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Children's anthropomorphism of inanimate agents

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Funding information: This work was supported by an Insight Grant from the Social Science and Humanities Research Council of Canada awarded to Diane Poulin-Dubois (#435- 2022-0805). Additional support comes from a Concordia University Horizon Postdoctoral Fellowship to Elizabeth Goldman.

Abstract

This review paper examines the extant literature on animism and anthropomorphism in infants and young children. A substantial body of work indicates that both infants and young children have a broad concept of what constitutes a sentient agent and react to inanimate objects as they do to people in the same situations. The literature has also revealed a developmental pattern in which animism decreases with age, but social robots appear to be an exception to this pattern. Additionally, the review shows that children attribute psychological properties to social robots less so than people but still anthropomorphize them. Importantly, anthropomorphizing of social robots is dependent upon their morphology and human-like behaviors. The extent to which children anthropomorphize robots is dependent on their exposure to them and the presence of human-like features. Based on the existing literature, we conclude that in infancy, a large range of inanimate objects (e.g., boxes, geometric figures) that display animate motion patterns trigger the same behaviors observed in child-adult interactions. The review concludes that additional research is needed to understand what infants and children judge as social agents and how the perception of inanimate agents changes over the lifespan. As exposure to robots and virtual assistants increases, future research must focus to better understand the full impact that regular interactions with such partners will have on children's anthropomorphizing.
(Word count: 221)

Keywords: anthropomorphism, animacy, social agents, social robots, mentalizing

Word count: 8479

Children's anthropomorphism of inanimate agents

The concepts of animacy and anthropomorphism, the tendency to perceive inanimate stimuli as animate and/or sentient, have been topics of study for many decades. In their seminal study, Heider and Simmel (1944) found that even adults perceive the contingent interactions of geometric figures as not only alive but also as possessing psychological attributes such as goal-directedness (for a review, see Scholl & Gao, 2013). Thereafter, a large body of work has identified several visual cues that contribute to such effects in adults, including self-propulsion (e.g., Dasser, Ulbaek, & Premack, 1989; Pratt et al., 2010), defying physics (e.g., Gelman, Durgin, & Kaufman, 1995; Tremoulet & Feldman, 2000), and contingency (e.g., Gao, Newman, & Scholl, 2009; Gao & Scholl, 2011). Importantly, the perception of animacy seems to appear early in development and is universal (Barrett et al., 2005; Rutherford & Kuhlmeir, 2013), with the exception of individuals with certain neuropsychological impairments, including autism spectrum disorder (e.g., Klin, 2000; Rutherford, Pennington, & Rogers, 2006) or damage to some areas of the brain, like the amygdala (e.g., Heberlein & Adolphs, 2004).

It has been well-established that vision enables humans to detect agents and extract important information about their goals and intentions. A large body of work has been concerned with when and how children anthropomorphize inanimate objects at implicit and explicit levels. In a first wave of studies, researchers examined how children (and adults) differentiate the animates from the inanimates by conducting interviews with a series of images of animals, artifacts, and plants (Inagaki & Hatano, 1993; Ochiai, 1989; Opfer & Gelman, 2011; Piaget, 1929; Poulin-Dubois & Heroux, 1994; Rakison & Poulin-Dubois, 2001; Tao, 2016). A more recent wave of studies on animism and anthropomorphism has developed innovative ways to address the development of anthropomorphism. First, researchers have tested anthropomorphizing by administering tasks that require implicit judgments in addition to complementing interview questions that require explicit reasoning. Second, many studies have created contexts where human agents have been interchanged with inanimate agents to examine if similar behaviors are observed (e.g., gaze following). Third, with the increasing availability of social robots, robots have been the focus of many studies, as they allow for the direct manipulation of predictive cues of animacy (e.g., contingency, human-like morphology). The present review intends to review this body of work by reporting studies that have examined when and how children perceive non-human agents (e.g., robots, puppets, animals, artifacts).

Do young children initially perceive all non-human agents as alive and/or sentient? In other words, do they attribute life to artifacts and human-like properties to non-human agents? A prominent view argues that anthropomorphism is an acquired perspective that children learn over time as they gain more experiences (Herman, Waxman, & Medin, 2010). Regarding animism, a dominant view is that it decreases with age (Carey, 1985; Opfer, 2002; Somanader et al., 2011). If it is the case, when and how does the dissociation between reasoning about life and psychological properties emerge (Jipson et al., 2016)? In a recent paper, Clark and Fisher (2022) argued that even adults anthropomorphize artifacts to some extent. In other words, adults recognize that artifacts are not alive yet treat them as depictions of social agents. When is such dissociation observed developmentally? Do children believe all agents are like them? In commentaries to Clark and Fisher's article, developmental psychologists have addressed the developmental origins of when children see non-human agents (e.g., robots) as depictions of social agents and as learning sources (Goldman, Baumann, & Poulin-Dubois, 2023b; Haber & Corriveau, 2023). Importantly, a body of work suggests that infants treat any non-human agent (e.g., boxes, geometric shapes) that displays animate motion patterns as human-like (Baillargeon, Scott, & Bian, 2016) but gradually understand what is alive and what is not. The present review expands upon this important question by attempting to address when and how children anthropomorphize inanimate objects, including ambiguous objects such as robots, and how children's judgments of what constitutes a sentient agent change over time. We first review the empirical evidence that infants not only prefer and detect animacy cues but display the ability to associate them with animates. This is reflected in a sizeable body of studies showing that infants can categorize animates and inanimates by the end of the first year (for a review, see Rakison & Poulin-Dubois, 2001). Additionally, we demonstrate that both infants and older children anthropomorphize familiar and unfamiliar artifacts, including robots. Finally, we show that children gradually understand that artifacts are not alive but can be treated as depictions of social agents.

The animate-inanimate distinction

Piaget was the first to observe children's animism, which is the belief that inanimates are capable of sensations, emotions, and intentions (Piaget, 1929). Piaget put forward a stage theory that examined how children apply consciousness to and make life judgments about different entities. Piaget believed that children's judgments of aliveness were based on motion, specifically whether the item in question could move autonomously. In the first stage, children apply consciousness broadly to all things, and in the second stage, consciousness is attributed to things that move. In the third stage, children reserve consciousness to things that can move on their own; and in the fourth and final stage, children further restrict consciousness to animals. Piaget believed children's initial broad application of consciousness was revised as children gained more experiences. The consensus of recent research is that children are not as animistic as originally claimed by Piaget, who interviewed children about unfamiliar items (e.g., the wind and the moon) (Backscheider et al., 1993; Carey, 1985; Dolgin & Behrend, 1984; Opfer & Gelman, 2011).

Infants' concept of animacy

One way researchers have studied animism is to examine when infants and children can correctly categorize both living and non-living things. Since infants and young children are unable to respond to interview questions or complete tasks with high demands, much of the research has been based on infants' manipulation of replicas of animals and artifacts, as well as looking time measures. This body of work has revealed that by the end of the first year of life, infants can categorize both animals and vehicles (Mandler, 2003; Poulin-Dubois & Pauen, 2017). Such precocious categorization abilities are believed to be directed by dynamic information (e.g., motion patterns) rather than morphology or color (Caramazza & Shelton, 1998; Leslie, 1994;

Mandler, 1992; Premack, 1990). This hypothesis is supported by existing work indicating that infants display an attentional bias toward social agents and toward the motion patterns characteristic of animate beings, including contingency, self-propulsion, and the ability to change direction and speed (Bardi, Regolin, & Simion, 2010; Di Giorgio, 2021; Hofrichter et al., 2021; Sifre et al., 2018).

Research has shown that infants are biased to attend to humans and other animates early on in life. For example, newborns show a looking preference for face-like stimuli over other inanimate objects and process such stimuli using the same cortical pathways that adults do (Buiatti et al., 2019; Fantz,1963). When controlling for the familiarity of the stimuli, infants as young as 9 weeks smile and vocalize more towards a person than a doll (Legerstee et al.,1987). By the age of 3 months, infants show a looking time preference for a person over a monkey toy (Brazelton et al.,1974). Towards the end of the first year, infants, like adults, perceive the disappearance of animate objects in a visual image more easily than the disappearance of inanimate objects (Hofrichter et al., 2021).

The sensitivity to animacy is also expressed in an attentional bias to the motion patterns that signal animacy (Baker, Pettigrew & Poulin-Dubois, 2014; Gelman, 1990; Mandler, 1992; Premack, 1990; Saxe, Tzelnic & Carey, 2007; Spelke, Phillips &Woodward, 1995; Surian &Caldi, 2010). Among the most impressive findings are those showing sensitivity to the motion patterns of animates within the first 6-months of life. For example, infants differentiate self-propelled objects from inert ones by the middle of the first year (Leslie & Keeble, 1987; Pauen & Träuble, 2009). Even 3-month-olds understand that stationary objects will not move unless they are contacted by another moving object or through an internal mechanism that triggers self-propelled movement (Luo & Baillargeon, 2005). Additionally, infants recognize self-propulsion and expect different outcomes for physical events that involve self-propelled versus inert objects (Luo, Kaufman & Baillargeon, 2009). Even newborns can differentiate animate and inanimate motion (Di Giorgio et al., 2017, 2021), and infants prefer animate motion, such as contingency, over inanimate motion (Frankenhuis et al., 2013; Rochat et al., 1997). This early bias is not species-specific, as other mammals also show a preference for animate agents (Lorenzi et al., 2017; Rosa-Salva et al., 2018). Infants also show a sensitivity to self-propulsion and other animacy cues (Di Giorgio et al., 2017), presume animate agents will act in a rational way (Csibra et al., 1999), exhibit goal-directed behavior (Wagner & Carey, 2005), and to abide by the laws of physics (Arterberry & Bornstein, 2002; Spelke, Phillips, & Woodward, 1995).

But does an early sensitivity to the dynamic features of animacy imply an association to animacy? Answers to this question have come from studies that exposed infants to inanimate objects that violate the expectations about how they should move. In one of the first experiments testing such a link, 8- and 9-month-olds showed surprise (looked longer) when a chair moved on its own (Golinkoff et al., 1984; Poulin-Dubois & Shultz, 1990) or when a small humanoid robot moved autonomously (Poulin-Dubois et al., 1996). In another experiment, seven-month-old infants acted surprised if a shadow that moved on its own and changed speed and direction was later revealed to be an inanimate object but were not surprised when it was revealed to be an animal (Träuble et al., 2014). Interestingly, 8-month-old infants identified a violation when it was revealed that agentive objects are capable of self-propulsion were hollow (Setoh et al., 2013). Furthermore, Poulin-Dubois et al. (2015) observed that 12-month-old infants who saw point-light displays of animate motion better categorized animates than those who saw random motion patterns. These results indicate that biological motion may be one of the motion cues that serve as the foundation for infants' understanding of animacy. Taken together, prior work suggests that during the first year of life, infants both prefer animate stimuli and have also developed a precocious knowledge about the agency characteristics associated with animacy.

Young children's concept of animacy

A developmental pattern emerges when older children are tested in interviews with images of animals, people, artifacts, and plants. A review of this body of literature indicates that overall young children tend to accurately categorize animals as animate and artifacts as inanimate but struggle to classify plants as living. For example, Hatano et al. (1993) investigated cultural differences in children's understanding of biology and how children classify something as living or non-living. The study included kindergarteners, second graders, and fourth graders from three countries (Japan, Israel, and the United States). Children were asked if plants, animals, and people were living or non-living. The results indicated that children, regardless of age and country, understood that inanimates, plants, animals, and people had different properties. Overall, children were least accurate about the properties of plants, the Israeli children tended to classify plants as non-living, and the Japanese children anthropomorphized inanimate objects the most. In a related study by researchers Richards and Siegler (1986), children responded to the question, "Can you tell me how things that are alive are different from things that are not alive?" The children thought that animals and plants had few properties in common, despite plants and animals both being alive. The researchers found that 5-year-olds almost never named characteristics that belonged to both animals and plants. Instead, children listed characteristics true of animals but not plants (e.g., movement). Interestingly, most of the 5-year-olds thought that plants were non-living, but all of them knew that animals were living.

Similarly, Inagaki and Hatano (1996) asked children ranging from 4 to 11 years of age, "What is an X?" Children were shown pictures of plants, animals, and artifacts. Next, children responded to questions like “Is X living?” and “Why do you think X is living or non-living?” A majority of 5-year-olds justified that plants and animals were living things using three criteria: the ability to grow, the need to eat/drink, and the idea that living things could become ill. When children were asked if plants had the same characteristics that animals do, the children said that plants grew, needed to eat/drink to survive, and died eventually,

Work by Fouquet, Megalakaki, and Labrell (2017) examined the biological properties 3- and 6-year-olds attribute to animals, plants, and artifacts. Children viewed pictures of animals, artifacts, and plants and were then asked about different biological properties (i.e., the ability to move, grow, eat, reproduce, become ill, die, and age). Although the 3-year-olds attributed more properties to animals compared to artifacts and plants, the attribution of biological properties to animals increased with age. Yet, the attribution of properties to plants remained constant with age. These findings suggest that animism is well developed by age 3 years except for plants and other ambiguous objects (e.g., robots). The literature review thus far has focused on research studies where children were requested to make judgments about the animacy of common things that children are likely familiar with (e.g., animals, clear inanimate objects) as well as ambiguous objects, like plants. This body of literature shows that children tend to deny life to plants as they lack animate cues (e.g., movement). More recent studies have focused on robots that though not alive, have animacy, as robots are the opposite of plants which are alive but lack some of the animacy characteristics we see in animals and humans. For example, in work by Saylor et al. (2010) 3- and 4-year-olds were asked to attribute properties of both living things and machines to different artifacts (e.g., a robot, a human girl, a camera). Children were presented with images of the artifacts and asked questions typically associated with living things (e.g., can see, think, is alive) and questions associated with machines (e.g., is a tool, has wires). Children provided justifications for their responses. Justifications included five categories: kind (label), internal features (stuff on the inside), origin explanation (where it came from), external explanations (surface features visible to the eye), size, and function (what it was used for). Both age groups attributed properties of living things to the girl more than the robot or camera. Only the 4-year-olds classified the robot as a machine. Overall, older children were more accurate in their classification of both living and non-living things.

Okanda and colleagues (2021) asked 3-year-olds, 5-year-olds, and adults to attribute different type of properties to a humanoid robot (Kirobo) before and after interacting with it. The properties included: Biological (e.g., eating), artifact (e.g., can this one break?), psychological (e.g., thinking,), and perceptual (e.g., seeing). Overall, the 3-year-olds performed poorer than the older groups on most of these properties. They found that after the interaction, both 5-year-olds and adults attributed more properties (psychological and perceptual) to the robot. In contrast, after the interaction with the robot, the 3-year-olds no longer attributed properties to the robot (biological, psychological, and perceptual). In other words, the youngest children were more likely to think the robot was an artifact. These results suggest that younger children could have limited understanding that a robot is an artifact but the ambiguity of the robot and the fact the human-like morphology of the robot (e.g., had a head, torso, and arms) may have contributed to the 3-year-old's uncertainty about whether the robot has biological properties. Similarly, Kim et al. (2019) demonstrated a transition between the ages of 3 and 4 years.

Recent work has tested the concept of animacy in a more direct way with tasks like a naïve biology task (Gottfried & Gelman, 2005). Beyond interviews, Gottfried and Gelman (2005) used a naïve biology task to investigate if children assigned biological or mechanical internal parts to unfamiliar plants, animals, and artifacts. The 3-,4-, and 5- year-olds were asked to decide if something biological (e.g., heart) or mechanical (e.g., battery) belonged inside unfamiliar plants, animals, or artifacts. They found that the younger children assigned fewer correct internal parts compared to the older children. These findings indicate that by 5 years of age, children are better at judging internal parts (mechanical or biological) of plants, animals, and artifacts.

In a recent study, Goldman, Baumann, & Poulin-Dubois (2023a) adapted Gottfried and Gelman's (2005) task and asked children whether unfamiliar animals, artifacts, and robots had mechanical or biological insides. Both age groups (3- and 5-year-olds) knew animals had biological insides and artifacts had mechanical insides. However, only older children thought that robots had mechanical insides, whereas the younger children assigned both biological and mechanical insides to the robots equally. These results suggest that by 5 years of age, children understand the internal parts of different entities (i.e., robots, animals, and artifacts).

Another task-based measure developed by Hermann, Waxman, and Medin (2010) used an inductive-reasoning task to determine whether young children anthropomorphize. Children were asked whether novel properties (e.g., “Do x’s have an omentum?”) could be found inside various objects, including humans, animals, plants, and artifacts. For each property, the experimenter asked whether the object in question had the property inside – two puppets responded (one puppet answered “Yes” while the other answered “No”). Then, the children indicated which puppet was correct. These findings indicate that 5-year-olds anthropomorphize but that younger children, the 3-year-olds, do not. This suggests that anthropomorphizing is something that children learn to do over time, particularly between the ages of 3 and 5 years.

Kominsky, Shatto, and Bonawitz (2021) examined whether preschool children expected animate agents to have biological internal properties. Preschoolers were shown videos of two different puppets. Although both puppets were covered in fur, only one puppet was self-propelled. Preschoolers were also presented with images of familiar artifacts (i.e., a motorcycle) and a familiar animal (i.e., a sheep). Children selected whether something biological, something mechanical, or nothing at all belonged inside these puppets, artifacts, and animals. The children were less likely to think that the self-propelled puppet was empty compared to the puppet which was unable to move by itself. However, preschoolers had no biological expectations despite the fact that they knew animals had biological insides and artifacts had mechanical insides. Importantly, these results suggest that preschoolers lack specific biological expectations about animate agents, even though they know that agents should not be empty. In sum, prior work suggests that animism decreases as children grow older (Bullock, 1985; Carey, 1985; Jipson et al., 2016; Opfer, 2002; Somanader et al., 2011), although it may not disappear completely in the presence of certain powerful animacy cues (Opfer, 2002).

Developmental changes in anthropomorphizing

Beyond the judgment of animacy, more recent work has focused on anthropomorphizing using artificial stimuli (e.g., robots, geometric figures) that vary in their animate features. Using artificial stimuli provides many benefits. First, using stimuli that are not alive yet exhibit animate characteristics complements plants that are alive but lack some of the animacy characteristics seen in humans and animals (e.g., autonomous movement, speech, facial features). Second, plants and artificial stimuli are ambiguous as they possess both animate and inanimate characteristics. An important question to consider is how much anthropomorphizing young children do to these artificial stimuli that can, in some contexts and situations, serve as non-human social partners or agents. Although Piaget believed that infants anthropomorphize artifacts (e.g., non-human agents), recent work has yielded contradicting findings.

To better understand how and when, developmentally, infants and children anthropomorphize, researchers have exposed children to an ecologically valid context that involves non-human agents to examine whether children treat these agents as depictions of social agents. Additionally, these contexts can determine if and how children react to non-human agents as they would human agents. Our tendency to anthropomorphize, to see human-like traits such as intentions and beliefs, increases as the non-human entity takes on more animate characteristics (Broadbent, 2017). There are a number of cues that have been shown to trigger anthropomorphism and animate judgments toward non-human agents. Importantly, when non-human agents exhibit these cues, this can lead to a variety of different levels of anthropomorphism (e.g., intentions, goal-directedness, learning). Below, we explore these different levels with studies that examined infants' and children's behaviors about non-human agents directly to human agents.

Gaze following

The ability to follow the gaze of others plays an important part in our ability to both communicate and interact with others (Argyle & Cook, 1976). Unlike other species, humans pay attention to other people's gaze as a source of information, as gaze following can strongly indicate another's intentions and future actions (Clifford & Palmer, 2018). Following the gaze of an agent is in itself low-level anthropomorphizing. The conditions which lead to gaze following in young children have been well-studied by researchers. Prior research has shown that 12- to 18-month-olds follow the gaze of a person looking at targets but stop doing so when that person's view of the targets is obscured (e.g., closed eyes, a blindfold, target covered by an opaque screen) (Brooks & Meltzoff, 2002; Butler, Caron, & Brooks, 2000; Dunphy-Lelii & Wellman, 2004; Moll & Tomasello, 2004). In another study, 12-month-olds followed the gaze of an asymmetrical object when the object had facial features and behaved in a contingent manner (Johnson, Slaughter, & Carey, 1998). Gaze following changes with age, specifically with the ability to follow the head developing before the ability to follow eyes (Brooks & Meltzoff, 2005; Carpenter, Nagell, & Tomasello, 1998; Moore & Povinelli, 2007; Mundy et al., 2007).

Prior work has examined what conditions and situations lead to following the gaze of others (Akhtar & Gernsbacher, 2008; Beier & Spelke, 2012; Capparini, To, & Reid, 2023). Adults and older children pay attention to a person who adjusts their head in the direction of an object. Yet they fail to do so if a swivel chair spins or a teapot turns. How does one determine whether a gazer is worth following? How does an infant recognize a gazer's importance? Is gaze following interpreted as referential when the agent is non-human? Many studies have tested adults to address these questions (for a review, see Admoni & Scassellati, 2017). For infants, interpreting robot gaze appears to be dependent upon whether the robot is judged to be a social agent. In the first study to investigate infants' gaze following with robots, O'Connell et al. (2009) had a humanoid robot teach novel words to 18-month-olds. As the infant and robot held two different unfamiliar objects, the robot gazed at either the infant's toy or at its own toy and labeled it (e.g., "That is a Dax"). Infants followed the robot's gaze at the target object when it labeled the novel object in both conditions. Subsequent work reported that only when a long turn-taking interaction was observed by the infant between a humanoid robot and an experimenter did 18-month-olds follow the robot's gaze (Meltzoff et al., 2010). The fact that the robot in O'Connell's study displayed salient animacy cues (e.g., very large eyes and speech) might explain these conflicting findings. More recently, an eye-tracking study showed that the anticipatory eye gaze of 12-month-olds only shifts in response to the referential gaze of a human agent but not a robot agent (Okumura et al., 2013a). However, when infants are shown videos of human and robot agents looking at objects, they can follow the gaze of both agents. Still, infants look longer at the objects the human gazed at (Okumura et al., 2013b). Similarly, researchers have shown that infants only imitate a robot's actions if the robot engages in mutual gaze with a human (Itakura et al., 2008). These findings suggest that robot gaze is not as meaningful as human gaze, yet it can become more meaningful through social interaction. More recently, Manzi, Ishikawa, et al. (2020) showed 17-month-old infants videos that featured a human or a robot (Robovie) completing an action. The agents gazed at a cup, the target object (congruent), or an empty space (incongruent). The findings indicate that infants prioritized attending to the face of the agents and were attentive to initial eye contact from both agents. However, they were more engaged by the human agent's gaze. Additionally, infants attended to the target more quickly when they watched the human agent. Although perceptive of some of the robot's human-like morphology (facial features, ability to make eye contact), the infants failed to recognize the robot's referential gaze.

Importantly, prior work has shown that even adults will follow the gaze of inanimate objects (e.g., a pointer) (Breil et al. 2019). Adults will follow the gaze of a face but will also do so for stimuli that have no eyes (e.g., arrows). These results suggest that adults act like the arrow is a pair of eyes, as they direct their gaze and attention to where the arrow is pointing. Thus, gaze following is an implicit form of anthropomorphizing and continues to be important in our evaluation of animacy across the lifespan.

Goals and intentions

Previous research has demonstrated that infants in the first year of life are capable of attributing goals to other people (Woodward, 1998). Importantly, the ability to attribute goals during infancy predicts better performance in mentalizing tasks at preschool age (Aschersleben et al., 2008; Yamaguchi et al., 2009). The classic paradigm to test goal attribution is a novel preference task (e.g., Woodward 1998, 1999). In the standard task, 5- to 12-month-olds watch familiarization trials where an agent reaches for and grasps one of two objects (grasped object A). In test, the location of the objects is swapped, and the agent reaches for object A (old-object) or object B (new-object). Infants look longer when the agent reaches for the new object, object B. This suggests that infants attribute object A as the agent's goal or preferred object. Infants are also able to identify the goals of the agent in imitation tasks. For example, prior work has found that infants tend to imitate intentional actions ("There!") more so than accidental ones ("Woops") (e.g., Carpenter et al., 1998, Olineck & Poulin-Dubois, 2005). Additionally, infants will duplicate intended outcomes after observing an incomplete demonstration or a successful one at roughly equal rates (e.g., Meltzoff 1995, Olineck & Poulin-Dubois 2009); and they are sensitive to goal-relevant actions, reproducing them more than goal-irrelevant ones (e.g., Brugger et al., 2007, Carpenter et al., 2005).

What about goal attribution to non-human agents? Early research in the classic goal attribution paradigm reported that infants interpret the goals of a human hand and an inanimate claw differently (Woodward 1999). However, in subsequent work that modified the Woodward (1998) paradigm, Hofer et al. (2005), 9- and 12-month-olds observed a mechanical claw that performed an action. Only the 12-month-olds interpreted the mechanical claw's action as being goal-directed. In a second study, the 9-month-olds received information that showed that a human had operated and controlled the mechanical claw. The results indicated that this additional information (a human controlled the claw) allowed the 9-month-olds to interpret the claw's action as goal-directed (Hofer et al., 2005). In another study, Kamewari and colleagues (2005) investigated if 6.5-month-olds interpret goal-directed actions differently depending upon the agent (human or non-human). The findings showed that infants attributed goals to humans but not to a box that moved autonomously. Furthermore, two studies have shown that infants view the actions of a self-propelled box as being goal-directed, suggesting that infants will attribute goals to anything they view as being an agent (Luo & Baillargeon, 2005; Luo & Choi, 2013). This was extended to 3-month-olds in a subsequent set of experiments (Luo, 2010). There is also evidence that by 6 months, goal attribution is linked to biological motion (Schlottmann & Ray, 2010).

The attribution of goals and intentions to non-human agents has also been examined using robots (Itakura et al., 2008; Kocher et al., 2020; Manzi et al., 2022; Somanader et al., 2011). In one study, researchers investigated whether toddlers would imitate the goal-directed actions of a robot (Itakura et al., 2008). Toddlers (ranging from 24 to 35 months) watched videos that featured a robot attempting to but failing to place beads into a cup. The researchers manipulated whether or not the robot made eye contact. The toddlers only imitated the robot's actions when the robot made eye contact. These findings indicate that human-like gaze, rather than human-like morphology, could be a critical factor in children's decision to imitate the goal-directed actions of a non-human agent.

Prior work has shown that when evaluating whether something unfamiliar (i.e., a blob) is alive, young children and adults take into consideration the blob's capacity for goal-directed movement (Opfer, 2002). In older children, research has not been about attributing goals but rather manipulating goal-directedness and observing its impact on anthropomorphizing. One way to do this is to have the agents demonstrate a goal-directed action (e.g., reaching for an object). Next, we zoom in on research that focuses on the importance of goal-directedness and intentions in interactions non-human social partners have with children. In fact, when a social partner shows intentionality, children tend to attribute animate qualities. A study by Meltzoff (1995) examined whether young children would reproduce what the adult did over what the adult had intended. The children watched an adult who had tried but failed to complete specific actions. The findings revealed that even unsuccessful or failed attempts could help children infer the actions that were intended. In a follow-up that featured an inanimate object, children failed to produce the target actions. This suggests that children can follow the intentions and goals of a person more easily than they can inanimate objects.

Non-human agents' intentionality can also be judged by other cues, like their ability to move autonomously. In a study by Somanader, Saylor, and Levin (2011), 4 and 5-year-olds interacted with an experimenter and a robot. The robot had eyes and one arm but otherwise lacked human features. Children were assigned to one of two conditions: Autonomous (robot moved autonomously) or controlled (a remote-controlled robot). Two balls were placed on the table, and the robot moved toward one of the balls and hit it. In the autonomous condition, the robot moved autonomously and independently, whereas, in the controlled condition, it looked like an experimenter directed the robot using a remote control. The 5-year-olds differentiated the remote-controlled robot from the autonomous robot, yet children a year younger were unable to make this distinction. Thus, children who see the robot moving autonomously may infer that the autonomous robot intended to hit that specific ball off the table. In comparison, children may be less likely to attribute goal-directedness to a robot that performed that same action, hitting the ball off the table, if the robot was controlled by a remote control.

Additionally, researchers have examined whether children will help a non-human social partner. For example, will young children recognize a robot’s intentions and help the robot complete its task as infants complete an unfulfilled goal? Kocher et al. (2020) examined whether children identified a robot’s failure and correct it. Working with a non-humanoid robot, children aged 3 to 7 years of age completed a collaborative building task. The findings indicated that the autonomous movement of the robot led to most of the children attempting to help the robot. Additionally, the researchers found that children engaged with the robot and treated it as a social partner.

Mental states

The spontaneous understanding of others’ beliefs, desires, emotions, and intentions is defined as Theory of Mind (Wellman, 2014). Agents are those we attribute mental states to, and agents can include people, animals, and even inanimate objects that display animacy cues. Some researchers believe that infants possess an innate concept of an agent that is like the hard-wired language-learning mechanism that is characteristic of our species (Luo & Choi, 2013). Of importance are true and false belief scenarios. A true belief is when one’s belief is in line with reality. A false belief is when one’s belief is not in line with reality (e.g., believing an object is one location when it is actually located in a different one). A widely used false belief task is the Sally-Anne task. In this task, children must decide where Sally will look for her marble after Anne moved it to a new location when Sally is not present (Baron-Cohen et al., 1985). This explicit task requires the participant to provide their response verbally. In contrast, implicit false belief tasks are measured via looking time (e.g., how long the participant looks at the scene). For example, Onishi and Baillargeon (2005) tested 15-month-old's false belief understanding using a violation-of-expectation paradigm (VOE). VOE tasks examine if infants look longer (i.e., find something surprising) when an agent’s behavior is inconsistent with their beliefs. In a familiarization phase, an agent played with a toy and then placed the toy inside a green box. Next, the toy changed location (e.g., moved from a green box to a yellow box) when the agent was present or absent. In test, infants saw the agent reach into the green or the yellow box. If the infants anticipated that the agent would look for her toy based on her belief about its location (and not its actual location), then infants would look longer when that expectation was violated. The findings supported the predictions and suggested that infants could attribute both true and false beliefs. Baillargeon and colleagues (2010, p. 110) stated that “false-belief understanding provides evidence for a sophisticated (and possibly uniquely human) ability to consider the information available to an agent when interpreting and predicting the agent’s actions – even if this information is inaccurate and incompatible with one’s own.”

The original false belief study was conducted with human agents. However, replications have been published with non-human agents that possess a variety of animacy characteristics. Prior research has shown that infants can ascribe beliefs to mechanical toy cranes (Burnside, Severdija, & Poulin-Dubois, 2019), geometric shapes (Surian & Geraci, 2012), and blobs that engage in turn-taking by emitting sounds and lights (Tauzin & Gergely, 2018). Another paradigm used to test false belief attribution, an anticipatory-looking task, has also been tested with cartoon animals (Southgate et al., 2007) and geometric figures (Surian & Franchin, 2020). Thus, the early mentalizing view argues that the ability to reason about mental states is not restricted to animate objects but to agents. Agents can display both mechanical (e.g., self-propulsion) and actional properties (e.g., goal-directed behavior) (Carey, 2009; Csibra, 2008; Leslie, 1994; Scholl & Tremoulet, 2000; Surian & Caldi, 2010). In sum, while morphological features are often linked to animals (e.g., eyes, limbs, and biological motion) and can be used for the purpose of categorization, the early mentalizing view states that these features are not necessary or adequate to prompt mentalizing in infants. If infants understand the actions of inanimates (e.g., chasing shapes, communicating blobs) in line with their mental states, this is evidence that infants mentalize about agents, even those without those animal-like features (see Kano et al., 2019 for related findings on apes).

In older children and adults, anthropomorphizing of mental states has been studied using interviews. Some prior work conducted by Beran et al. (2011) investigated whether children (5- to 16 -years old) attribute human qualities to a robotic arm. The robotic arm had eyes and a mouth; however, these facial features never changed during the interaction. Children observed the robotic arm attempt to complete a specific goal. The robotic arm in this study picked up and stacked six blocks. After stacking each block, the robot moved its "face" to look at the child. Children reported having a positive overall impression of the robot. However, most of the children believed the robot was incapable of having feelings or emotions. When asked to justify their responses, children attributed this to the lack of human-like features and facial expressions. More recently, research with older children has tended to focus on children's interactions with a specific type of non-human agent, robots (for a review of Theory of Mind and robots, see Marchetti et al. (2018)). Understanding that someone can intentionally lie is part of Theory of Mind (ToM). For example, Peretti et al. (2023) examined whether 5-and 6-year-olds could differentiate between intentionally and unintentionally false statements that were made by a human and a humanoid robot. Children were less critical of the lies of a robot compared to those of a human. Zhang and colleagues (2019) used two task-based measures, the change-of-location false belief task (Wimmer & Perner, 1983) and the unexpected-contents false belief task (Perner et al., 1987), to investigate how children with autism spectrum disorder (ASD) and typically developing children attribute false beliefs to a robot. The results indicated that typically developing children attributed false beliefs to the robot more than children with ASD.

In work by Manzi et al. (2020), young children aged 5, 7, and 9 years were asked to attribute mental states to two robots (NAO and Robovie). The findings revealed that younger children (the 5-year-olds) anthropomorphized robots more than older children. Both 7- and 9-year-olds attributed mental states to both robots. However, they attributed more mental states to the NAO robot. Manzi and colleagues (2020) concluded that children attributed more mental states to a humanoid robot (NAO) but attributed fewer mental states to both robots compared to humans.

Di Dio et al. (2020) evaluated whether preschoolers would attribute mental states to a social partner (human or robot) after a social interaction. The researchers found that the older children, the 7-year-olds trusted the robot more than the human agent. Whereas 3-year-olds trusted the human more. Overall, fewer mental states were attributed to the robot compared to the human. However, children behaved the same way when they related to both agents. These results indicate that children can establish meaningful relationships with both human and robot agents. In recent work by Oranç & Küntay (2020), the more perceptual abilities children attributed to a robot (e.g., can the robot see or be tickled?), the more likely the children opted to learn novel information from the robot compared to an adult.

More recently, a study by Goldman, Baumann, and Poulin-Dubois (2023a) examined children's anthropomorphism of robots, animals, and artifacts by asking 3 and 5-year-olds to respond to interview questions (psychological questions: the ability to talk, think, and feel; biological question: is alive). To examine whether morphology plays a role in children's anthropomorphizing, both a non-humanoid robot (Dash) and a humanoid robot (NAO) were used. Regardless of the questions (psychological or biological), children responded similarly. Specifically, the younger children attributed animacy to the robots, animals, and artifacts at chance level. In contrast, 5-year-olds knew that animals were animate, and that artifacts, and the non-humanoid robot (Dash) were inanimate. Crucially, the 5-year-olds were unsure about the animacy of the humanoid robot (NAO), performing at chance level. These results suggest that the 5-year-olds were uncertain of the psychological properties of a robot that is human-like in its morphology. Thus, morphology can play an important role in children's judgments of animacy. These findings demonstrate that young children infer mental states to a greater extent to robots when they display animate qualities, and the number of mental states children attribute to different non-human agents can vary.

Learning

A large body of literature has explored whether children can learn from non-human social agents, as learning is evidence of anthropomorphism. Non-human agents can interact with people during their everyday experiences. Whom children learn from is an important question, and researchers have examined whether children will learn from non-human social partners. A large body of prior research has examined whether children can learn from tablets, computers, and social media (Danovitch & Alzahabi, 2012; Tong et al., 2022; Yan, 2006). In this review paper, we zoom in on children's abilities to learn from robots. For a review of children's trust in social robots as informants, see Stower et al. (2021). Learning has been assessed in many ways, for example, how non-verbal cues can impact a child's ability to learn from non-human agents. In one of the first studies to investigate this question, O'Connell et al. (2009) showed18-month-olds a robot that provided a novel label for an object. Infants followed the robot's gaze toward the object but failed to learn the novel labels, even when they observed a brief contingent interaction between a human experimenter and the robot.

In one study, researchers Kennedy, Baxter, and Belpaeme (2017) investigated whether robots' nonverbal behaviors can provide social cues and aid in learning. Specifically, researchers were interested in whether adults and child participants perceived a difference in robots with high and low levels of nonverbal immediacy. Gestures, gazes, intonation, and body language were used to establish different levels of immediacy. Adult participants and children (M = 7.8 years old) were assigned to a robot with high nonverbal behaviors, a robot with low nonverbal behaviors, or a human. Participants listened to a short story that was read by either the human or the robot agent, depending upon the condition. After the story, a recall test was administered. The findings demonstrated that both children and adults perceived the nonverbal behaviors of the robots. Importantly, children's recall of the story improved when the story was read by the robot with high non-verbal behaviors. Thus, nonverbal behaviors such as eye gaze, body positioning, and vocal intonation should be considered when designing robots for both adults and children.

In another study, children (4 to 6 years of age) played a game with a robot over the course of 2 months (Kory-Westlund & Breazeal, 2019). In the storytelling game, the story level was either matched or unmatched to the child's language ability. The researchers found that as time went on, children emulated the robot more and that children who did emulate more scored higher on the vocabulary posttest. When the story level was matched to the child's own language ability, children emulated more. Thus, young children can learn from a robot, particularly a robot that matches their skill and ability level. In a recent study, Oranç and Küntay (2020) found that the more 3- to 6-year-olds attributed perceptual abilities to the robot (e.g., can the robot see or be tickled?), the more likely they were to select the robot instead of a human for learning novel information.

Another way to look at whether children can learn from non-human social partners is to examine whether children will imitate or overimitate (copy unnecessary actions) them. In a recent paper, Schleihauf et al. (2020) examined if children would imitate the irrelevant actions completed by a human and a robot at similar rates. Children who were 5 to 6 years of age saw an agent (human or robot) open a puzzle box to obtain a reward. Children copied the demonstrated actions of both agents, suggesting that both human and non-human agents can lead to over-imitation in children.

Recent research has examined whether young children can learn from social robots. Some of this recent work has examined selective social learning, defined as the ability to know whom to learn from (Harris & Corriveau, 2011; Juteau et al., 2019; Poulin-Dubois & Brosseau-Liard, 2016; Sobel & Finiasz, 2020). In these studies, informants, human or non-human, are pitted against each other to determine whom children will elect to learn from. For example, Breazeal and colleagues (2016) demonstrated that young children learned new words from robots that resembled stuffed animals. In a study by Moriguchi et al. (2011), preschoolers watched a video where either a human or a robot labeled novel objects. Children were then required to select the objects using the labels provided in the video. The results revealed that children who watched the video with the human agent selected more correct objects than those who saw the video with the robot. Nevertheless, the five-year-olds who saw the robot video performed above chance levels but the younger children, the 4-year-olds, did not. In another study, Kory-Westlund et al. (2017) had children aged 2 to 5 years view pictures of unfamiliar animals with either a robot or a human agent. Both agents named the unfamiliar animals shown in the pictures. On a recall test, children performed equally well regardless of which agent (human or robot) provided the names.

Building upon prior work, researchers have sought to vary the epistemic characteristics (e.g., accuracy, competency, confidence) of two social agents. In a recent paper, Baumann et al. (2023) presented children with an incompetent human agent and a competent humanoid robot, NAO. They found that 5-year-old children elected to learn the novel words from a robot that had demonstrated competency when the human agent had shown incompetency. In contrast, the younger children, 3-year-olds, opted to endorse the labels provided by both informants, the competent robot and the incompetent human, at equal rates. In a follow-up study, the researchers replaced the humanoid-looking robot, NAO, with a non-humanoid-looking robot, Cozmo. As the robot agent looked even less human-like, this was a conservative test of the importance of epistemic characteristics. The results mirrored those of Study 1, which featured the humanoid robot NAO. The 3-year-olds continued to be unsure about whom to learn from, whereas the 5-year-olds prioritized competency and opted to learn new words from the robot.

Some of this work presents children with two non-human agents rather than pit a human agent against a robot. Breazeal and colleagues (2016) had 3- and 5-year-olds interact with two "DragonBots" robots. Both robots had eyes, wings, and fur. One of the robots behaved contingently (was engaged, looked at the child), and the other robot exhibited non-contingent behavior (was disengaged, looked away from the child). First, the participants were greeted by both robots and encouraged to tell the robots about their favorite animal. Next, the robot told the child about their favorite animal (an animal that was likely unfamiliar to children at this age). Children recalled information provided by both robots and correctly indicated which of the novel animals were the robot's favorites. Crucially, children preferred to ask the contingent robot for additional information about the novel animal. Thus, it appears that children are more likely to treat a robot as knowledgeable if the robot behaves contingently.

In a study by Brink and Wellman (2020), young children (3 to 4 years of age) watched two humanoid robots (NAO) label familiar and unfamiliar objects. The two robots were identical except for their color; one had orange accents, the other purple. One of the robots provided the children with accurate labels (i.e., competent), whereas the other gave inaccurate labels (i.e., incompetent). The findings revealed that children learned from and trusted information that had been supplied by the robots (i.e., names for novel items). However, children trusted information that had been provided by the accurate robot more than they trusted information from the inaccurate robot. In addition to word learning, a line of work has emerged that focuses on whether robots can help children learn a second language (Kanda et al., 2004; Kennedy et al., 2015). For a summary of word learning with robots, please see Vogt et al. (2017).

Conclusion

In conclusion, the extant research on animism and anthropomorphizing indicates that infants and young children have a broad concept of what constitutes a sentient agent. Although it is unknown whether preverbal infants believe that inanimate objects are alive or not, they react to them as they react to people in the same situations. We saw that some motion cues are particularly powerful in triggering anthropomorphic behaviors in infants, such as self-propulsion and goal-directedness. Findings from a large body of literature have revealed a developmental pattern in that animism decreases with age, even when unfamiliar stimuli are human-like in their morphology. Three-year-olds already attribute more biological properties to animals than artifacts but less so than 5-year-olds. This developmental pattern has been confirmed when children are asked about the insides of animals and artifacts. Children of that age are also accurate about the inside of artifacts and animals but uncertain about unfamiliar and ambiguous artifacts, like robots. Thus, robots are a more conservative test of animism because of their salient agency properties, making them a form of hybrid artifacts. In comparison, 5-year-olds correctly infer that robots are artifacts, even if they have never had experience with robots.

With regard to anthropomorphism, more specifically attributing psychological properties to inanimate but social agents, is present in infancy. This has been demonstrated in studies showing that they tend to behave with inanimate agents as if human as long as they display typical motion patterns of animates. At a later stage of development, children still anthropomorphize but tend to attribute psychological properties to robots less so than people. The extent to which children anthropomorphize robots is dependent upon both the robot's behaviors and whether the robot has human-like morphology. However, much of the research on the attribution of sentience to artifacts, like robots, have been based on interviews that could over or underestimate children's anthropomorphizing. Like in the case of animism, future research should make children reason about artifacts' sentience by testing them in situations where they typically mentalize when humans are involved. In a first attempt with such a design, the Theory of Mind Scale (Wellman & Liu, 2004) was administered to 4-year-olds using figurines representing a humanoid robot (NAO) or a person as the protagonist. Children tended to attribute mental states more often in the human condition confirming previous research based on interviews (Goldman, Baumann, Beaudoin, & Poulin Dubois, 2023c).

In conclusion, the present review has examined how children perceive inanimate objects, including social robots. In a recent article published in *Behavioral and Brain Sciences,* Clark and Fischer (2022) argued that adults treat social robots as depictions of social agents. In reaction to their paper, many commentators have argued that robots though not human are not merely depictions of social agents but are considered genuine social agents (Eng et al., 2023; Orgs & Cross, 2023). Others have argued that increased exposure to virtual assistants may lead both children and adults to categorize robots as members of a unique ontological category (Girouard-Hallam & Danovitch, 2023; Kim et al., 2019). In another commentary, researchers have proposed that children and adults do not view robots as interactive toys; rather, they see robots as learning partners that can provide valuable information (Haber & Corriveau, 2023). Based on the existing literature, we conclude that in infancy, a large range of inanimate objects (e.g., boxes, geometric figures) that display animate motion patterns trigger the same behaviors observed in child-adult interactions. With age, the scope of social agents gradually narrows, except in the case of social robots. Thus, a gradual refinement of what constitutes a sentient agent occurs. Yet, additional research is needed to better understand what infants and children judge as social agents and how this ability changes over the lifespan. As exposure to robots and virtual assistants increases, moving forward, more studies must be done to understand the full impact that regular interactions with such partners will have on children's anthropomorphizing.

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