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You made him be alive: Children's perceptions of animacy in a humanoid robot

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Abstract. Social robots are becoming more sophisticated; in many cases they offer complex, autonomous interactions, responsive behaviors, and biomimetic appearances. These features may have significant impact on how people perceive and engage with robots; young children may be particularly influenced due to their developing ideas of agency. Young children are considered to hold naive beliefs of animacy and a tendency to mis-categorise moving objects as being alive but, with development, children can demonstrate a biological understanding of animacy. We experimentally explore the impact of children's age and a humanoid's movement on children's perceptions of its animacy.
Our humanoid's behavior varied in apparent autonomy, from motionless, to manually operated, to covertly operated. Across conditions, younger children rated the robot as being significantly more person-like than older children did. We further found an interaction effect: younger children classified the robot as significantly more machine-like if they observed direct operation in contrast observing the motionless or apparently autonomous robot. Our findings replicate field results, supporting the modal model of the developmental trajectory for children's understanding of animacy. We outline a program of research to both deepen the theoretical understanding of children's animacy beliefs and develop robotic characters appropriate across key stages of child development.

Keywords: human-robot interaction, humanoid, animacy, psychology

1 Introduction

With the increased use of social robots as companions and tutors for children, it becomes essential for effective progress in human-robot interaction (HRI) to understand how children perceive and evaluate robots. Advances in robots' responsive interaction-capabilities, autonomy, and biomimetic morphology may blur boundaries between object and agent in a child's perspective [1]. Research already explores high-level social issues concerning children's perceptions of robots, such as its 'role' as co-learner or teacher [2] and its adherence to social norms (e.g., as an (in)attentive listener [3]). However, much of the fundamentals concerning children's perceptions of social robots remain to be explored. In this paper, we explore factors that can shape children's perceptions of social robots as being machines, agents, or agent-machine hybrids.

A theoretical understanding of the perceptions children have of social robots can not only inspire better HRI design, but also address questions in developmental psychology. Opfer and Gelman highlight children's understanding of the object-agent distinction as a research area that biomimetic robotics could benefit, '*As technology improves and robots become increasingly animal-like in appearance and capacities, it will be intriguing to examine if and/or how children interpret such entities.*' [4]. If advanced social robots genuinely have the potential to span boundaries between object and agent [1], these can be used as research tools to explore development in children's understanding of animacy.

Children show a developmental pattern in their understanding of animacy. In early-childhood, children show naive theories of animacy [5, 4]. They may attribute life to simple objects [6] and describe an object's behaviour (e.g., a ball rolling down a hill) in terms of it's *intentions* (e.g., the ball wanted to go home). The naive theory of animacy is considered to be supplanted by a theory of biology in late-childhood [5, 4] and so animacy is less likely to be mis-attributed. However, even among adults, users may describe robots as if they are animate and make judgments based on their beliefs of a robot's animacy [7]. Robots may be an ideal tool to explore children's development in their understanding of animacy from early- through to late-childhood, as, unlike simple objects, they can cross boundaries that challenge even adults' theories of animacy.

1.1 Developmental understanding of animacy

Children's understanding of animacy as a reasoned process is presented by Piaget as an extension of their understanding of causality [6]. It is observed that young children often make category errors in regarding beings as animate or inanimate, typically favoring animate explanations for an object's behavior [4].

Piaget offers explanation for these errors in terms of children's accessible reasoning. The understanding of cause-and-affect for a child is intertwined with an understanding of their own intentions [6] (i.e. my actions occur because I first intend them to; thus objects perform actions because they intend to). However, this perspective has been criticized on account of children as young as four being able to articulate mechanical cause-and-effect with no reference to intention [8].

In contrast to Piaget's model, a substantial body of research tracks recognition of animacy in terms of infants' social development [9]. Despite an infant's limited movement and communication, his or her world is nevertheless a social one and, so, animate beings are uniquely important. Carey's model [9] for children's understanding of animacy suggests that children hold two innate processes for determining animate beings: face-detection and recognition of reactive, or autonomous, goal-directed movement. These processes are argued to lay the foundation for early-childhood category mistakes made with animacy [5].

Newborns have been shown to attend to schematic face-like stimuli but not the same schematic stimuli in a scrambled arrangement [10]. This is argued to arise from newborns needing carers for survival and that many significant changes in newborns' environment arise from a carer's actions. These changes coincide with the carers' face in the newborns' vision: the presence of a face *is* the presence of agency [9]. In infancy, further signs of recognizing agency from faces emerge, with infants following another person's gaze [11, 12]. Remarkably, this behaviour is apparent even with infants observing a robot's 'gaze' [13].

Like Piaget, Carey argues that young children's understanding of animacy is influenced by movement [9]. However, Carey narrows her model to argue that animacy is inferred from *autonomous* and *goal-directed* movement to manipulate, or respond to, the environment [9]. A wealth of research, using abstracted agents as stimuli, supports this position: infants habituate towards animations of one shape 'chasing' another until the roles of the shapes change [14, 15]; children prefer animated shapes that 'help' other shapes in apparent movement goals over shapes that hinder the same [16, 17]. Adults' descriptions of similar animations are rich with intentions, emotions, and even invented relationships between shapes [18], yet adults do not make the same animacy mistakes as children.

With development, children can articulate their naive theories of animacy and demonstrate a transitioning through stages of what constitutes an animate being [4]. Piaget presented a series of stages that children progress through: from random judgments, via progressively more refined understandings autonomous movement, to adult concepts of life [6]. Carey posits that autonomy is a factor in children's decision making but not the *sole* factor [5]. Rather, young children attempt to apply their limited biological knowledge [5], leading to the categorical errors not seen from older children. From seven onward, children appear to rapidly develop a deeper biological understanding and application of this knowledge to address the question: What is alive?[19]. Bio-inspired robotics can be used to explore contrasting models of children's development in understanding animacy. By shaping robots' appearances and behaviors in a program of experimental studies we may determine particular and combined influences on childhood perceptions of animacy in robots.

1.2 Animacy in HRI

Current HRI research offers mixed indications concerning children's perceptions of robots as animate beings [20, 21]. Studies point towards aspects of Carey's model of conceptual change [5] but offer contrasting outcomes. For example, in one study, children aged three to five present inconsistent beliefs regarding a robot dog's agency and biology [22], while in another children of this age evaluate a robotic dog as comparable to a stuffed dog toy in terms of animacy, biology, and mental states [23]. Studies further indicate children articulate beliefs that biomimetic robots can be between alive and inanimate [24–26].

It is this boundary-spanning nature of biomimetic robots that presents HRI research as a unique opportunity to study children's understanding of animacy, through use of embodied characters and agents. Key factors in Carey's model, such as autonomy in movement, can be isolated and tested in physical agents. We identify three common, key factors that could influence children's perceptions of animacy in robots: morphology, responsiveness, and autonomous movement.

Morphology A robot's appearance can substantially influence users' immediate impressions of its capabilities and interaction potential (e.g., [7]). Users may expect more sophisticated interaction potential from a life-like humanoid than that of a robotic table. Indeed, biomimicry in particular, both in terms of the physical structure and movement, can promote engagement [27], and suggest animacy [22].

Young children show low reliability when classifying a humanoid as a machine or living thing; however, they did not show reliability difficulties to the same extent with a picture of a girl, nor of a camera [28]. This suggests that children struggle with discrete classification when it comes to humanoids. More recent work identifies that children classify a humanoid robot as a person-machine hybrid [25] following a short, interactive game with the robot. Their classifications are somewhat stable across repeated interactions with the robot: neither familiarity with the interaction scenario nor differences in the robot's behavior substantially influenced participants' ratings.

Responsiveness A robot's responsiveness is considered to impact on users' perceptions of animacy. Johnson and colleagues demonstrated that infants will direct their visual attention to follow apparent attention-cues of a robot that is responsive to their babbling or movement but not one that exhibits the same behavioral signals independent of the infants' own behaviors [13]. The authors conclude that infants are attributing some agency to the robot: a capacity for attending, and responding, to the environment.

Older children are also seen to shape their social behavior and visual attention, during interaction with a social robot, based on the robot's responsiveness [3]. In a question-and-answer scenario, children tended to engage in human-human-like social behaviors with a robot that showed socially-appropriate attention cues but not with one that showed attention cues outside social norms. It appears that responsiveness *meaningful to the user* could contribute to individuals perceptions of animacy.

Autonomous Movement A robot's autonomy in movement can shape user perceptions of animacy, particularly if the movement can be interpreted as goal-directed. Somanader and colleagues report that children aged four or five attribute fewer living properties to a robot with a mechanical appearance, if its complex, goal-directed behavior is revealed to be controlled by a human [21]. These findings are mirrored in adult HRI, where goal-directed movement supports perceptions of animacy, unless the user is *directing* the same robot towards a goal [29].

While studies manipulating the apparent origin of a robot's movement suggest autonomy has an important role in perceptions of animacy, further work offers a less clear picture. Children playing with a robot- and a stuffed-toy-dog make no meaningful distinctions between the animacy of the two objects, despite the robot presenting autonomous movement [22]. Inconsistencies, such as these, across the literature warrant deeper exploration; yet a systematic approach to exploring the factors behind children's understanding of animacy through robotics still remains to be undertaken.

1.3 Testing children's perceptions of animacy

The Expressive Agents for Symbiotic Education and Learning (EASEL) project [30, 31] explores children's interactions with, and perceptions of, a humaniod synthetic tutoring assistant, using the Robokind Zeno R25 platform (citehanson2009zeno, Figure 1). The current study draws from EASEL research exploring children's representations - through interview, questionnaire, and open-ended HRI - of the humaniod as being something between animate and inanimate [25, 26] to provide children the opportunity to clearly articulate the potentially boundary-spanning nature that a humanoid robot can appear to have [1].

Fig. 1. The Robokind Zeno R25 platform (humanoid figure approximately 60cm tall)

The results from Cameron et al.s' study indicate a difference in animacy perceptions between children aged six-and-under and those aged over-six [25]. As anticipated by Carey's model of conceptual change [5], younger children regarded the robot as more animate than older children. Results further indicate that children, irrespective of their age, tended to report Zeno as being between person and machine; their ratings of Zeno were largely stable across repeated interaction.

We propose that the stability of ratings across conditions (the presence or absence of life-like facial expressions) may be due to a ceiling effect, arising from the interaction scenario used [25]. The children interacted with a responsive and autonomous humanoid: such a scenario would present all animacy cues identified by Carey [9]. Further cues, such as facial expression, may not suggest 'more' animacy. To address this potential ceiling effect on children's perceptions, we create a minimal model for an HRI scenario, in which only autonomy is manipulated. We anticipate: 1) while younger children will report the humanoid to be more animate than older children will, 2) only younger children will be influenced by the autonomy of the robot. Younger children will report an autonomous robot as being more animate than one they observe being operated.

2 Method

2.1 Design

We employed a between subjects design. Participants were randomly allocated to one of three conditions for the interaction: (1) the robot remained motionless (*Still*), (2) the robot was directly activated by the experimenter (*Operated*), and (3) the robot was covertly activated by the experimenter (*Autonomous*). In the Operated condition, the experimenter pressed a button on the robot's chest screen to initiate the robot's synthetic facial-expressions; in the Autonomous condition the same facial-expressions were covertly activated remotely via laptop.

This design isolates autonomous movement as the variable of interest. While children can observe that the robot is responsive to the experimenter's actions in the Operated condition, earlier work indicates that only robot responsiveness *meaningful to the observer* impacts on beliefs of animacy [3, 13].

2.2 Measure

To assess perceptions animacy we used a one-item likert-scale measure, used in prior HRI research on animacy [25, 32], contrasting the humanoid as a *person* and as a *machine*. This measure uses age-appropriate terms, drawn from qualitative HRI research on children's self-generated questions to Zeno [26][1].

2.3 Procedure

The experiment took place in publicly-accessible spaces. The animacy measure was presented as the first of a series of questions about the robot's appearance (further questions were used for an unrelated study on robotic expressions). For Operated and Autonomous conditions, participants completed the measure after observing the robot demonstrate two types of facial expressions (Happiness and Sadness). For the Still condition, participants completed the measures before they observed any movement from the robot. Interactions lasted approximately five minutes. Brief information about the experiment was provided to parents/carers; informed consent for participation was obtained from parents/carers prior to participation; and parents/carers were available to offer reassurance, if needed. Ethical approval for this study was obtained prior to any data collection.

[1] Children's questions fall into two distinct umbrella categories: the robot's experiences as a *person* and its capabilities as a *machine*.

2.4 Participants

The study took place across two university public-engagement events. Children aged four and over visiting the events were invited to participate in playing a game with Zeno, titled "Guess the robot's expressions". In total, 72 children took part in the study (32 female and 40 male; M age = 6.71, SD = 1.91; 35 aged six-and-under and 37 aged over-six, evenly divided across conditions). Power analysis indicates that the sample size of 72 participants across the three conditions would be sufficient to detect medium-small size effects (eta-squared = .05) with 95% power using an ANOVA between means with alpha at .05.

3 Results

A preliminary check was run to ensure even distribution of participants across age groups to conditions. There was no significant difference between conditions for participants' ages $F(1, 69) = 1.64$, $p = .20$. This outcome was not affected when ages were categorised across the theory-driven bounds of: six-and-under and over-six (35 six-and-under, 37 over-six; χ^2 (2, N = 72) = 1.30, $p = .52$).

A regression of age against animacy rating indicated that older children view the robot as being significantly less like a person (β = -.30, t = 2.68, $p < .01$). When ages are categorized as being six-and-under and over-six, we observed significant main effects for age ($F(1, 66) = 4.48$, $p < .05$) on children's reports of animacy. Older children viewed the robot as being significantly more like a machine (M = -.42, SD = 1.16) than younger children did (M = .14, SD = 1.06)[2]. This is a medium sized effect (Cohen's d = .50).

There was no significant main effect for condition ($F(2, 66) = 2.25$, $p = .11$) on children's reports of animacy. There were no differences observed between the Still (M = .10, SD = 1.07), Operated (M = -.56, SD = 1.07), or Autonomous conditions (M = .03, SD = 1.07).

There was a significant interaction effect between age and condition on children's reports ($F(2, 66) = 3.48$, $p = .04$; see Figure 2). This interaction is a medium-large sized effect (partial eta^2 = .10). Older children's (aged over-six) responses were no different across conditions: Zeno appeared to be more machine-like across the Still (M = -.67, SD = 1.04) Operated (M = -.43, SD = 1.06) and Autonomous (M = -.17, SD = 1.06) conditions. In contrast, younger children (aged six-and-under) showed a marked difference across conditions: those who saw the Still and Autonomous robot reported it as being more person-like (M = .88, SD = 1.05; M = .24, SD = 1.07 respectively), whereas those who saw the Operated robot reported it as being more machine-like (-.70, SD = 1.04).

Simple effects tests indicate that there is a significant difference for younger children between the Still and Operated conditions ($p < .01$) and a further difference between the Autonomous and Operated conditions ($p = .03$); there was no significant difference between the Still and Autonomous conditions ($p = .16$). There were no differences across conditions for older children.

[2] Positive scores indicate more person-like; negative scores indicate more machine-like, 0 indicates an even mix of person and machine

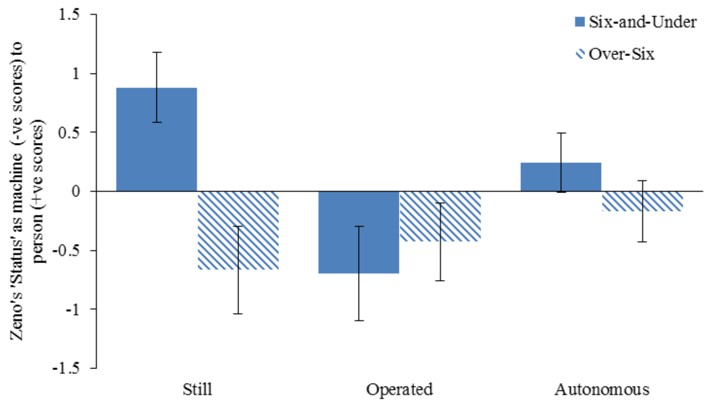

Fig. 2. Mean ratings of Zeno as machine-like (-ve) or person-like (+ve); SE bars shown.

4 Discussion

Our findings further indicate a sizable influence of age and autonomy on whether children regard humanoid robots as being person- or machine-like. *Hypothesis 1* is supported through the difference in responses between older and younger children. Younger children classify the humanoid robot, with life-like facial features, as being significantly more person-like than older children do. Younger children's responses are influenced by the robot's autonomy, supporting *hypothesis 2*. Direct robot-operation by an individual impacts on young children's reports of animacy; the robot is classified as significantly more machine-like than an Autonomous or even Still robot. In contrast, older children are not influenced by the autonomy, reporting the robot as slightly more machine-like across conditions.

The primary finding lends support to Carey's model of children applying their developing ideas of biology to determine animacy [5, 19] and challenges Piaget's model [6]. Younger and older children show a distinct difference in their responses, even in the Still condition; Piaget's model would suggest that younger children would rate this as less-animate (more machine-like on our scale), however this is not the case. Children may be drawing from other cues, such as the robot's biomimetic features (figure 1, [33]), to evaluate the robot.

Nevertheless, autonomy of movement is seen to have an impact on judgments of animacy for younger, but not older, children. Again, Carey's model would suggest this difference as younger children attempt to draw together naive cues of animacy in lieu of a well-rounded working model of biology [5]. The isolated finding of autonomous movement's impact also supports Piaget's model [6]. Autonomous movement may suggest animacy to more of the younger children than externally driven movement does (the former being a more advanced stage than the latter), whereas older children, in final stage of understanding animacy are uninfluenced. However, in the context of the complete study, support is limited.

In comparison to the earlier study, this replication produced a reduced main effect size. Younger children report the robot as being closer to a machine-person hybrid overall than children of the same age do in earlier work (Figure 3). This is as anticipated for two reasons: 1) the current study replicates with autonomy only and does not include relevant responsiveness from the robot, which is indicated to be an animacy cue [13], 2) the current study includes a condition (Operated) explicitly designed to reduce young children's perceptions of animacy. It is also worth noting that older participant's responses are extremely similar across both studies and across conditions within the current study.

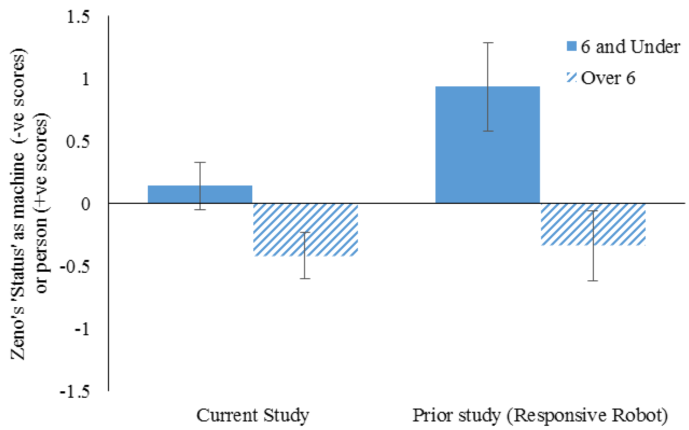

Fig. 3. Mean ratings of children's perceptions of Zeno. Main effects of age shown for current study and prior research [25]. SE bars shown

Remarkably, the Still condition in the current study shows the closest resemblance to prior findings. Morphology alone replicates the distinction between ages in a study using morphological, responsiveness, and autonomy cues. The Autonomous condition in the current study shows the same trend as prior findings [25] but, again, as a much smaller effect. Both these outcomes may be explained through a model of perceptual coherence.

In essence, perceptual coherence refers to the degree that user percepts of a robot align (i.e. physical features, movements, communication, apparent 'intelligence', and so on). The uncanny-valley phenomena [34], particularly the 'eeriness and repulsion' may arise from incoherent perceptual cues [35]. It is possible that low coherence limits children's perceptions of animacy.

In prior work, morphology, movement, and expression had a coherent *context* of playing a game [25]; movements and expressions are life-like, not just in their form [33], but also in their context. However, efforts in the current study to create minimally animate conditions mean expressions lose context, potentially creating incoherence in perceptual cues; young children may regard the robot as less animate because life-like movement occurs without context. In contrast, children may be using the coherent morphology cues of the Still robot, absent of possibly incongruent movement. This explanation presents a further possible factor for determining animacy in robots (beyond morphology, responsiveness, and autonomy) of *coherency* as an avenue for explorative research.

Future Directions

The current research indicates that children can use specific criteria to determine animacy of humanoid robots and that this is contingent on children's ages. The existent literature and current findings indicate that a systematic program of study is needed to address the individual and interactive effects of factors influencing children's views of animacy in robots. As suggested in the developmental literature [4], HRI literature [1], and current results, advanced social robots may present as interesting boundary cases for children's understanding of animacy.

In this paper, we draw from HRI and developmental literature to highlight key factors that may influence children's perceptions of animacy. Each of these can be manipulated, either in isolation in conjunction, to 1) develop a multidimensional model of animacy cues in robotics, 2) explore optimal parameter sets for effective user- and context-driven HRI, and 3) deepen the theoretical understanding of child development. First steps to achieve this are the development of a research program testing across and within factors for animacy cues.

Further work could explore within factors. Use of alternate robots of varying 'life-like' appearance such as the Nao humanoid [36], or bio-mimetic mammalian-robots such as MIRO [37], may further illuminate children's use of physical appearance to identify animacy. Alternatively, perceptions of animacy may be further explored by manipulating the extent or nature of autonomous motion: reaching for a ball may better suggest goal-directed motion than expressive moments which may better suggest affective states. Autonomy may be further manipulated by shaping the apparent control children observe others to have over a robot's actions. Varying operation from direct control, to wireless, to remote location operation may influence apparent autonomy and animacy.

Changes in perceptions of animacy may be explored across a developmental trajectory, exploring children's progress with age through Carey's or Piaget's stages [5, 6], or in an interventionist manner, examining if perceptions can change through alteration of animacy cues. Education on a robot's behavior, physical mechanisms, and computation, delivered by a researcher or even the robot itself, could also help shape perceptions of animacy.

Finally, it is important to acknowledge the value of extended interviews or multiple questions [22]; despite their time-consuming nature, they may draw out nuances in children's reasoning. However, longer, more-involved questionnaires may fatigue young participants without any justifiable improvement in data quality. A continued effort in developing unobtrusive or brief measures, built on the systematic categorization of children's spontaneous interactions and remarks towards or about a robot, may be beneficial (e.g, [26]). Children's spontaneous, brief comments could reflect their understanding of social robots as boundary-spanning [1], and research may benefit from efforts made to capture these.

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