both developmental and adult cognitive neuropsychology.

1. Protracted learning about human body structure

Despite possessing good visual processing capacities from very early on, which are successfully deployed to learn about objects and faces, human infants are surprisingly slow at learning about the human body structure. A number of studies have shown that it takes between 9 and 18 months to tell apart a scrambled human figure from a typical one, depending on the realism of the figure (Slaughter & Heron, 2004; Slaughter, Heron, & Sim, 2002 and see Slaughter, Heron & Christie, in this volume). These results are surprising, considering that, at only a few months old, infants are able to acquire visual categories based on a variety of visual dimensions. For example, presented with a succession of differently shaped triangles, four month-olds will notice the shape similarity and look longer if a different shape is presented in a habituation design (Quinn, 1987). As they grow older infants become able to learn categories based not only on one common feature but also on combinations of shapes or parts (Younger & Cohen, 1986), one of their most well-known abilities in this sense being their face processing skills. In a task equivalent to the body discrimination study discussed above, infants as young as 2 months look longer towards a normal face than towards a scrambled one (Maurer & Barrera, 1981). By 5 months of age, infants would even notice a change in the orientation of only one face element, within an otherwise typical face (Bhatt, Bertin, Hayden, & Reed, 2005).

These studies show that even young infants posses detailed knowledge about the human face structure. Brain imaging studies, measuring event related potentials (ERPs) have shown that neural specialization for face processing parallels the behavioural findings. Two posterior components, the N290 and the P400 are recorded in infants in response to visual stimulation (Gliga & Dehaene-Lambertz, 2005), and are considered to be the precursors of the adult N170, a face sensitive component (Carmel & Bentin, 2002). The N400 is stronger for typical than for scrambled faces in 3-months-olds (Gliga & Dehaene-Lambertz, 2005) and at 12 months of age the N290 differentiates between inverted and upright human faces but not monkey faces (Halit, de Haan, & Johnson, 2003).

In contrast to their knowledge of human faces, infants' knowledge about the human body structure seems very limited. Like faces, human bodies are processed within specialized brain areas in the adult brain (Taylor, Wiggett, & Downing, 2007), and evoke similar electrophysiological responses to the N170 (Gliga & Dehaene-Lambertz, 2005). Bodies and faces seem to be processed in a similar way, e.g. both show an inversion effect (Reed, Stone, Bozova, & Tanaka, 2003; Stekelenburg & de Gelder, 2004). This parallel between face and body perception has motivated research into the development of body representations, which were expected to closely follow that of face representations. In one of these studies, a preferential looking paradigm was used to investigate whether infants aged 12, 15 and 18 months could discriminate between a typical and a scrambled body shape (Slaughter et al., 2002). Only at 18 months did infants show a preference for the scrambled body, suggesting that only these older infants found the scrambled body to be unexpected. When more realistic body representations are used, i.e. real people in movement, infants as young as 9 months or 4-6 moths show discrimination of scrambled and intact bodies see

(Slaughter, Heron & Christie, in this volume). These results contrast with infants' performance with a class of artificial objects. These objects were similar to bodies in the sense that they also had a number of component parts whose relative position could vary. Even 12-month-old infants succeeded at discriminating the prototypical from "scrambled" versions of these objects (Slaughter & Heron, 2004). What is it about bodies that makes it so difficult to grasp their typical configuration?

To account for the relatively poor knowledge about the structure of human bodies, Salughter & Heron (2004) make an interesting observation: when bodies are in movement, the relative position of the limbs on the body or the body symmetry are frequently violated. The many possible positions in which the human body may be viewed (e.g. upright, seated, kneeling) may thus be the reason behind young infants' failure to build a human body category. This may also explain the fact that four-months-olds (unlike seven-month-olds) who are habituated to various exemplars of human figures, in different positions, do not subsequently dishabituate when they see a picture of an animal (Quinn, 2004). Infants experience with people might be too variable to lead to a narrowly defined human body category. While animals can be equally versatile, it is possible infants have seen more 2-D depictions of animals (in probably prototypical postures) than real life exemplars.

While body movement might prevent infants from learning the normal configuration of the human body, movement in itself can be a source of valuable information. Adults use body motion to gain information about a person's emotional state, identity, gender, or the action accomplished (Blake & Shiffrar, 2007; Hill & Johnston, 2001). A great proportion of the studies investigating the perception of body motion employed point-light-displays (PLD), in which the movement of the body is conveyed in the absence of any surface feature information. Despite the poverty of these displays, adults immediately perceive them as representations of humans in motion. Infants as well seem to be "recognizing" biological movement in these displays. For example, 2-day-old infants prefer human PLDs to scrambled PLDs, in which the dots' positions and movements are randomized (Simion, Regolin, & Bulf, 2008). Infants also discriminate and prefer upright human PLD to inverted PLDs (Bertenthal, 1996; Reid, this volume). Inversion effects are taken as evidence for specialized processing of certain object configurations which, in this case, imply that infants also posses some knowledge about the typical body configuration. While these studies suggest that there are some similarities between how infants and adults perceive PLDs, we are still far from knowing whether infants can gather the same amount of information from these displays as adults do, i.e. gender, identity and actions. It is still unknown whether infants even perceive PLDs as representations of their conspecifics, and as equivalent to a picture of a human body.

Telling apart biological and non-biological movement is useful but it is equally useful to know the range of possible body movements. As adults we are highly sensitive to movements that go beyond what is humanly acceptable (e.g. a contortionists' movements). When brain activity is measured in adults in response to human actions, possible actions evoke stronger parietal activity (Costantini, Committeri, & Galati, 2008; Stevens, Fonlupt, Shiffrar, & Decety, 1999). Attempts to show similar knowledge about constraints in body movements in infancy have been inconclusive (Beier & Spelke, personal communication). In these studies infants showed no preference when presented with video sequences depicting possible or impossible arm or body rotations (e.g. someone's arm doing a 360 rotation or someone making a sharp bend backwards).

What the studies briefly reviewed here clearly show is that infants possess knowledge about biological motion and, as we will see further, human actions, from very early on, before they acquire knowledge about the structure of human bodies. We will see in the next section that young infants ignore body structure knowledge when involved in understanding the meaning of human body actions.

2. Early understanding of actions

Unlike knowledge about human bodies, infants appear to have a much earlier understanding of human action, and researchers agree that infants interpret actions as goal-directed from at least 6 months of age. This is not a trivial feat. Most actions occur within a continuous and unsegmented stream, and in order to find intentional, goal-directed actions, individuals must be capable of segmenting this continuous stream into meaningful units (Zacks, Tversky & Iyer, 2001). Evidence that infants are able to do this comes from studies by Wynn (1996) and Baldwin and colleagues (Baldwin, Baird, Saylor & Clark, 2001). For example, 6-month-old infants habituated to a puppet jumping two times, look longer when shown an event in which a puppet jumps three times, than infants who were habituated to a three-jump event (Wynn, 1996). This is the case even when these jumping events are embedded in a continuous stream of motion, suggesting that they were able to parse this dynamic event into discrete units. In a different study, Baldwin and colleagues presented 10 to 11-month-old infants with dynamic events (someone cleaning the kitchen) in which the events were paused either at time points coinciding with the actor's goal or at points which interrupted the actor's pursuit of a goal. Infants in this study looked longer at the interruption events than at the completion events. Furthermore, even when these dynamic events were unfamiliar, infants were still able to detect the endpoints of intentional actions (Saylor & Ganea, 2007). Recent evidence measuring brain activity suggests that 8-month-olds also detect these interruptions in dynamic events, exhibiting an increase in gamma-band activity when they are presented with an incomplete pouring event but not a completed pouring event (Reid, Csibra, Belsky, & Johnson, 2006).

Infants are also able to predict human action outcomes. Employing eye-tracking technology, Falck-Ytter and colleagues showed infants small balls either being placed by a hand into a container, or moving by themselves into the container. 12-month-old infants made predictive saccades, anticipating the action outcome, only when the balls were moved by the human hand (Falck-Ytter, Gredeback, & von Hofsten, 2006). In another study, 10-12 month-olds were repeatedly shown the end of a throwing event in which a previously shown inert beanbag landed on a stage floor in front of them. Crucially, they did not see what caused the beanbag to land on the stage. In test trials, they were shown a human hand appearing, either from the side from which the beanbag had emerged, or the opposite side. Infants looked significantly longer at the event in which the hand appeared from the opposite side, suggesting that they expected that a hand would have been the cause of the event and were surprised when it appeared from a side incongruent with this expectation (Saxe, Tenenbaum, & Carey, 2005). In a follow-up study, 7-month-old infants were shown a similar beanbag event, but this time on test trials they were first briefly shown the location of a hand. Then, the beanbag either appeared from this location or from another location and infants looked longer at the event in which the beanbag appeared from the location without the hand (Saxe, Tzelnic, & Carey, 2007). Together these studies suggest that infants have an early understanding of the causal role that human hands play in the movements of inert objects.

This early ability to detect intentional action units, even within novel streams of action, alludes to a brain prepared to detect goals in the actions of others. This is unsurprising given the immense advantage such ability would offer. Detecting goals enables individuals to predict outcomes as well as intervening actions, and prepare one's own actions for coordinated interaction with others (Csibra & Gergely, 2007). Furthermore, for young learners, goal detection may provide a valuable basis for imitative behaviour in the absence of ostensive cues to disambiguate which elements of a demonstration are worthy of imitation (Bekkering, Wohlschlager, & Gattis, 2000; Call, Carpenter, & Tomasello, 2005).

Goal attribution in infancy is also evidenced by their behaviour in another paradigm, developed by Amanda Woodward. In this paradigm, infants are habituated to a person repeatedly reaching for one of two toys. In test trials, the two toys switch locations and the person either continues to reach for the 'old' toy in its new location, or reaches for the 'new' toy in the old location. Infants from 6 months of age look longer when the person reaches for the new toy (despite the pathway the arm takes being the perceptually more familiar one) than when the person reaches for the old one, suggesting that they had encoded the persons goal as the toy which they were repeatedly reaching for and were surprised when the person reached for the other toy.

This section has revealed a puzzling contrast between the late acquisition of knowledge on human body appearance, and the impressive early capacities to understand and predict the goals of human action. Infants' "obsession with goals" (Csibra & Gergely, 2006) derives from their high dependence on people for both survival and knowledge acquisition. To predict other people's actions (e.g. is mummy preparing my bottle?) or to learn from others (e.g. that's the way you open the toy box!), infants have to first identify the goals of their actions. We propose here that it is their 'obsession' with goals early in life that directs infants' attention away from learning about the detailed structural properties of the human body to first learning about body actions. Some evidence exists to show that infants pay more attention to object directed actions than to object appearance. (Perone, Madole, Ross-Sheehy, Carey, & Oakes, 2008). In this study 6- to 7- months olds were habituated to events in which a hand acted on an object to produce a sound. In the test phase infants robustly responded to changes in action type e.g. squeeze or roll, but did not respond to changes in object appearance, e.g. colour and shape. By 10 months of age infants' attentional abilities improve and they manage to encode both the actions and the sounds of objects as well as the relationship between specific object appearances and actions (Perone & Oakes, 2006). One could test in a similar way the hypothesis that younger infants are biased towards the goal of the action and not the agent's body properties. One could familiarize infants with goal directed actions and non goal-directed actions and subsequently measure their ability to detect a change in structural properties of the agent or in the action. Based on the evidence that infants are particularly interested in goal-directed actions we also make the prediction that infants will encode body properties better when the action cannot be interpreted as goal-directed.

We proposed here that infants' poor knowledge about the human body configuration stems from their preferential interest in what one does and not who does it. A similar bias was previously proposed to explain the discrepancy between the excellent gaze-processing abilities infants have early in life, at a time when their face recognition is still poor (Gliga & Csibra, 2007). In the case of the face it is the need to interact with others rather than recognising them that induces the early attentional biases to the eyes and away from other face parts and their relationships. Recognizing conspecifics is an equally important ability but it may be that the richness of the multi-modal cues available for discriminating individuals, e.g. the odours, the voices, can compensate for the lack of visual expertise and is initially sufficient to tell apart the small number of relevant individuals in a toddler's environment.

3. The principles used to understand the goals of human actions could drive learning about the human body

A debate has arisen over how the ability to attribute goals emerges. On one side there are researchers who advocate the view that this ability develops slowly through experience, both observing other people's actions and carrying out actions themselves (Woodward, Sommerville, & Guajardo, 2001). This view is supported by a growing number of studies. For example, three-month-olds, who do not make purposeful reaches and grasps themselves, do not look longer when a person reaches for a new toy in test events on the Woodward paradigm. However, Sommerville and colleagues have shown that if 3-month-old infants are given some experience with grasping objects – they give them experience wearing Velcro mittens that enables their swipes at objects to result in obtaining the object – they do subsequently look longer at someone else's reach for a new object with the Velcro mittens (Sommerville, Woodward, & Needham, 2005). In another demonstration of the important role that experience plays, Sommerville and Woodward showed infants an event in which an actor pulled one of two cloths to obtain an out of reach toy. Only those infants who themselves were adept at cloth-pulling looked longer when the actor now pulled a cloth to obtain a different toy (Sommerville & Woodward, 2005).

An alternative view is that infants do not need experience with actions and agents in order to attribute goals to them – this feat is achieved through the deployment of abstract principles that are insensitive to the type of agent, and goals are attributed whenever an action is efficient with respect to a goal (Gergely & Csibra, 2003). These researchers propose that infants apply a non-mentalistic inferential principle in order to interpret actions as goal directed. Specifically, infants (like adults) assume that actions bring about goals through the most efficient means possible, given the particular situational constraints. Indeed, infants do appear to be willing to attribute goals to a wide range of actions and agents, for example to small geometric animations, agents that are presumably completely new to the infant, if the efficacy principle is satisfied. In the original demonstration of this principle at work, 12-month-old infants were habituated to animations in which a small red ball jumped over a wall and came to rest next to a blue ball. Then, infants saw two test events in which the wall was no longer there and the red ball either moved in a straight path towards the blue ball or continued the jumping path even though it was now unnecessary. Despite the jumping action being the perceptually more familiar action, infants in fact looked longer at this action than the straight pathway, However, if infants were habituated to an agent that was not behaving in an efficient way (jumping when the location of the wall did not necessitate it), they did not look longer at either of the two test events, suggesting that in this condition infants have not inferred the goal of the small red ball to be that of approaching the blue ball (Gergely, Nadasdy, Csibra, & Biro, 1995). In a number of variations on the Woodward paradigm, researchers have shown how infants will attribute goals to an unfamiliar mechanical claw (Biro & Leslie, 2007).

In the same way as infants use situational constraints (i.e. the presence of a barrier) to infer action goals, they can infer the presence of a constraint to explain the inefficient path taken to achieve a goal. If no obstacle blocks the path from the hand to an object one wants to grasp, infants expect the hand to follow the shortest path to the object (Kiraly, Jovanovic, Prinz, Aschersleben, & Gergely, 2003; Southgate, Johnson, & Csibra, 2008). Nonetheless, if a non-efficient means is repeatedly used to attain a goal, infants infer the existence of a constraint. This is what happens in a follow up study to Gergely at al., 1995. This time all infants see is the small ball jumping to approach the other ball (i.e. an inefficient way of achieving that goal) but they do not see the barrier, which is hidden from view by an occluder (Csibra, Biro, Koos, & Gergely, 2003). When the occluder is removed, in the test trials, 12-month-old (but not 9-month-old) infants look longer in the wall absent versus the wall present condition, suggesting that they inferred the existence of a barrier the agent has to jump over. 9-month-old infants, who succeeded at inferring which path the small ball will take, in the absence of the barrier fail at making the reverse inference.

These latter studies strongly suggest that it is not necessary for infants to identify the perpetrator of an action as human, and hence to paying attention to human-specific body structure is not necessary in order to successfully interpret their actions as goal directed. Indeed, one particular study demonstrates the redundancy of body structure knowledge for successful goal attribution. In this study, having been habituated to an event in which a human arm behaves efficiently to obtain a small ball, 6-month-old infants then saw two test events in which a box now obstructed a direct reach for the ball (Southgate et al., 2008). In the first test event, infants watched the arm move the box out of the way and then reach for the ball. In the second test event, the human arm was seen ‘snaking’ around the box in a biologically impossible manner. However, if it were possible, the second event would be a more efficient route to the goal as it would not require the effort of moving the box out of the way first. 6-month-olds apparently agreed as they looked significantly longer at the possible (but less efficient) than the impossible (but more efficient) test event. This is a striking finding because it suggests that knowledge about body structure is unnecessary for goal attribution and that goal attribution in this case is driven by the recognition of an efficient action relative to the goal state.

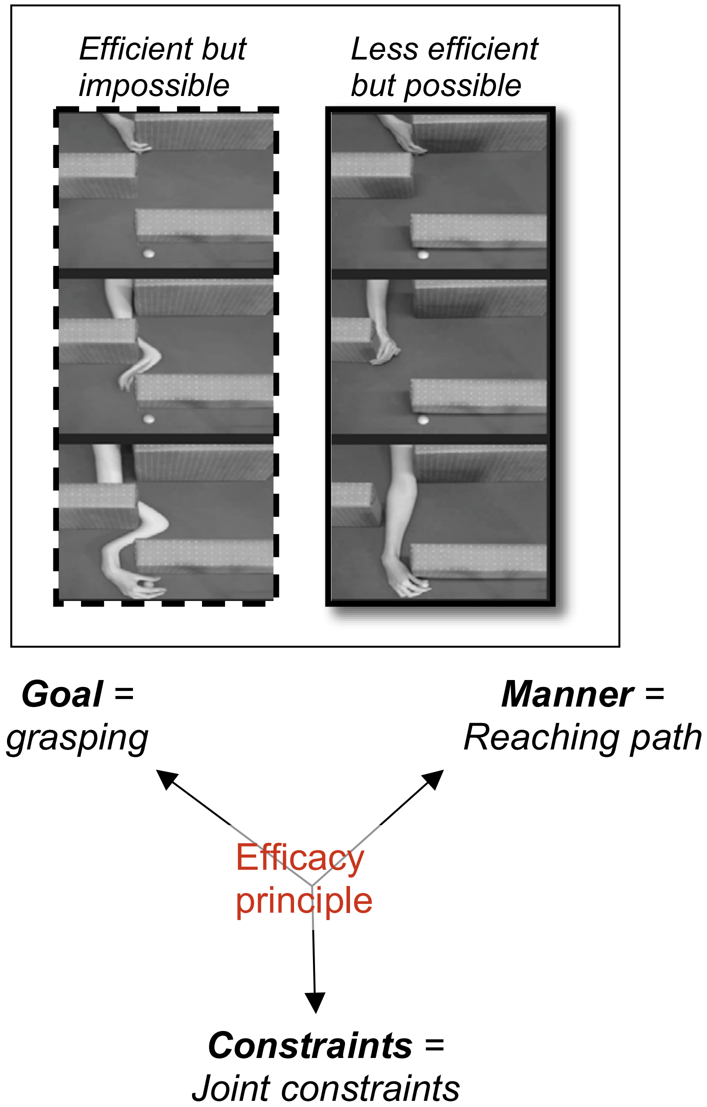

Figure 1. Inferential learning of bodily mechanical properties based on the "efficacy" principles. 6-months-olds do not find the biologically impossible but efficient arm movement unexpected (Southgate et al., 2008) but older infants, having experienced the non-efficient possible movement more often might reverse their expectancies.

In their daily lives infants only experience a limited (though rich) variety of body movements. The movements we can make are constrained by the rigidity of bones and by limited rotation permitted by the anatomy of joints. Young infants seemed to be unaware of these constraints (Southgate et al., 2008). We propose that the same principles used to infer situational constraints (i.e. the presence of a barrier that forced the ball to take a curvilinear trajectory (Csibra et al., 2003)), will allow infants to infer the existence of human body constraints and, therefore, to learn about human body structure. The principle of efficacy states that infants expect goals to be reached through the most efficient means (Gergely & Csibra, 2003). If, when reaching for an object, arms repeatedly take a longer route than the expected efficient route, and if no external barrier is present, this would make infants infer constraints internal to the human body (figure 1). When would infants start making these inferences? Both the amount of exposure to human actions and their ability to make inferences about hidden properties are limiting factors. Remember that only 12-month-olds, but not 9-months-olds, inferred the presence of a hidden barrier in Csibra et al., (Csibra et al., 2003). It is thus possible that we would not find evidence of knowledge about possible and impossible body movements before one year of age.

There are other routes to learning about possible body movements. Infants could make use of their powerful statistical learning skills to extract a prototype of "possible actions" based on the most frequent movements encountered. Statistical learning is slow however, as it would require frequent exposures to a variety of possible actions. Making use of their ability to infer body constraints when seeing inefficient goal-directed actions can give infants an additional powerful learning strategy. Based on only a few instances in which the observed bodily movement does not correspond to what was expected in that context, i.e. not efficient, infants can make predictions about the whole range of impossible movements (e.g. the whole rotation range that is beyond the point at which the arm stopped, is inferred to be "impossible").

Observing other people's actions is of course not the sole source of information about body movements. Infant's proprioceptive and visual experience with their own body may provide equally rich information about which movements can or cannot be achieved. This is illustrated in a study of action perception in which participants were people born with or without arms. When presented with images of two successive arm positions, all participants experienced an illusory arm movement. However, while control participants saw a biologically possible but longer path movement, participants born without hands, who had never experienced this movement themselves, reported seeing the most efficient albeit biologically impossible illusory arm movement (Funk, Shiffrar, & Brugger, 2005).

Research on body perception in infancy placed the emphasis on infants' ability to learn the structural properties of bodies, probably inspired by previous work on face perception. However, body movement makes this task difficult, as it continuously modifies the outline of the body and the position of limbs with respect to each other (which does not happen in the case of faces). On the other hand, although problematic for learning configural properties, body movement and more particularly the goal-directedness of human actions (others or one owns), may be one of the key information infants use to eventually learn about their conspecifics' appearance, in their first years of life. Although infants seem to be able to grasp the meaning of goal-directed action from very early on, a full blown understanding of the principles involved, e.g. inferring action constraints when efficacy is not attained, may take longer, making body perception in infancy less prodigious, but not less fascinating a topic.

Conclusions

Infants' knowledge about the structure of the human body improves slowly over the second year of life. In contrast, they already make use of the ability to understand and predict the goals of human actions before their first birthday (Southgate, Johnson, El Karoui & Csibra, 2010). We attempted to explain this discrepancy by raising the hypothesis that infants have a bias to attend to action goals (i.e. what people do) and not to structural body properties (i.e. who does the action). Young infants posses limited attentional resources and the existence of processing biases is crucial for acquiring essential initial knowledge. Anticipating other people's actions may be of greater urgency in the first year of life, than discriminating people from other animate agents or identifying people based on their body silhouettes. The body structure will contribute eventually to individual recognition but faces are sufficient, initially, to allow recognition of the few caregivers infants rely upon. From very early on, nonetheless, infants have to anticipate and respond to other people's actions. By paying attention to body actions and their constraints, infants will learn about body structure. Although highly speculative, this chapter provides a coherent explanation for what seemed like a paradox in infants' cognitive development. We hope to have inspired a new approach to studying body perception in infancy and perceptual development in general.

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