The minds of machines: Children's beliefs about the experiences, thoughts, and morals of familiar interactive technologies

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All data, analyses, and experimental materials are available: https://tinyurl.com/yssyx8p9

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Abstract

Children are developing alongside interactive technologies that can move, talk, and act like agents, but it is unclear if children's beliefs about the agency of these household technologies are similar to their beliefs about advanced, humanoid robots used in lab research. This study investigated 4-11-year-old children's (N=127, M_{age}=7.50, SD_{age}=2.27, 53% females, 75% White; from Northeastern United States) beliefs about the mental, physical, emotional, and moral features of two familiar technologies (Amazon Alexa and Roomba) in comparison to their beliefs about a humanoid robot (Nao). Children's beliefs about the agency of these technologies were organized in three distinct clusters – having experiences, having minds, and deserving moral treatment. Children endorsed some agent-like features for each technology type, but the extent to which they did so declined with age. Furthermore, children's judgment of the technologies' freedom to "act otherwise" in moral scenarios changed with age, suggesting a development shift in children's understanding of technologies' limitations. Importantly, there were systematic differences between Alexa, Roomba, and Nao, that correspond to the unique characteristics of each. Together these findings suggest that children's intuitive theories of agency are informed by an increasingly technological world.

***Keywords*:** agency beliefs, child-robot interactions, social cognition, theory of mind, moral judgment

Public Significance Statement: We show that children (ages 4-11) growing up with household interactive technologies (such as autonomous vacuums and voice assistants) experience them as social agents, believing they have sensory capabilities, feelings, minds, and even moral status. These beliefs are higher in younger than older children and depend on the characteristics and capabilities of the technology (e.g., for movement or for communication, respectively).

Interactive technology is ubiquitous in our lives, aiding us in many of our daily tasks. Children growing up today take most of this technology for granted – it is becoming natural for them to talk to smartphones, watch vacuums clean floors on their own, and interact socially with robotic toys. As adults, we are entertained by examples of children talking, laughing, and playing with interactive technologies as if they are animate beings. We laugh at what feels to us like a charming mistake, a case of misplaced attributions of life to an inanimate object. But of course, what makes common interactive technologies so easy to like and use are precisely the appearances and abilities that mesh well with our own. These characteristics – the ability to communicate verbally, to move autonomously, to act contingently – trigger our sense that we are, indeed, interacting with a social agent.

For children, these anecdotal accounts may not be charming mistakes but instead a reflection of their conceptual understanding of interactive technologies as agents. As adults, many of us grew up in a world where encounters with interactive robots were infrequent outside of science fiction. But children in the current world are encountering interactive technologies at an early age. Autonomous robot vacuums were released in 2002 and smart speakers like Siri and Amazon Alexa were released in 2011 and 2012, and the inclusion of such technologies in the home have continuously increased. This changing technological landscape may be a relevant influence on children's beliefs. Indeed, research has shown that cultural context and experience each play a large role in shaping how we conceptualize agents and agency – both in the natural world and in supernatural entities and events (ojalehto et al., 2017; Richert & Corriveau, 2022; Weisman et al., 2021; Willard & McNamara, 2019). We can therefore think of the current world of childhood as a unique technological culture; and ask questions as to how children's social and moral cognition (Carey, 1985; Hamlin, 2013; Piaget, 1929; Inagaki & Hatano, 2006) applies to their specific interactions with technologies.

An emerging body of work now shows that children of all ages in the modern world form beliefs about the social, mental, and even moral qualities of interactive technologies (Brink et al., 2019; Chernyak & Gary, 2016; Sommer et al., 2019). But thus far, most of this research has been conducted in laboratories or classrooms using robots with a full range of human-like or animal-like physical and behavioral features (Brink et al., 2019; Chernyak & Gary, 2016; Jipson & Gelman, 2007; Kahn et al., 2012; Kim & Lee, 2018; Martin et al., 2020; Sommer et al., 2019; Bethel et al., 2011; Chen et al., 2020; Kahn et al., 2004; Kory-Westlund & Breazeal, 2019). These technologies that are currently the focus of research are expensive and specialized, rarely resembling the technology common in everyday life. In contrast, technologies that may be familiar to children from their everyday life experiences display a restricted set of characteristics designed for a particular function. For example, a vacuum robot needs to be able to move autonomously to perform its function, but it does not need to verbally communicate to do so. A voice assistant provides information contingent on verbal requests but does not have a moving, human-like body. Children's beliefs about these ordinary interactive technologies, and how those beliefs change over development, remains an open area of research.

In the current study, we take an initial step towards understanding children's developing beliefs about ordinary technologies. We employ a "feature clustering" analytic approach drawn from prior work on adults' intuitive theories of biological and non-biological agents (Gray et al., 2007; Malle, 2019; Weisman et al., 2017) to ask 4-11-year-old children whether a range of features – from physical and emotional experiences, to mental states, to deservingness of moral treatment, to free will abilities – apply to three different interactive technologies. We focused on two technologies commonly found in households – Amazon Alexa and Roomba – and compare them to a humanoid robot that is not commercially available but is commonly used in research – Nao (Brink et al., 2019; Martin et al., 2020; Sommer et al., 2019; Bethel et al., 2011).

Children's agentic beliefs about technologies

Work on children's agentic beliefs about technologies builds upon the work done on children's agency beliefs more generally (Carey, 1985; Hamlin, 2013; Piaget, 1929; Inagaki & Hatano, 2006). For example, infants, children, and adults judge non-human entities (e.g., animals, plants, geometric shapes, unfamiliar objects) to have psychological, physiological, and social characteristics if they have a face (Jipson & Gelman, 2007; Johsnon, 2000), can move autonomously in a goal-directed pattern (Hamlin, 2015; Opfer, 2002; Rakison et al., 2007), and interact contingently with the environment (Johsnon, 2000; ojalehto et al., 2017).

Just as these external, perceivable cues to agency influence children's judgments of animals, plants, and objects, they also influence judgments of technologies. For example, Meltzoff et al. (2010) found that 18-month-old infants are more likely to follow the gaze of a robot if it interacted contingently with others. Chernyak & Gary (2016) found that 5- and 7-year-old children ascribed higher emotional states, physical experiences, and moral concern to an autonomous robot dog than a remote-controlled one. Gray & Wegner (2012) found that adults were more likely to ascribe physical and emotional experiences to a robot with a human-like face than a robot with a mechanical face.

Children also think that technologies have moral status, to a certain degree. For example, children think that it is wrong to harm a robot, but acknowledge that it is more wrong to harm a biological agent (e.g., human, dog; Kahn et al., 2012; Reinecke et al., 2021; Sommer et al., 2019). Furthermore, children's moral treatment of robots is related to children believing that the robot has mental, emotional, and physical states (Reinecke et al., 2021; Sommer et al., 2019).

When we reason about other humans, our beliefs in agency are accompanied by beliefs in free will and moral responsibility (Behne et al., 2005; Gergely et al., 2002; Gray & Wegner, 2009; Monroe et al., 2014). Whether these co-occurring beliefs extend to non-humans (and, in this case, to robots) is an active area of investigation. Some studies have found that adults' moral judgments of technologies are related to their belief that the technology has mental, emotional, and physical states, and the ability to act intentionally (Nahmias et al., 2020; Young & Monroe, 2019). But it remains an open question as to whether children's moral judgments and agency judgments of technologies are related in the same way. One of our recent studies (Flanagan et al., 2021) has asked this question, with mixed results. In this study, children were unsure if a robot would be able to freely change its behavior to avoid harming a person. But the study left open two interpretations: children's uncertainty could have been due to thinking that robots do not care about avoiding harm or to thinking robots do not have mental capabilities to avoid harm (e.g., such as being free to choose, or think through reasons for action).

Agency judgments of technologies also change with age. Younger children are more likely to judge robots as having physical, emotional, mental, and moral states than older children (Brink et al., 2019; Sommer et al., 2019) and this difference is even more pronounced when comparing young children to adults (Flanagan et al., 2021; Reinecke et al., 2021). It is possible these age-related changes reflect a general change in agency beliefs as well as a specific change in beliefs about technology. With respect to a domain general change, prior work has found that children of all ages, and even adults, are sensitive to the same external cues to agency (Arico et al., 2011; Opfer, 2002), but older children are less willing to attribute psychological, physiological, and moral capabilities to non-human entities (Carey, 1985; Jipson & Gelman, 2007; Lesage & Richert, 2021; Piaget, 1929; Shtulman, 2008; Wilks et al., 2021). This developmental shift could reflect developing cognitive skills (e.g., executive function; Zaitchik et al., 2014) or reflect a developing bias towards human entities (e.g., speciesism; Wilks et al., 2021). With respect to technology, it is possible that as children have more experience with technology, they gain more knowledge about the technology's mechanisms and limitations and so are less influenced by surface appearances and abilities (Bernstein & Crowley, 2008). For each of these reasons, it is therefore important to investigate children's technology belief across development.

To date, most research on children's beliefs about the mental, social, and emotional qualities of technological agents has focused on "humanoid" robots: robots that are designed to mimic human features and abilities. For example, the Nao is a 58 cm tall robot that is humanoid in shape, with legs, arms, a torso, and a head with eyes and a mouth. The Nao can be programmed to move autonomously and interact with people in real time. Given these characteristics, it is no surprise that both adults and children believe that Nao and other robots like it have some of the qualities of living beings (Bernstein & Crowley, 2008; Bethel et al., 2011; Breazeal et al., 2016; Brink et al., 2019; Gray & Wegner, 2012; Kahn et al., 2012; Kim & Lee, 2018; Short et al., 2010; Sommer et al., 2019). But children's beliefs about familiar technologies with non-humanoid features may be quite different. Familiar technologies designed for a particular function generally only have appearances and capabilities relevant to their function. Children, therefore, may view a familiar technology's agency in a more piecemeal fashion, if at all.

Here we consider examples of two classes of familiar technologies – home appliances and voice assistants – that display cues to agency in some regards but are lacking in others. The Roomba is a home appliance robot that cleans floors as a vacuum. Roombas are short, cylindrical robots and are non-humanoid (e.g., no eyes, arms, or legs), but can move autonomously around the house in accordance with the environment (e.g., moving when an object is in the way). Since autonomous, responsive movement is a cue to agency perception of non-living beings (Chernyak & Gary, 2016; Opfer, 2002; Dolgin & Behrend, 1984; Wheatley et al., 2007), it is possible that children would ascribe agency to these autonomous vacuums. The current open questions are how much or what kind of agency children ascribe to Roomba and whether this varies by age.

Another technology that displays limited agentic cues are voice assistants. Voice assistants, like Amazon Alexa, are popular for their ability to engage with our verbal requests to complete a number of actions (e.g., play music, answer questions, set timers). Voice assistants also lack humanoid appearances and do not move autonomously. Despite this, voice assistants communicate with humans in a sophisticated manner, responding to questions, telling jokes, and thanking children for speaking politely. Communication is another cue to agency perception of non-living beings (ojalehto et al., 2017; Bernstein & Crowley, 2008; Meltzoff et al., 2010; Zaga et al., 2017). Furthermore, most voice assistants use human-like speech and prosody, which likely plays a role in children's agency perception (Strathmann et al., 2020; Yarosh et al., 2018).

Research has only recently begun investigating children's beliefs about voice assistants (Druga et al., 2017; Festerling & Siraj, 2020; Girouard-Hallam et al., 2021; Girouard-Hallam & Danovitch, 2022; Strathmann et al., 2020; Yarosh et al., 2018). Studies have demonstrated, for example, 3-10-year-old children generally believe that voice assistants, like Amazon Alexa, are smart and friendly (Druga et al., 2017; Girouard-Hallam et al., 2021). Younger children, however, are more willing to anthropomorphize voice assistants (Strathmann et al., 2020), believe that voice assistants have a moral standing (Girouard-Hallam et al., 2021), and trust voice assistants to give accurate personal information, not just factual information (Girouard-Hallam & Danovitch, 2022). These studies suggest that children take the communicative abilities of voice assistants as a sign of some agentic features, but this changes with age. It is unclear, however, how children's beliefs about the Amazon Alexa compare to advanced, humanoid robots that have communicative abilities like the Alexa but also have a human-like appearance.

Overview of study

In the current study, we interviewed 4-11-year-old children about their beliefs about three different interactive technologies. We chose two that are familiar to children but are distinct from each other in their function and surface-level characteristics: *Roomba* and *Amazon Alexa*. As a comparison, following prior work, we included an unfamiliar, humanoid robot, *Nao.* Using the results of the interview, we then investigated whether agency beliefs about technological agents are organized into distinct clusters of agentic features, how the agency beliefs about the two familiar interactive technologies compare to their beliefs about the humanoid robot, and how these agency beliefs change across development.

We used a "feature clustering" exploratory factor analysis to investigate children's beliefs about the technologies' agentic features and how these features cluster for all three technologies together and for each technology separately. The "feature clustering" approach has been used to explore adult and children's beliefs about living and non-living agents (Brink et al., 2019; Gray et al., 2007; Malle, 2019; Weisman et al., 2017). For example, Weisman and colleagues (2017) found three distinct clusters of features, labelled Body, Heart, and Mind. The Body cluster combined all responses related to physical experiences (e.g., getting hungry, experiencing pain, experiencing fear). The Heart cluster combined all responses related to social-cognitive abilities (e.g., having thoughts, knowing right from wrong, feeling happy). The Mind cluster combined all responses related to perceptual-cognitive abilities (e.g., seeing things, remembering things, having goals). They also found that adults shown a static image of a humanoid robot say it has Mind abilities, but not Body nor Heart abilities.

For the current study, we created a comprehensive questionnaire that included a broad set of questions drawn from several bodies of work (Brink et al., 2019; Chernyak & Gary, 2016; Flanagan et al., 2021; Severson & Lemm, 2015). The questionnaire included questions on the technology's physical, mental, emotional, and socio-cognitive capacities (Brink et al., 2019; Chernyak & Gary, 2016).

We also extended the questionnaire to include questions relating to moral status – moral treatment (Chernyak & Gary, 2016) and judgments of moral intent (Flanagan et al., 2021). For questions relating to moral treatment, we asked whether it was okay to hit or yell at the technological agent (Chernyak & Gary, 2016). Prior work has found that younger children are more willing to treat humanoid robot as deserving of moral treatment than older children (Reinecke et al., 2021; Sommer et al., 2019). We suspect, therefore, to find similar age-related changes with the Nao, but it is unclear how children across ages would treat an Alexa or Roomba.

For judgments of moral intent, we investigated children's beliefs about the intentions and choices of the technologies' programmed actions. We contrasted two types of actions: actions within the agent's capabilities that had a neutral outcome (e.g., cleaning the bedroom floor for Roomba, answering science questions for Alexa, playing a science game for Nao) and actions within the agent's capabilities that have a harmful outcome (e.g., moving over and hurting someone's toe for Roomba and Nao; saying something and making someone cry for Alexa and Nao). For each scenario, we first asked whether the action was done on purpose or by accident (i.e., adapted from Severson & Lemm, 2015). We then asked whether the agent could have chosen to do otherwise or had to do what it did. The first question is open to different interpretations: with human actors, "on purpose" is used interchangeably with "intentional" (Behne et al., 2005; Josephs et al., 2016), but with machines, "on purpose" might be closer in meaning to "for its intended purpose or function" or, in other words, "by design" (Diesendruck et al., 2003; Gelman & Bloom, 2000). For this reason, we also included a counterfactual question that has been used in prior work to probe children's beliefs about freedom of choice vs constraint (Flanagan et al., 2021; Kushnir et al., 2015). Taken together, the questions probe whether children interpret actions of a technological agent as *only* and *always* consistent with its programming, or whether, in the scenarios in which programmed actions cause harm, children believe the agent is free to do otherwise, thus is capable of moral making moral decisions beyond its designed function.

By including different questions relating to moral treatment and moral judgment, we are also able to investigate whether children's responses for the moral status capacities relate to their responses for physical, mental, or emotional capacities. Prior work has found that children's moral treatment of humanoid robots is related to children believing that the robot has agentic features (Reinecke et al., 2021; Sommer et al., 2019), but it is unclear if there is such a relationship in children's beliefs about familiar technologies. While there has been extensive work on the relationship between adult's agency beliefs and moral judgments of technologies (Nahmias et al., 2020; Short et al., 2010; Yasuda et al., 2020; Young & Monroe, 2019), no prior study (to our knowledge) has linked children's moral judgments to beliefs about robot agency.

Given the prior work with adults, we expect that children's moral judgments will relate to their agency beliefs, but it is unclear whether each question will relate to different agentic features or if this will differ between technology types.

Finally, we included a direct question about the ontological status of each technology directly, using a rating scale from most "computer-like" to most "human-like" (adapted from Gelman & Markman, 1986). Given that western children and adults have anthropomorphic views of agency (Lane et al., 2010; Lesage & Richert, 2021; ojalehto et al., 2017; Severson & Lemm, 2015), we use an adult human as the comparison category. This is an initial step towards capturing children's beliefs about the ontological status of each familiar technology in contrast to each other and to Nao. This also allowed us to investigate relationships between their beliefs about the ontological status with their responses to clusters of items on the feature list.

Methods

Participants

The final sample consisted of 127 4-11-year-old children (M_{age} = 7.50, SD_{age} = 2.27, 53% females) recruited from a lab database and science museum in a small city in the Northeastern United States. There were 15-19 children in each age group (see Supplementary Materials Table S1 for the detailed age distribution). Of those that reported, 76% children were White, 11% were Mixed Race, 6% were Asian, 6% were Hispanic/Latino, and 1% were Black/African American. The majority of children's primary caregivers (91%) held a college degree or above. The majority of children (87%) had prior exposure to interactive technologies[1]. The majority of the children (92%) were tested in a quiet corner in a museum or lab. In April 2020, 8% of the

[1] Technology exposure was reported by the child's guardian prior to the study. The guardian was asked to report whether the child had experiences with home devices (e.g., Amazon Alexa, Echo, Google Home, etc.), toy robotics, appliance robotic devices (e.g., Roomba vacuum, etc.), and educational robotics. The report was combined into a score out of 4 (0 = no exposure to technologies listed, 4 = exposure to all types of technologies listed).

children were tested online over Zoom as a result of the COVID-19 pandemic. Two additional children participated but were excluded due to either a developmental disability or lack of compliance throughout the entire study. This study incorporated a preregistered pilot study (see https://osf.io/tnz8e). However, before the pilot data was analyzed, the researchers decided to continue this project into a larger study with an updated analysis plan. The analysis plan, materials, data, and coding scripts of this current project can be found at https://tinyurl.com/yssyx8p9. Ethical approval for the study was obtained from Cornell University's Institutional Review Board for Human Participation Research.

Materials & Procedure

Children were asked a series of questions about 3 different interactive technologies presented in a Latin Square counterbalanced order: a Roomba vacuum, an Amazon Alexa voice assistant, and a Nao humanoid robot. Roombas are short cylindrical autonomous vacuums with a diameter of approximately 35 cm and a height of approximately 9 cm. Amazon Alexas are grey cylindrical speakers. The one shown in our study was 23.5 cm tall by 8.4 cm in diameter. Nao robots are humanoid in shape, with legs, arms, a torso, and a head with eyes and a mouth, and are 58 cm tall. Participants first watched a video on an iPad of the technology performing its normal functions and were then asked a series of questions about the technology's physical, emotional, mental, deservingness of moral treatment, intentionality of actions, and ontological status (Brink et al., 2019; Chernyak & Gary, 2016; Flanagan et al., 2021; Severson & Lemm, 2015).

Videos

Videos of each technology were 17-20 seconds each showing the technology functioning normally (see https://tinyurl.com/yssyx8p9 for the exact videos used). The Roomba was shown moving around a bedroom carpet and turning multiple times upon encountering furniture and walls. The Nao was shown reciting an excerpt from a movie and gesturing. The Alexa was shown answering a man's questions. Participants were asked before and after the video if they were familiar with the technology. Of those that reported, the majority of children were familiar with the Alexa (81.9%) and Roomba (68.7%) and only a few children were familiar with the Nao (10.9%). Regardless if they were familiar with the technology or not, the experimenter explained the technology's function to the participant after the video (Roomba: "Roomba is a robot that moves by itself to clean the floor"; Nao: "Nao is a robot that speaks and moves by itself"; Alexa: "Alexa is a robot that answers people's questions").

Questionnaire and Coding

After watching the video of the technology, children were asked questions about the technology's agentic features. The questionnaire consisted of questions regarding the technology's emotional, mental, physical, socio-cognitive capabilities, as well as the technology's deservingness of moral treatment, judgments of moral intent (Purpose/Accident and Choose to/Have to), and similarity to humans (referred to as ontological status). Question order was randomized for each technology during the experiment. The full questionnaire is described in Table S2 in Supplementary Materials.

Mental, Emotional, Physical, Socio-Cognitive, and Moral Treatment Questions

Questions about mental (e.g., thinking, choosing to move/talk), emotional (e.g., having feelings, getting upset, getting scared), physical (e.g., feeling hungry, feel being tickled, feeling pain, getting hurt), and socio-cognitive (e.g., knowing good from bad) capabilities were presented in a two-part format. First, children answered either yes or no to a binary question. For example, "Does… have feelings, like happy and sad?". If children answered yes, they then answered a second Likert-type question. For example, "How much does … have feelings? A little bit, a medium amount, or a lot?”. The two-part question resulted in a 4-point scale for each of these questions coded as 0 (no), 1 (yes, a little bit), 2 (yes, a medium amount), and 3 (yes, a lot).

The moral treatment questions (e.g., okay to hit, okay to yell at, okay to neglect) were presented in a similar two-part format. First, children answered either okay or not okay to a binary question. For example, “Is it okay or not okay to hit…?”. If children answered not okay, they then answered a second Likert-type question. For example, “How not okay is it to hit…? Not okay a little bit, not okay a medium amount, or not okay a lot?”. The two-part question resulted in a 4-point scale for each of these questions coded as 0 (okay), 1 (not okay, a little bit), 2 (not okay, a medium amount), and 3 (not okay, a lot).

Judgment of Moral Intent Questions

For judgments of moral intent, children given a scenario where the agent did something within its programming, one which was neutral and one which caused harm to a person. The experimenter gave a definition of the word “programmed” (e.g., “programmed means that someone made [the technology type] to do something”) to some of the children who appeared confused by the word or requested a definition ($N = 16$). The programmed actions varied across technologies and was specific to the technology’s capabilities (e.g., “Someone programmed Roomba so that Roomba *only* cleans the bedroom and *not* the living room. Today, Roomba is cleaning the bedroom.”). For the *Neutral Action*, children were told that the technology was programmed to perform only one, default action. For the *Harmful Action*, children were told that the technology was performing its typical function (e.g., Roomba is cleaning the floor, Alexa is answering questions, Nao is walking/talking) and harmed someone (physically by hurting someone’s toe if Roomba, emotionally by making someone cry if Alexa, both if Nao for comparison). For each action, children were asked if the technology preformed the action on purpose or by accident. If the child said, “on purpose”, he/she received a score of 1. If the child said, “by accident”, he/she received a score of 0. Following this, children were asked questions about freedom of choice (if the technology “had to” perform the action or “could choose” to do otherwise). If the child said that the technology could choose to do otherwise, he/she received a score of 1, indicating an attribution of free choice. If the child said that the technology had to perform the action, he/she received a score of 0.

Ontological Status Question

The ontological status question was presented in a two-part format. First, children were shown a picture of a person and a computer (see Table S1). Children then answered either person or computer to a binary question, “Is… more like a person or a computer?” Children were then asked how similar the technology is to the child’s answer (person/computer). For example, if the child said the technology is more like a computer, they were asked, “Is… like a computer a little bit, a medium amount, or a lot?” The two-part question resulted in a 6-point scale coded as 0 (computer, a lot), 1 (computer, a medium amount), 2 (computer, a little bit), 3 (person, a little bit), 4 (person, a medium amount), 5 (person, a lot).

Results

We first present results from an exploratory factor analysis across and within technology types, followed by results on the differences between technology types. We then present results for the Purpose/Accident and Choose to/Have to questions as well as the ontological status questions, including the relationship with the factors. Preliminary analyses showed that exposure to technologies increased with age ($r = 0.33$, $p < .0001$). With every model/equation in our analyses, we included age, technology exposure, and gender as variables (see Supplementary

Materials for the full model results). We did not find a significant effect of technology exposure in any of the models/equations, so we did not include it in our final analyses. We only found a significant effect of gender with the purpose/accident question for the Emotionally Harmful Action, but every other model/equation did not include gender in our final analyses. See Supplementary Materials Table for the means and age relationships for each of the feature questions across and within technology types (Table S3).

Exploratory Factor Analyses

We conducted independent exploratory principal components factor analyses (varimax rotation) across and within technologies for the features[2]. We identified a three-factor structure that described all the technologies combined, labelled "Experience", "Mind" and "Moral Treatment" (see Table 1). We also found that the factor loadings deviated by technology type.

The overall Experience factor corresponded to physical and emotional reactions, including feeling scared, feeling pain, getting hungry, getting upset, having feelings, and feeling being tickled (loadings $\geq$ 0.55). The items above threshold for Nao were similar to the overall factor loadings. For Roomba this factor also included choosing to move (loading = 0.52). For Alexa, the factor was more restrictive, not including getting upset or having feelings (loadings $\leq$ 0.39). The Experience factor accounted for 19 – 29% of the total variance in the rotated maximal solution.

The overall Mind factor corresponded to mental states and abilities, such as thinking, knowing good from bad, having feelings, and choosing to move/talk (loadings $\geq$ 0.49). The items above threshold for Nao were similar to the overall factor loadings. For Roomba, however, this

[2] The original, preregistered plan was to create a correlation matrix to find any significant relationships between questions. However, upon further discussion, the researchers decided that an exploratory factor analysis would be a more uniform way to recognize the feature clusters.

factor did not include having feelings or choosing to move (loadings ≤ 0.40). For Alexa, the factor was more expansive, including feeling scared and getting upset (loadings ≥ 0.597). The Mind factor accounted for 12 – 18% of the total variance.

The Moral Treatment factor corresponded to treatment towards the technology. For each technology and overall, it was the dominant factor for saying the technology should not be hit and yelled at (loadings ≥ 0.66). The Moral Treatment factor accounted for 10 – 13% of the total variance.

Table 1

Factor loadings from exploratory factor analyses for each technology type and overall (after varimax rotation).

	Roomba			**Alexa**			**Nao**			**Overall**		
Question	1	2	3	1	2	3	1	2	3	1	2	3
Getting hungry	**.799**	.236	.169	**.599**	.354	-.010	**.724**	.163	.164	**.751**	.171	.128
Feeling pain	**.865**	.064	.078	**.789**	.230	.138	**.693**	.146	.163	**.764**	.124	.135
Feeling tickled	**.591**	.284	.141	**.664**	.131	.129	.479	.370	.288	**.552**	.266	.184
Getting scared	**.743**	.259	.119	**.665**	**.597**	.057	**.765**	.219	.238	**.773**	.316	.139
Getting upset	**.691**	.394	.136	.286	**.748**	.010	**.720**	.291	.251	**.635**	.443	.131
Having feelings	**.632**	.397	.310	.394	**.536**	.178	**.616**	**.521**	.305	**.594**	.492	.237
Choosing to move/talk	**.515**	.317	.095	.138	.454	.060	.219	**.696**	.025	.322	**.503**	.047
Thinking	.108	**.639**	.147	.172	**.527**	.201	.124	**.683**	.260	.149	**.663**	.185
Knowing good from bad	.263	**.656**	.216	.167	**.508**	.282	.289	**.582**	.183	.244	**.583**	.221
Not okay to hit it	.091	.119	**.811**	.027	.224	**.720**	.218	.130	**.774**	.122	.165	**.730**
Not okay to yell at it	.142	.234	**.686**	.143	.041	**.664**	.260	.207	**.708**	.186	.152	**.723**
Feeling of neglect	.308	.110	.359	.397	.322	.285	.345	.183	.338	.396	.164	.323
Getting Hurt	.387	-.074	.163	.298	.294	.085	.441	.283	.212	.379	.209	.135
% total variance explained (after varimax rotation)	29	12	12	19	18	10	25	16	13	26	14	11

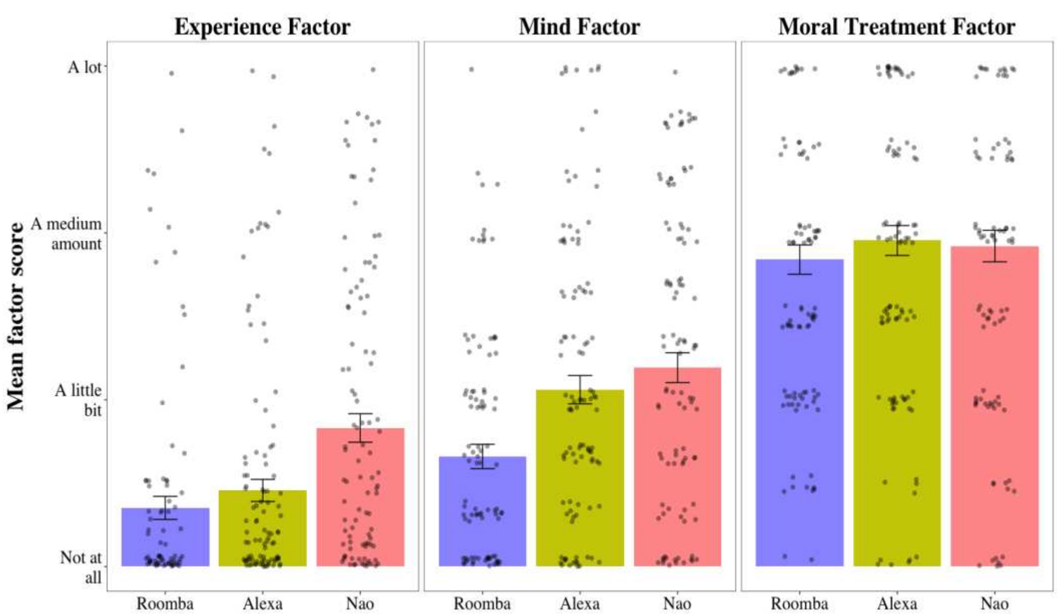
Factor Key:
1 = Experience 2 = Mind 3 = Moral Treatment

Differences between technologies

For each child, we created a factor score based on the mean response for each question within the 3 factors for each technology (e.g., the Mind factor score for the Roomba was the average of children's response to Roomba's ability to think and know good from bad). The mean ratings for each factor between technology types are shown in Fig. 1. We ran separate repeated measures General Linear models with the factor score as the outcome variable, technology type, and age (in years) as factors, and ID as a random factor. In each model, we included an interaction between technology type and age but removed it from the model if we did not find a significant interaction. To correct for multiple comparisons, any follow-up pairwise analyses use Tukey's honestly significant difference (HSD) test. Since we were interested in children's beliefs about the Roomba and Alexa in comparison to the Nao, we ran follow-up equivalence tests if the either of the familiar technologies did not differ from the Nao. The results of the models are shown in Fig. 2. We also report the findings from follow-up GLMs for each feature separately in Section 4 of the Supplementary Materials.

Figure 1

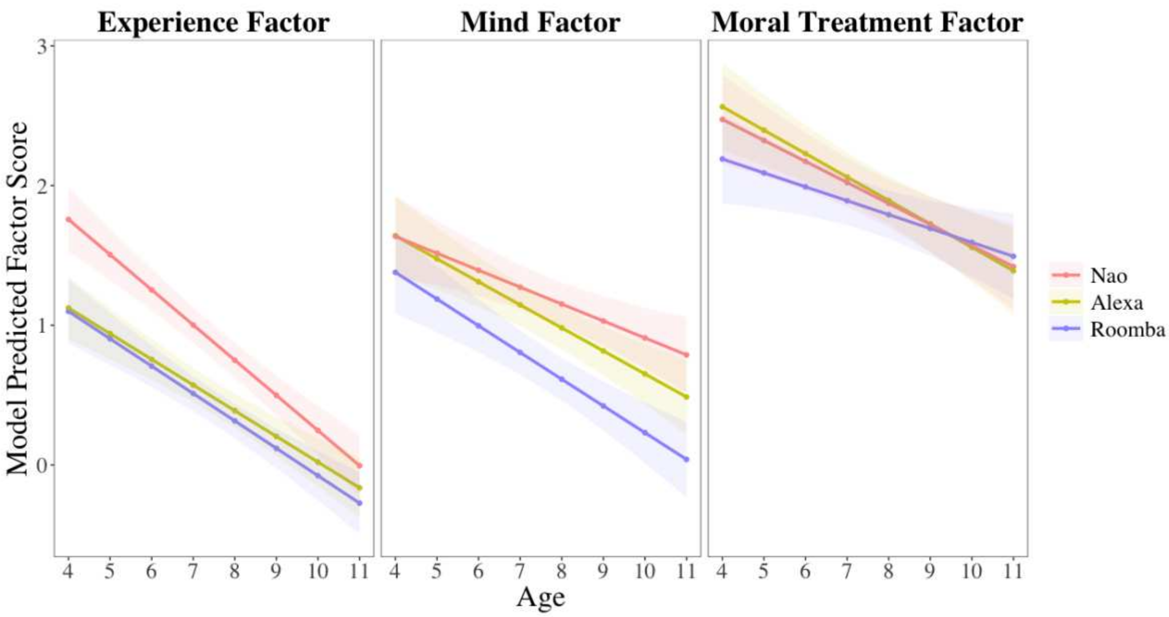
Children's mean responses for the Experience Factor (left column), Mind Factor (middle column), and Moral Treatment Factor (right column) between technology types.



Note. Error bars represent +/- standard error.

Figure 2

Model predicted relationship between Age and the Experience Factor (left column), Mind Factor (middle column), and Moral Treatment (right column), for each technology type.



For the Experience factor, we found a main effect of technology type, $F(2, 231) = 43.94$, $p < .0001$, partial eta squared (η_p^2) = 0.28, and age, $F(1,126) = 79.73$, $p < .0001$, $\eta_p^2 = 0.39$, and a significant interaction between the two, $F(2, 234) = 4.84$, $p = .03$, $\eta_p^2 = 0.04$. We first looked at the comparisons between the technologies, controlling for age, with Tukey's HSD test. Children ascribed more experiences to the Nao (*M* = 0.83, *SD* = 0.92) than Roomba (*M* = 0.35, *SD* = 0.75), $t(231) = 8.73$, $p < .0001$, $d = 0.57$, 95% CI (0.43, 0.71), and Alexa (*M* = 0.83, *SD* = 0.92), $t(230) = 7.48$, $p < .0001$, $d = 0.49$, 95% CI (0.36, 0.63). Alexa and Roomba did not differ, $t(231) = 1.33$, $p = .378$, $d = 0.09$, 95% CI (-0.04, 0.22).

To explore the interaction effect further, we looked at the effect of age for each technology separately. For each technology type we found that a 1-year-increase in age was predicted to have a 0.18-0.25 decrease in ascribing experiences to the technology, *ps* < .0001.

We then looked at whether the age effect differed by technology type, using Tukey's HSD test. Even though an increase in age decreased attribution of experiences for all technology types, the decrease was greater for the Nao compared to the Alexa, $t(232) = 2.941$, $p = .0100$, $d = 0.19$, 95% CI (0.06, 0.32), and compared to the Roomba, $t(233) = 2.35$, $p = .051$, $d = 0.15$, 95% CI (0.02, 0.28). We did not find a significant difference in slope between the Alexa and Roomba, $t(234) = 0.522$, $p = .861$, $d = 0.03$, 95% CI (-0.09, 0.16) (see Fig. 2). Taken together, children attributed more experiential capabilities to the Nao than the Alexa and Roomba, and children's attribution of experiential capabilities to all technologies declined with age. The decline in age, however, was greater for the Nao than the other technologies.

For the Mind factor, we did not find a significant interaction between technology type and age, $F(2, 235) = 1.98$, $p = .141$, $\eta_p^2 = 0.02$, so we reran the model without the interaction. We found a main effect of technology type, $F(2, 233) = 23.04$, $p < .0001$, $\eta_p^2 = 0.17$, and age, $F(1, 127) = 34.58$, $p < .0001$, $\eta_p^2 = 0.21$. Controlling for age, using Tukey's HSD test, children ascribed *fewer* mental characteristics to Roomba ($M = 0.66$, $SD = 0.79$) than Nao ($M = 1.19$, $SD = 0.96$), $t(232) = 6.61$, $p < .0001$, $d = 0.43$, 95% CI (0.30, 0.57) and Alexa ($M = 1.06$, $SD = 0.94$), $t(234) = 4.67$, $p < .0001$, $d = 0.31$, 95% CI (0.17, 0.44). A non-registered equivalence test demonstrated that children's responses for Alexa and Nao were equivalent in a range of 0.5 points, $t(232) = 4.41$, $p < .0001$, $d = 0.29$, 95% CI (0.16, 0.42). Across technology types, a 1-year increase in age was predicted to have a 0.16 decrease in saying the technology had mental characteristics, 95% CI (0.11, 0.21). To summarize, children's attribution of mental states declines with age, and across ages children attributed mental states similarly to Alexa and Nao.

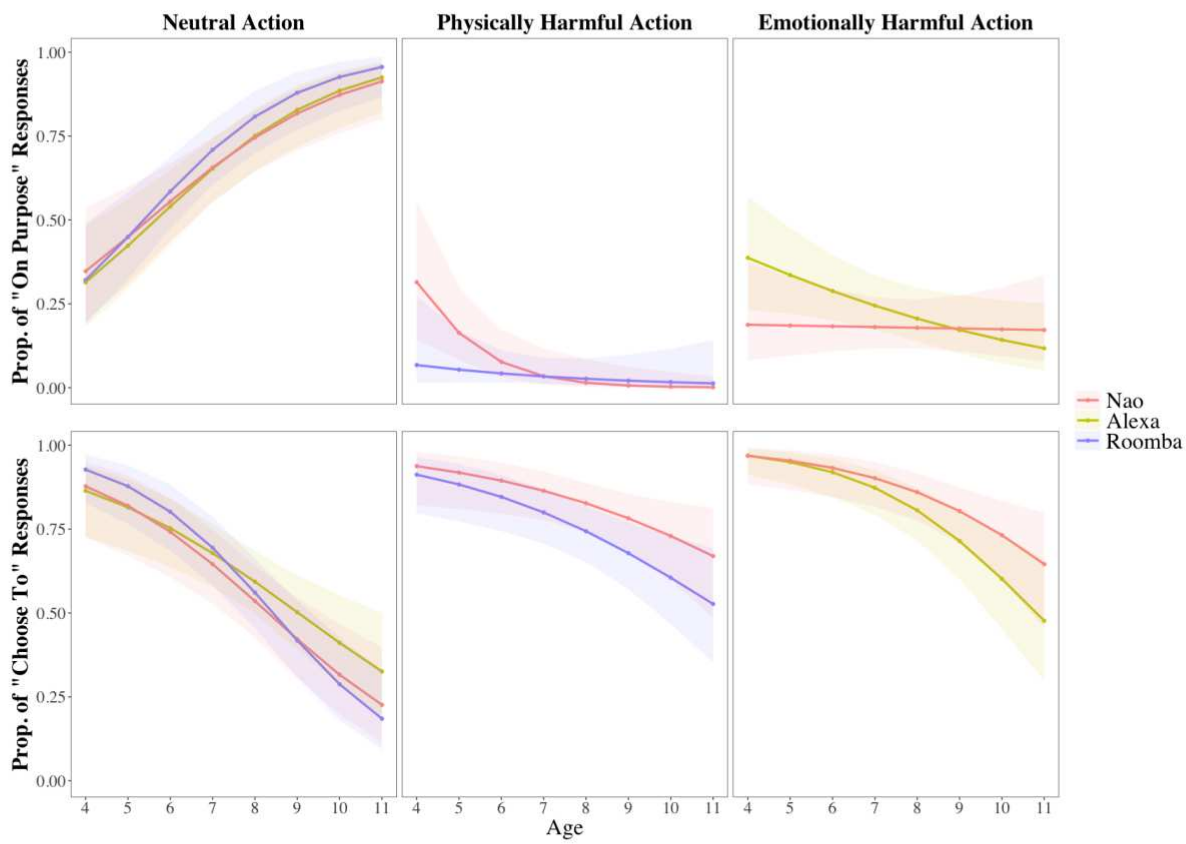
For the Moral Treatment factor, we did not find a significant interaction between technology type and age, $F(2, 239) = 2.08$, $p = .127$, $\eta_p^2 = 0.02$, so we re-ran the model without the interaction. We did not find a main effect of technology type, $F(2, 239) = 1.45$, $p = .237$, $\eta_p^2 = 0.01$, but we did find a main effect of age, $F(1, 125) = 18.84$, $p = .0002$, $\eta_p^2 = 0.13$. Controlling for age, children's ascription of Moral Treatment did not vary between technologies (Nao: M = 1.92, SD = 1.03 Alexa: M = 1.95, SD = 0.99; Roomba: M = 1.84, SD = .97). A non-registered equivalence test demonstrated that children's responses for Alexa and Roomba were equivalent to the Nao in a range of 0.5 points, $ps < .0001$. Across technology types, a 1-year increase in age was predicted to have a 0.14 decrease in saying the technology deserves moral treatment, 95% CI (0.08, 0.20). To summarize, children across all ages, said it was "not okay" to harm any of the technologies, regardless of the technologies' appearance or abilities, but younger children thought it was less ok than older children.

Judgments of Moral Intent

For each of the purpose/accident and choose to/have to questions for both the neutral and harmful actions, we ran separate repeated measures Generalized Estimating Equations with technology type and age as factors, and ID as a random factor. We also included whether the participant received a definition of the word "programmed" in our equations but removed the factor from the equation if we did not find a significant effect. We did not find any significant interactions between technology type and age in the equations (see Supplementary Materials), so they were not included in any of the final equations. Fig. 3 shows the equations' predicated relationships between the two questions and age for each technology type for each action. Results for binomial tests can be found in the Supplementary Materials.

Figure 3

Equation predicted relationship between age and "on purpose" response (top row) and "choose to" response (bottom row) for the Neutral Action (left column), Physically Harmful Action (middle column), and Emotionally Harmful Action (right column), for each technology type.



For the on purpose/by accident question for the neutral action, we did not find an effect of definition given, $\chi^2(1) = 0.51$, $p = .475$, so it was removed from further analyses. We found a main effect of age, $\chi^2(1) = 28.18$, $p < .0001$, such that, across technology type and gender, a 1-year-increase in age was predicted to increase the odds of saying the technology performed the action on purpose by 61%, 95% CI (35%, 93%). We did not find a main effect of technology type, $\chi^2(2) = 1.12$, $p = .57$ (Nao: 69%, $N = 80/116$; Alexa: 67.8%, $N = 82/121$; Roomba: 71.9%, $N = 87/121$). This demonstrates that older children were more likely to think that a technology's neutral programming-consistent action was done on purpose than younger children, regardless of the technology type.

For choose to/have to question for the neutral action, we found a main effect of age, $\chi^2(1) = 31.84$, $p < .0001$, such that a 1-year-increase in age was predicted with a 37.2% decrease in the odds of saying the technology could choose to go against the programmed action, 95% CI (26.2%, 46.6%). We also found a main effect of definition given, $\chi^2(1) = 8.21$, $p = .004$, such that children who were given a definition of programming were more likely to say that the technologies could choose to go against the programmed action (81.3%, $N = 13/16$) than children who were not given a definition (48.7%, $N = 54/111$), $OR = 7.00$, 95% CI (1.85, 26.5). We did not find a main effect of technology type, $\chi^2(2) = 1.11$, $p = .573$ (Nao: 53.8%, $N = 63/117$; Alexa: 58.1%, $N = 68/117$; Roomba: 56.6%, $N = 69/122$). In summary, we found that, regardless of the technology type, older children were more likely to think a technology had no choice but to perform its programmed action than younger children.

The harmful actions were designed to compare each common technology to Nao based on their abilities (physical harm for Roomba, emotional harm for Alexa). In the case of physical harm (Roomba and Nao), we did not find a significant effect of definition given, $ps \geq .445$, so it was removed from the following equations. For the on purpose/by accident question, we found a main effect of age, $\chi^2(1) = 6.22$, $p = .013$, such that, across technology type, a 1-year-increase in age was predicted to decrease the odds of saying the technology hurt someone's toe on purpose by a 43%, 95% CI (11.4%, 63.4%). We did not find a main effect of technology type, $\chi^2(1) = 2.66$, $p = .103$ (Nao: 6.7%, $N = 8/119$; Roomba: 3.3%, $N = 4/121$). Therefore, while all children think that a technology did not hurt someone's toe on purpose, regardless of technology type, this was more pronounced in older children than younger children.

For the same scenario of physical harm, we found a main effect of age in children's choose to/have to response, $\chi^2(1) = 9.89$, $p = .002$. Across technology type, a 1-year-increase in age was predicted with a 26.3% decrease in the odds of saying the technology could choose not to hurt someone's toe, 95% CI (10.9%, 39%). We also found a main effect of technology type, $\chi^2(1) = 5.85$, $p = .016$, such that children were more likely to say that the Nao could choose not to hurt someone's toe (82.2%, $N = 97/118$) than the Roomba (74.4%, $N = 87/117$), $OR = 1.68$, 95% CI (1.10, 2.54). Additionally, binomial tests found that only 4-9-year-old children were more likely to say that the technology could choose not to hurt someone's toe (see Supplementary Materials). This suggests that, up until 10-years-old, children think that both technologies have a choice in whether they harm someone, but this is more pronounced for the Nao than the Roomba.

In the case of emotional harm (Alexa and Nao), we did not find a significant effect of definition given, $ps \geq .175$, so it was removed from the following equations. Preliminary analyses also found a significant effect of gender for the on purpose/by accident question, $\chi^2(1) = 3.93$, $p = .047$, so it was included in the final equation as a control. For the on purpose/by accident question, we did not find a main effect of age, $\chi^2(1) = 2.33$, $p = .127$, or a main effect of technology type, $\chi^2(1) = 1.45$, $p = .228$ (Nao: 18.6%, $N = 22/118$; Alexa: 24%, $N = 29/121$). This demonstrates that children of all ages thought both technologies did not purposefully cause emotional harm.

For these same scenarios of emotional harm, we found a main effect of age in children's choose to/have to response, $\chi^2(1) = 16.98$, $p < .0001$. Across technology type, a 1-year-increase in age was predicted with a 37% decrease in the odds of saying the technology could choose not to make someone cry, 95% CI (21.5%, 49.4%). We also found a main effect of technology type,

$\chi^2(1) = 4.52$, $p = .034$, such that children were more likely to say that Nao could choose not to make someone cry (84.2%, $N = 96/114$), than the Alexa (79.1%, $N = 91/115$), $OR = 1.62$, 95% CI (1.04, 2.51). Additionally, binomial tests found that only 4-9-year-old children were more likely to say that the technology could choose not to make someone cry (see Supplementary Materials). This is similar to our findings for the physically harmful action, such that children under the age of 10 are more likely to think that both technologies have a choice in whether they harm someone, but this is more pronounced for the Nao than the Alexa.

Table 2

Relationship between harmful action questions and factor scores for each technology type, controlling for age

			Experience	Mind	Moral Treatment
Physical harm	"On Purpose"	Roomba	.349***	.145	.159
		Nao	.225*	-.005	-.071
	"Choose to"	Roomba	.132	.202*	.062
		Nao	.107	.259**	.100
Emotional harm	"On Purpose"	Alexa	.066	.163⁺	.070
		Nao	.274**	.255**	.248**
	"Choose to"	Alexa	.091	.200*	.164⁺
		Nao	.111	.288**	.062

$^{+}p < .1$; *p < .05; **p < .01, ***p < .001

In an exploratory analysis, we analyzed the relationship between the on purpose/by accident and choose to/have to questions and the three factor scores, controlling for age (see Table 2). The factor scores did not correlate with the neutral action questions, *ps* ≥ .103, but did correlate with harmful action questions: for Roomba and Nao, children who said that the technology performed the harmful action “on purpose” also attributed higher Experience factor scores, *ps* ≤ .016 (see Table 2). For all technologies, children who said that the technology could have chosen not to cause harm also attributed higher Mind factor scores, *ps* ≤ .036.

Ontological Status

To measure the differences of children’s judgments of ontological status (“more like a computer or person?”) between technologies, we ran a repeated-measures GLM with technology type and age as factors, and ID as a random factor. We did not find a main effect of age, $F(1, 121) = 2.53$, $p = .11$, $\eta_p^2 = 0.02$, or a significant interaction effect between age and technology type, $F(2, 240) = 1.00$, $p = .37$, $\eta_p^2 < 0.001$, so the final model did not include these variables. We found a main effect of technology type, $F(2, 240) = 28.41$, $p < .0001$, $\eta_p^2 = 0.19$. Using Tukey’s HSD test to correct for multiple comparisons, children said that Nao was more like a person ($M = 2.08$, $SD = 1.72$) than Alexa ($M = 1.07$, $SD = 1.37$), $t(240) = 6.13$, $p < .0001$, $d = 0.40$, 95% CI (0.26, 0.53), and Roomba ($M = 0.95$, $SD = 1.28$), $t(241) = 6.90$, $p < .0001$, $d = 0.44$, 95% CI (0.31, 0.58). Children’s responses for Alexa and Roomba did not differ, $t(241) = 0.79$, $p = .709$, $d = 0.05$, 95% CI (-0.08, 0.18). Children of all ages, therefore, had similar judgments of the technology’s ontological status, such that the Nao was judged as a little bit like a computer, while the Alexa and Roomba were judged as more computer-like.

We measured the three factors’ predictive value for judgments of ontological status. We ran a repeated-measures GLM with the factors as the predictors, controlling for technology type, and ID as a random factor. We did not find a significant effect of the Experience factor, $F(1, 289) = 0.19$, $p = .663$, $\eta_p^2 < 0.001$, or the Moral Treatment factor, $F(1, 300) = 3.47$, $p = .064$, $\eta_p^2 = 0.01$, so we re-ran the model without those two factors. After re-running the model with the Mind Factor, controlling for technology type, and ID as a random factor, we found that the Mind factor was a significant predictor for judgments of ontological status, $F(1, 306) = 9.67$, $p = .002$, $\eta_p^2 = 0.03$. Across technology types, a one-point increase in the Mind factor was predicted to have a 0.29 increase in saying the technology was more like a person, $p = .002$, 95% CI (0.11, 0.47). In summary, children who thought that the technologies had more mental abilities also thought the technologies were more human-like.

Discussion

In this study we investigated 4-11-year-old children's beliefs about two familiar technologies – home appliances (Roomba) and voice assistants (Amazon Alexa) – in comparison to beliefs about a humanoid robot (Nao). Using feature clustering, we found that children's beliefs about the characteristics of technological agents are organized into three distinct clusters – having experiences, having minds, and deserving moral treatment. We also found that children endorsed some agent-like features for each technology type, but the extent to which they did so declined with age. Furthermore, as children got older, they were more likely to view the technologies' actions as constrained by their programming, regardless of the technology type. Finally, we found that for each agent, children's attribution of physical and mental states predicted their beliefs about the agents' moral capabilities. Across these results, we found systematic differences between Alexa, Roomba, and Nao, that correspond well to the unique characteristics and functionality of each.

Differences in Agency Beliefs Across Technology Types

We found that children organized the features of the humanoid robot Nao in a way that echoes prior work on children's organization of social, cognitive, and emotional states for humans (Weisman et al., 2021). Paralleling knowledge that human emotions are tied to physical experiences (Barden et al., 1980), children's beliefs about Nao's physical experiences (e.g., hunger) clustered with beliefs about Nao's emotional states (e.g., fear). Paralleling beliefs that human actions are motivated by mental states with the intention to accomplish goals (Wellman & Woolley, 1990), children connected Nao's mental abilities with intentional actions (e.g., choosing to move). To be clear, it is not that children thought that Nao was human (they rated Nao as being more "computer-like" than human). Rather, since most children were unfamiliar with the Nao prior to watching the video at the beginning of the study, they most likely drew on knowledge of human minds and experiences to understand the humanoid appearance and abilities they observed (Gelman & Markman, 1986; Gopnik & Wellman, 1992). It is possible that beliefs about the Nao's capabilities and limits would refine with more familiarity, especially with more opportunity for live interaction.

Children's beliefs about the two familiar household appliances Roomba and Alexa, in contrast, were more closely aligned with each technology's specific functions. For example, the Roomba is designed to sense, move, and react to the world, but it is not designed to engage socially. As such, we found that children connected most of Roomba's features within the experiences cluster. Specifically, children connected "having feelings" and "choosing to move" to physical experiences and did not connect either one to mental states. Alexa, on the other hand, is designed to be interactive, verbal, and socially helpful, but not embodied. Our results suggest that children's beliefs about Alexa correspond roughly to a thinking and feeling agent without physical experiences: Alexa's emotional states were clustered with other mental states, but, unlike Roomba, children's beliefs about Alexa's mental abilities were not linked to beliefs about Alexa's ability to feel hungry, ticklish, or feel pain. Our findings leave open the question of the role that human interaction plays in children's beliefs about technologies. For example, would children's beliefs about the Roomba echo their beliefs about the Alexa if they saw the Roomba move in response to a human's movements? Furthermore, do children believe that the Alexa is a communicative, thinking, feeling agent beyond its interactions with humans, possibly with interactions with technologies?

Children's beliefs about the disembodied but communicative voice assistant are interesting to consider with respect to naïve dualism – that the body and mind are distinct and separable from each other (Bloom, 2004; Chudek et al., 2013). Our analysis demonstrates that children did not think Alexa needs a body for it to have a mind, and that Alexa's mental abilities played a central role in children's judgments of Alexa's human-like mental and even moral capabilities. In some ways, children's beliefs about Alexa parallel beliefs about other disembodied agents, in particular ambiguous agents (Chudek et al., 2013), dead agents (Astuti & Harris, 2008; Bering & Bjorklund, 2004), and spiritual agents (Shtulman, 2008). For example, children believe they can communicate with disembodied agents (e.g., God or spirits; Lane et al., 2016) and consider disembodied agents to have thoughts and other mental states (Lane et al., 2010; Piazza et al., 2011). Disembodied technological agents, like voice assistants, would be an exciting new domain in which to investigate the relationship between an agent's ability to communicate and children's theories about the existence of minds without bodies.

Similarities and Differences in Moral Status

Our results suggest that children believe interactive technologies to be responsible moral agents, at least to the extent that their programming offers the potential for causing harm. Specifically, we found evidence that children's judgments that each of the technologies could cause intentional harm were correlated with their judgments of each of the technologies' *capabilities* to cause harm. For the two embodied agents, judgments of purposeful physical harm related to physical capabilities, and for the two communicative agents, judgments of freely chosen emotional harm related to mental abilities. Furthermore, children thought that the Nao could choose not to harm more than the Roomba and Alexa. This investigation of children's moral judgments of technologies only scratches the surface, leaving open questions for future research. Even so, these preliminary findings highlight the sophisticated nature of children's moral judgments – ones that are specific to the agency feature, action ability, harm type, and technology type.

Children's moral judgments of the technologies may have also been influenced by the extent to which children viewed the technology as a piece of property or as an agent. Specifically, we found that younger children viewed the technologies as more agentic, so children may have interpreted "on purpose" for technologies as "intentional", as they would for human actors (Behne et al., 2005; Josephs et al., 2016). For example, younger children possibly thought the programmed, neutral action was done "by accident" because it was random – the technology could have done something else, according to young children. Younger children also may have thought that the technologies caused harm "by accident" because children think that technologies do not want to cause harm, similar to how children think of human agents (Chernyak et al., 2013). Older children, on the other hand, may have interpreted "on purpose" for technologies as "by design", as they would for objects (Diesendruck et al., 2003; Gelman & Bloom, 2000). In this case, older children possibly thought that a technology performs a programmed, neutral action "on purpose" because that is what it is designed to do but performs a harmful action "by accident" because it is not designed to cause harm.

Similarly, children's belief that all the technologies deserved moral treatment may have also been due to children considering treatment based on moral agency with treatment based on property value. For example, children's belief that the technologies deserved moral treatment was related to their belief that the technologies had experiences, such as feeling pain, suggesting concern about moral agency. But there was also a tendency for children to say it was at least "a little bit" not okay even when they did not endorse experiential features, suggesting concern about property value. By 2-years-old, children are already sensitive to ownership and property rights over objects (Neary & Friedman, 2014; Pesowski & Friedman, 2015; Pesowski et al., 2022), so it is likely that this sensitivity includes technologies. Furthermore, anecdotally, we found that children would spontaneously mention both reasons for treatment. For example, a 10-year-old said that it was not okay to yell at the technology because "the microphone sensors might break if you yell too loudly", referencing concern for property value, while another 10-year-old said that it was not okay "because the robot will actually feel really sad", referencing concern about moral agency. In future work, experimentally manipulating both property value and agentic features may shed light on the relative influence on children's moral treatment and moral judgments of technologies.

Changes in Agency Beliefs Across Age

Age-related changes in children's beliefs about technologies suggest a general trend that younger children attribute more agency – more experiences, more mental states, more deservingness of moral treatment, and more ability to do otherwise - to interactive technologies than older children. Our findings extend work showing similar age-related changes in children's beliefs about humanoid robots (Bernstein & Crowley, 2008; Brink et al., 2019; Flanagan et al., 2021; Reinecke et al., 2021; Sommer et al., 2019). There are a number of possible reasons for why younger children attribute more agency to technologies than older children. For example, children's developing technology beliefs may reflect a domain general change in beliefs about non-human entities. As such, the findings in our own study echo findings that children's attribution of agentic features to animals and spiritual beings decline with age (Jipson & Gelman, 2007; Lesage & Richert, 2021; Shtulman, 2008; Wilks et al., 2021). From this point of view, it is possible that children's developing cognitive ability to distinguish between being merely animate and being a living thing may apply to their beliefs about technologies (Carey, 1985; Piaget, 1929; Zaitchik et al., 2014). Additionally, children may be developing "speciesist" attitudes as they get older (i.e., the belief that human agents are more sophisticated and have more moral value than other agents; Reinecke et al., 2021; Wilks et al., 2021). Of course, these developing beliefs can co-occur, thus it is an open question whether one or both contributed to the age-related changes we found in this study.

An additional possibility is that children's specific experiences with interactive technologies are relevant to developing beliefs about the technologies' capabilities and ontological status. Research shows that, with age, children's technology use increases in multiple contexts (e.g., entertainment, information seeking, social interactions; Girouard-Hallam et al., 2022). One possibility is that increasing engagement with interactive technologies for a broader set of goals also offers children more opportunities to encounter a broader range of mistakes, which may diminish children's trust of the technology as being communicative or autonomous. In support of this, we found that by around 8-years-old, children began to recognize that a technology's programming limits it from performing certain actions. By 10-years-old, children began to recognize that a technology's programming can even limit it from avoiding harm, similar to adults' beliefs about technologies' limitations (Flanagan et al., 2021). Anecdotal evidence from children's spontaneous comments during the interview offer some support for this idea as well. For example, when explaining why Alexa cannot get upset, a 6-year-old said, "I tried it before but she's like 'I'm not sure about that,'" referencing Alexa's lack of contingent interaction. When explaining why Roomba cannot choose to move, a 7-year-old said, “You send it to move around, you send it to clean rooms, but basically it has to move no matter what,” referencing Roomba’s lack of autonomy.

It is important to note, however, that the type of mistake may play an important role in children’s agency judgments. Some mistakes may actually make technologies appear more agentic. For example, prior work has found that adults prefer and anthropomorphize robots that make social errors (e.g., not following the rules, incongruent gestures, cheating; Mirnig et al., 2017; Salem et al., 2013; Short et al., 2010) or provide further social cues after the error (e.g., giving an apology; Lee et al., 2010). However, adults do not anthropomorphize technologies that make technical errors (e.g., typos; Bührke et al., 2021; Westerman et al., 2018). It remains an open question as to whether children are sensitive to these two types of errors, but we suspect that children regularly encounter these technical errors with the technologies in their home more so than social errors.

A better appreciation of the limits of technology with age and experience might not only influence agency attributions but might also lead to a decline in trust. In fact, prior research using humanoid robots has found that the two – agency attribution and trust – are linked (Brink & Wellman, 2020). Since technological agents are being relied on more and more as teaching tools both at home and in classrooms (Belpaeme et al., 2018; Hashimoto et al., 2013; Scassellati et al., 2012; Wei et al., 2011), and trust is critical for children’s learning (Harris et al., 2018; Koenig & Harris, 2005; Sobel & Corriveau, 2010; Sobel & Kushnir, 2013), the age-related declines in agency beliefs we found here might have far-reaching implications for the effectiveness of educational technology that occasionally “mess up.” However, since children are willing to trust and learn from people who make occasional mistakes (Kushnir & Koenig, 2018; Oostenbroek &

Vaish, 2019) and adults attribute agency to technologies that make mistakes marked by social cues (Lee et al., 2010; Mirnig et al., 2017; Salem et al., 2013; Short et al., 2010), perhaps building technologies that are more believably human-like might mitigate some of these concerns.

Limitations and Future Directions

The limitations of the current study raise important questions for future research. First, this study was conducted in one small university town in the U.S. and most of the children who participated in this study were White, had caregivers with a bachelor's degree or higher, and had experience with technologies. Previous work has demonstrated that agency beliefs vary across cultures (ojalehto et al., 2017; Weisman et al., 2021). Our findings, therefore, may not be generalizable to the greater global population. Furthermore, we only asked children's caregivers to indicate what technologies the child has had experience with – we did not ask them to detail the nature of the child's experience (e.g., how many times a week children use the technology, what children use the technology for, whether the technology is in their house or at school, etc.). The nature of children's technological experiences varies by age and culture (Girouard-Hallam et al., 2012). Therefore, while we suspect that there is a relationship between the nature of children's technological experience and their agency beliefs, we were unable to investigate this relationship directly in the current study.

Our study presents new avenues for research on children's developing understanding of programming. In our study, we only provided a definition of the word "programmed" to children who seemed confused by the word. Surprisingly, we found that children who were given a definition were more likely to say that the technologies could go against their programming. This finding should be interpreted with caution, however, as only a few children were given the definition (16) and it may be that they still did not understand the concept of programming. It is also unclear if the children who were not given a definition had a similar interpretation of the word programmed, which may influence their subsequent responses. There has been extensive work on young and older children's ability to learn programming as a skill (Bers, 2010; Sullivan & Bers, 2013; Sullivan et al., 2015), but we do not know how acquiring programming skills plays a role in children's understanding of technological agents. For example, would having an opportunity to program an agent's behavior influence children's judgments about the agent's free will or other mental capabilities?

Our methodology was an interview format, including questions from prior studies that investigated different aspects of children's agency beliefs of technologies and that had different question formats (Brink et al., 2017; Chernyak & Gary, 2016; Flanagan et al., 2021; Severson & Lemm, 2015). This was an initial step towards creating a comprehensive questionnaire to investigate children's technology beliefs, but more work is needed to address the current limitations. Specifically, most of our questions asked if the technology had an agentic feature in a yes/no format (e.g., "If Nao did not eat breakfast, would Nao feel hungry?"). The yes/no question format does not distinguish between young children saying "yes" because they believe that the technology has the agentic feature or because young children have a yes bias (Moriguchi et al., 2008; Okanda & Itakura, 2011). We suspect that young children are more willing to view the technologies as more agentic, but more work is needed to rule out the possibility of a yes bias. Furthermore, our questions relating to moral treatment, moral intent, and ontological status were asked in a different format from the yes/no questions. Instead, we asked children if the technology had an agentic feature or non-agentic feature (e.g., "Did Nao play the science game on purpose or by accident?"). While we found that these different questions relate to each other in a coherent way, it would be best to modify these questions into a standardized format for future research.

Our findings also leave open the question of how children's technology judgments compare on a continuum from biological kinds (e.g., animals) to inanimate objects (e.g., toys, household appliances). In our study, we were interested in how children categorized technological agents so children were only asked whether the technologies were more like a human or computer. Since we did not also ask about children's agency judgments of a human or computer, it is unclear how children's responses for each feature for the technology would compare to biological or inanimate kinds. Furthermore, only including a human as the biological kind in our categorization question primarily targets children's anthropomorphic views of agency. Anthropomorphizing, however, is not the only agentic view (ojalehto et al., 2017). Therefore, we might see that other features are more important in children's categorization of technologies compared to other kinds, especially for familiar technologies that are more like toys or appliances found in homes. Additionally, we chose to investigate children's beliefs about two specific types of familiar technologies. Since we found that children's beliefs about these technologies are distinct from each other, it remains an open question as to whether these beliefs generalize to other technologies. For example, animal robot toys are familiar to children, and they display a unique set of abilities that may make them seem agentic. Whether children's beliefs about animal robot toys, or other technologies, are similar to their beliefs about Alexa, Roomba, humanoid robots, or are something entirely unique, is open to future research. As we have found in our study, it is important for future research to include various types of technologies in their methodology to highlight that children's technology beliefs are type specific.

Conclusion

Children's beliefs are the window to our early intuitions of the world around us (Shtulman, 2017). Our results in particular uncover the emerging intuitions in the new, yet already commonplace, culture of technology– children's theories about the "minds of machines." Specifically, we found that, despite cute anecdotal examples, even young children do not seem to lose sight of the fact that they are interacting with artifacts that are designed for a particular function. Even with this awareness, young children attribute agency to technologies more so than older children. Furthermore, the extent to which a technology is capable of interactive communication, beyond its physical appearance, is most predictive of children's beliefs that a technology is a thinking, feeling, knowing agent. Finally, what it means to be an experiential or mindful agent is dependent on the technology's functional and abilities, and are sensibly related to children's moral and ontological judgments. Together, we believe this demonstrates that children of all ages are forming coherent and type-specific beliefs about various categories of non-living technological agents in their daily lives, rather than having a single unified theory of "robots."

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