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Robots and Autism: How Children with Autism Spectrum Disorder Perceive Social Robots

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Abstract

With the recent boom in artificial intelligence and robotics, social robots are being increasingly used as therapeutic devices for children with Autism Spectrum Disorder (ASD). These social robots are thought to be effective because of their object-like simplicity combined with human-like social behaviors. Researchers have found that social robots have a multitude of beneficial outcomes for children with ASD, including increased engagement, the emergence of new social behaviors, and reduced social anxiety. However, despite their growing use as therapeutic devices within this community, surprisingly little is known about how children with ASD interpret social robots. To explore this question, in the current study, six 7- to 10-year-olds with ASD and five typically developing 6- and 7-year-olds interacted with a social robot and then answered a series of questions about its physiological, perceptual, cognitive, and social-emotional properties. For comparison, questions were also asked about a child and a dog. Results revealed that both children with ASD and typically developing children endorsed properties of all types for the child and, to a lesser extent, for the dog. However, children gave more varied responses to questions about the robot suggesting that both children with ASD and typically developing children show confusion about how to interpret robots displaying social cues. Results are discussed in light of what they tell us about children with ASD's conceptual development and what they mean for the use of social robots in intervention.

Robots and Autism: How Children with Autism Spectrum Disorder Perceive Social Robots

According to the American Psychiatric Association (2013), Autism Spectrum Disorders (ASDs) represent a spectrum of developmental disorders characterized by impairments in social communication and repetitive and restrictive behaviors. These symptoms must be present across multiple contexts during the early developmental period and adversely affect day to day functioning (American Psychiatric Association, 2013). Because ASD is a spectrum disorder, symptoms can vary greatly in degree and manifest themselves in different ways among the population (Johnson & Myers, 2007; Newschaffer et al., 2007; Robins, Dautenhahn, Te Boekhorst, & Billard, 2005). Much is still unknown about what exactly causes ASD, but researchers propose a complex combination of biological and environmental origins (Johnson & Myers, 2007; Newschaffer et al., 2007).

A central focus of research on ASD is its cardinal symptom—social deficits. Social deficits can manifest themselves in many different ways and at varying levels of severity. Many aspects of the disorder, such as poor communication and difficulty with interpersonal relationships, can be related back to core social deficits (Sartorato, Przybylowski, & Sarko, 2017). According to the American Psychiatric Association (2013), there are three main areas of social deficits in ASD: (1) social-emotional reciprocity, including difficulties with back and forth conversation and a failure to initiate or appropriately respond to social interaction, (2) nonverbal communication, including trouble maintaining eye contact and proper interpretation of gestures and facial expressions, and (3) developing, maintaining, and understanding relationships, including appropriately adjusting behavior to various social contexts and difficulties in imaginative play (American Psychiatric Association, 2013).

While there is no known cure for ASD, several types of interventions have proven to be effective, including behavioral interventions, such as cognitive-behavioral therapy (CBT) and applied behavior analysis (ABA) (Weitlauf et al., 2014). These behaviorally based interventions often take the form of training in imitation, emotional recognition, and turn taking, among other strategies. According to Weitlauf et al. (2014), in children with ASD, such interventions have been shown to increase language and communication skills, improve social behaviors, joint attention, and imitation behaviors, decrease stereotypical behaviors, and accelerate developmental rates relative to IQ. Behavioral interventions also appear to have a lasting effect beyond the conclusion of the intervention program. These therapies yield the best results when they are both intensive (>15 hours per week) and comprehensive (addressing multiple areas of functioning) (Thill, Pop, Belpaeme, Ziemke, & Vanderborght 2012; Weitlauf et al., 2014). However, there is much individual variability in the efficacy of these interventions and they can be quite time consuming (Thill et al., 2012).

The use of therapeutic animals with children with ASD is also fairly common. Animals, such as dogs, communicate in more basic ways than humans, which makes children with ASD more comfortable interacting with them (Thill et al., 2012). In therapy with dogs, children with ASD seem more socially motivated, show increased language and positive social behavior, and demonstrate increased social initiation. However, these interventions are limited because animals can be difficult to predict and control, and some people may be allergic to animals (Thill et al., 2012).

With the rapid growth in technology and artificial intelligence in recent years, researchers have also begun exploring the possible therapeutic benefits of robots. In particular, there is a growing body of research in *socially assistive robotics* (SAR), which aims to assist special

populations via social interactions with specially designed robots. The ASD community is one of

the first applications of SAR (Scassellati, Admoni, & Mataric, 2012). According to Cabibihan,

Javed, Ang, & Aljunied (2013), there are several reasons why the use of social robots is

promising for interventions with the ASD community. First, socially assistive robots are

designed to facilitate social interaction—an area of particular challenge for children with ASD.

Second, the features of social robots are well-suited to the strengths and preferences of children

with ASD. Children with ASD tend to show strengths in comprehending physical objects, but

show discomfort with the complexity and unpredictability of the social world. Robots offer a

unique combination of object-like simplicity and predictable behavior together with human-like

social behaviors (Thill et al., 2012). Because of this, children with ASD feel more comfortable

interacting with them, and social robots have the potential to elicit social behavior from children

with ASD that is seldom observed during human-human interaction (Sartorato et al., 2017).

Several studies have supported the potential benefits of interaction with social robots for

people with ASD. For example, in a longitudinal study, Robins et al. (2005) evaluated aspects of

social interaction when young children with ASD were exposed to a humanoid robot over a

period of several months. The researchers slowly introduced each participant to a human-like

robot. Initially, the participants were wary of the robot, but over time they became more

accustomed to it. Robins et al. (2005) found that repeated exposure to the robot resulted in

increased spontaneous interactions with the robot, increased imitation of the robot, increased turn

taking and role switching with the robot, and even increased interaction between the child and

the experimenter.

A similar pattern of results was observed in a study on the use of a social robot in the

form of a dog. Stanton, Kahn, Severson, Ruckert, & Gill (2008) investigated how children with

ASD interact with an autonomous robotic dog called AIBO versus a more simplified mechanical dog called Kasha. AIBO had sensors that allowed it to respond contingently to touch, sound, and proximity. It could play fetch with a ball and demonstrated pleasure and displeasure with green and red lights respectively. In contrast, Kasha was a simple version of a toy dog. It could wag its tail, make noise, and walk, but did not respond contingently to its environment. Stanton et al. (2008) found that children with ASD interacted with AIBO for longer periods of time when compared to Kasha. The children also, on average, spoke more words to AIBO than Kasha. Overall, the participants showed increased verbal engagement, interactions with the intent of eliciting a response, and spontaneous authentic interaction with the experimenter when interacting with AIBO (Stanton et al., 2008).

The benefits of social robots for children with ASD have also been shown to vary based on the design and features of the robot. In their review of several robots' effects on children with ASD, Sartorato et al. (2017) found that simplistic humanoid robots increased social interaction in children with ASD and elicited enhanced generalization of skills learned with social robots to real human-to-human social interactions. Cartoonish robots were found to be more approachable to children with ASD and elicited the most social engagement This is likely because the minimalistic design of many cartoonish robots allows children with ASD to easily hone in on the social cues that the robot is expressing, rather than focusing on the many confusing nuances that come across during social interactions with humans. Finally, highly complex and mechanically appearing robots were found to be overwhelming and overstimulating to children with ASD. In particular, some complex and realistic appearing humanoid robots seemed so human-like that children with ASD became uncomfortable and anxious when they were exposed to them, reducing the potential benefits of these interactions (Sartorato et al., 2017).

Given the increasing amount of research on the use of robots as therapeutic instruments in the ASD population, it is important to understand how children with ASD perceive and understand social robots. Although studies have explored the benefits of social robots for children with ASD (Kozima et al., 2009; Robins et al., 2005; Scassellati et al., 2012; Stanton et al., 2008) and how those benefits vary based on the type of robot (Sartorato et al., 2017), surprisingly little is known about how children with ASD actually think about or make sense of these robots. This question is important because research suggests that typically developing children are confused by social robots that seem to blur the lines between living and non-living things.

Several studies have shown that typically developing children often categorize humanoid robots as social beings belonging somewhere in between the categories of animate and inanimate objects (Kahn et al., 2012; Saylor, Somanader, Levin, & Kawamura, 2010). Often times, children will acknowledge that robots are not actually biological entities, but still categorize them as having psychological and perceptual abilities, and interact with them *as if* they were living things (Melson et al., 2009; Severson & Carlson, 2010). For example, Melson et al. (2009) found that when given the opportunity to interact with a live dog and a robotic dog, 7- to 15-year-old children interacted socially with both. These social interactions consisted of petting, speaking, and engaging in interaction (e.g., fetching a ball), to name a few. The children treated both the live dog and the robotic dog as living beings. However, when questioned about the specific properties of the dogs, the children attributed more biological and psychological properties, higher levels of social companionship, and higher moral standing to the live dog (Melson et al., 2009). Confusion regarding the categorization of social robots has been shown to be strongest in younger children. For example, Melson et al. (2009) found that 7- to 9-year-olds were more

likely to affirm that social robots have mental states and can be social companions than 13- to 15-year-olds (Kahn et al, 2012; Melson et al, 2009). Overall, these studies show that typically developing children classify robots as more animate than artifacts, but less animate than living things. Because of this, several authors suggest that robots belong to a new ontological category completely (Melson et al., 2009; Severson & Carlson, 2010).

To date, only one study has specifically investigated how children with ASD categorize social robots when compared to their typically developing peers. Peca, Simut, Pintea, Costescu, & Vanderborght (2014) examined whether children categorized a variety of social robots displayed as still pictures as being the most similar to humans, machines, toys, or animals. The researchers found that both typically developing children and children with ASD most frequently associated the robots with the toys category. However, children with ASD also strongly associated the robots with the machine category whereas typically developing children did not. These findings provide initial evidence that children with ASD may be thinking about robots differently from their typically developing peers (Peca et al., 2014).

Although no other studies have directly examined how children with ASD interpret social robots, research on the interpretation of ambiguous social stimuli and animacy cues shows that children with ASD may interpret social stimuli differently from their typically developing peers (Klin, 2000; Rutherford, Pennington, & Rogers, 2006; Salter, Seigal, Claxton, Lawrence, & Skuse, 2008). For example, Rutherford et al. (2006) found that, compared to typically-developing children and age-matched children with other developmental disorders, children with ASD require more explicit training to recognize how animacy cues, such as self-propelled motion, differentiate animate and inanimate objects. Once children with ASD are tuned in to these cues, they can accurately discriminate between animate and inanimate objects; however,

children with ASD may be less motivated to attend to these cues spontaneously (Rutherford et al., 2006). Moreover, Klin (2000) investigated how high functioning adolescents and adults with ASD interpreted ambiguous stimuli (e.g., animated shapes moving contingently in social-like ways), including their likelihood to interpret the stimuli in social terms, to make personality attributions to the stimuli, and to describe these stimuli using terms that describe mental states. Klin found that when compared to neurotypical controls, the group with ASD showed marked deficits in all measured categories (Klin, 2000). These results reveal that people with ASD interpret social cues and cues to animacy in notably different ways than neurotypical individuals. Even the underlying brain mechanisms involved in animacy detection and attribution of mental states have been shown to be different in adults with ASD compared to neurotypical adults (Castelli, Frith, Happé, & Frith, 2002). These differences could have important implications for how children with ASD interpret social robots displaying various animacy and social cues.

Overall, despite the growing use of social robots in interventions for children with ASD (Ricks & Colton, 2010; Sartorato et al., 2017; Scassellati et al., 2012; Thill et al., 2013), little is known about how children with ASD interpret and make sense of social robots. Existing evidence from typically developing children suggests that social robots can be confusing for children because they blur the lines between living and non-living things (Kahn et al., 2012; Melson et al., 2008; Saylor et al., 2010; Severson & Carlson, 2010). However, given that individuals with ASD interpret cues to animacy differently than their neurotypical peers (Castelli et al., 2002; Klin, 2000; Rutherford et al., 2006; Salter et al., 2008), it remains an open question how children with ASD perceive, interpret, and categorize social robots.

Current Study

The current study was designed to directly examine how children with ASD perceive and understand social robots. Specifically, we were interested in assessing children with ASD's beliefs about four key types of properties of social robots (adapted from Weisman, Dweck, & Markman, 2017): physiological properties (e.g., feeling hunger or pain), perceptual properties (e.g., seeing and hearing), cognitive properties (e.g., thinking and remembering), and social-emotional properties (e.g., feeling embarrassed or lonely). Additionally, we were interested in how children with ASD's beliefs about social robots differ from their beliefs about standard living things – specifically, people and animals. Finally, we wanted to investigate whether the pattern of responding to items regarding the physiological, perceptual, cognitive, and social-emotional properties of social robots versus people and animals differs for children with ASD and typically developing children.

To explore these questions, in the current study, a group of elementary school children with ASD and a comparison group of typically-developing children were introduced to a social robot showing various animacy and social cues. Following a brief interaction with the robot, participants were asked a series of questions designed to assess their beliefs about the physiological, perceptual, cognitive, and social-emotional properties of the robot and two standard living things: a roughly 8-year-old child and a dog. Children responded to these questions by answering "yes", "no", or "a little yes, a little no". We examined similarities and/or differences in responses based on the participant group (ASD or typically developing), stimulus (robot, child dog), and property type (physiological, perceptual, cognitive, social-emotional).

Based on prior research (Kahn et al., 2012; Melson et al., 2008; Saylor et al., 2010; Severson & Carlson, 2010), we predicted that the typically developing children would show a

different pattern of responses for the robot, child, and animal. Specifically, we expected that typically developing children would show the highest level of yes responses for the child, followed by the dog, followed by the robot. We also predicted that the typically developing children would strongly endorse properties of all four types (physiological, perceptual, cognitive, social-emotional) for the child, and strongly endorse physiological and perceptual properties of the dog while attributing fewer cognitive and social-emotional properties to the dog than the child. Finally, we predicted that typically developing children would attribute some perceptual and cognitive abilities to the robot with little acknowledgement of physiological and social-emotional properties.

Predictions for children with ASD were more exploratory. However, we predicted that children with ASD would show a different pattern of responding overall than typically-developing children. Specifically, we proposed at least two plausible patterns of results for children with ASD. Our first prediction was that children with ASD may be less likely to differentiate the child, dog, and robot on the cognitive & social-emotional properties given reduced sensitivity to animacy and social cues (Castelli et al., 2002; Klin, 2000; Rutherford et al., 2006). An alternative possibility that we considered was that children with ASD may be more likely to deny perceptual, cognitive, & social-emotional properties to the robot given greater sensitivity to its machine-like features (Peca et al., 2014). This conflicts with the first prediction because if children with ASD are attributing machine-like features to robots, the endorsement of perceptual, cognitive, and social-emotional properties of the robot may be significantly different from the endorsement of these properties to the dog and the child. This would demonstrate that children with ASD are capable of distinguishing between features of dogs, children, and robots, and may be conceptualizing robots in a unique way.

Method

Participants

The participants in this study consisted a group of six 7- to 10-year-old students ($M =$ 9.21 years, $SD = 1.29$; all male) with a either a psychiatric diagnosis of ASD or an educational classification of ASD and a comparison group of five 6- and 7-year-old typically developing children ($M = 7.14$ years, $SD = .64$; 2 male, 3 female). Participants with ASD were recruited from the Centennial School, a school in Bethlehem, PA that serves students of all ages with ASD and Emotional Behavioral Disorders. Typically developing children were recruited from a pool of families that have indicated interest in participating in developmental research at Lehigh University.

Materials

The social robot used in this study was "Keepon" (See Figure 1). According to Kozima, Michalowski, & Nakagawa (2009), Keepon is designed to optimize interactions with children with ASD. It has a minimalistic, cartoonish design while also possessing some basic traits of living things, such as eyes and a nose. It displays attention and expressions via simple movements and noises. According to Kozima et al. (2009), Keepon has an ideally simplistic but human-like appearance so that it is approachable but not overwhelming for kids, especially those with developmental disorders such as ASD.

The version of Keepon used in experiments such as Kozima et al. (2009), Keepon Pro, is a highly-sophisticated robot with the ability to be controlled remotely by a computer and with internal cameras and a microphone that monitor how the child is interacting with the robot. Due to the prohibitive cost of Keepon Pro, the robot used in the current study is the commercially available version, My Keepon. This robot is identical in appearance and also has a microphone to

listen for music and beats. It has several touch sensors that evoke contingent behaviors when they are activated. However, it does not have a camera to view the interactions with the child in real time, and does not have the ability to be remotely controlled.

In an attempt to enhance the responsiveness and appearance of contingency, we tried to "hack" My Keepon using an Arduino. Following the procedure suggested by Michalowski, Machulis, Gasson, & Hersan (2013), we opened up the control panel, attached wires to the control panel, and attached an Arduino board to the wires. Once the Arduino was attached, it was able to be connected to a computer via USB. On the connected computer, we hoped that My Keepon would be able to be coded to behave in specific ways on command (Michalowski et al., 2013). Our goal in this was to make the robot appear more sensitive to the participants' behaviors and react more contingently to its environment. However, the software associated with hacking was outdated and did not function the way we had anticipated. The system was sporadic and would often loose communication with the controller for unknown reasons. Therefore, we made the decision to use the unhacked version of My Keepon for the study. The unhacked version still had sensors and behaved contingently based on the child's touch. However, it did not respond to non-tactile behaviors (e.g., the child's speech or movements), and sometimes acted autonomously.

Procedure

For participants with ASD, data collection took place in a conference room in children's school. The participants were introduced to the experimenter by a familiar aid from the school. The typically developing children participated with their parent or guardian in the Cognitive Development Lab at Lehigh University.

In the first part of the study, participants were familiarized with the robot and given approximately five minutes to freely interact with it. The experimenter obtained assent from the participant, gave a brief demonstration of what Keepon could do, and then encouraged the participant to try and interact with it on their own Although Keepon did not have the ability to be remotely controlled to give the appearance of behaving very contingently to the children's behavior, it was still effective in eliciting social behaviors from both typically developing children and children with ASD. The sensors that came built in to the robot allowed for certain contingent behaviors, which the children quickly picked up on and responded to. The children's interactions were video recorded for future coding.

Following the interaction phase, the experimenter asked participants a series of questions about the robot they just interacted with. They also answered the same questions about two comparison stimuli depicted in photographs: a roughly 8-year-old gender-matched child and a dog. Questions targeted 4 types of properties of the stimuli (adapted from Weisman et al., 2017): (1) physiological properties, (2) perceptual properties, (3) cognitive properties, and (4) social-emotional properties. Five questions were presented for each property type. (See Table 1 for the list of questions asked.)

Participants were asked to respond to each question on a "yes", "no", or "a little yes, a little no" scale. We chose to use this three-point scale because many of the questions we asked do not neatly fit in to the rigid categories of "yes" and "no". Using this procedure, we hoped to gain a more nuanced understanding of how participants conceptualize the robot compared to a human and an animal. "Yes", "no", and "a little yes, a little no" responses were translated to scores of 1, 0, and 0.5 respectively. Children's average response for each property category

(physiological, perceptual, cognitive, social-emotional) and each stimulus (robot, child, dog) was calculated.

Results

Interactions with Keepon. Both typically developing children and children with ASD appeared to enjoy playing with Keepon, often continuing to interact with it beyond the initial five-minute encounter. Children frequently talked to Keepon, waved at it, and laughed at it. Many asked questions, for example, what Keepon was made of and why it behaved the way it did. Most participants seemed a bit puzzled and curious about what Keepon was, and were eager to interact with it. Participants also frequently looked to the experimenter and/or the parent/school aide to engage in joint attention. Some children verbally expressed that they thought playing with Keepon was fun, and several even asked where he came from because they wanted one of their own. There were not any obvious differences in the ways that the typically developing children and children with ASD interacted with Keepon. Video recordings of these play sessions are available for future coding.

Responses to Questions. Children's responses to the target questions were analyzed using a 2 (participant group: ASD vs. typically-developing; between subjects) X 3 (stimulus: robot, child, dog; within-subject), X 4 (property type: physiological, perceptual, cognitive, social-emotional; within-subject) analysis of variance (ANOVA). Significant main effects and interactions were further explored using pairwise comparisons.

Results revealed significant main effects of stimulus, $F(2, 18) = 26.26$, $p < .001$, and property type, $F(3, 27) = 3.42$, $p = .031$, as well as a significant stimulus by property type interaction $F(6, 54) = 5.84$, $p < .001$. The main effect of participant group was non-significant, $F(1, 9) = 1.46$, $p = .26$, and there were no significant interactions involving this variable.

As can be seen in Figure 2, both typically-developing participants and participants with ASD differentiated their responses based on the stimulus type. Participants showed the highest level of yes responses to questions about the child ($M = .97$, $SD = .06$), followed by the dog ($M = .85$, $SD = .09$), followed by the robot ($M = .53$, $SD = .21$) (all $ps < .01$). Both groups of participants also differentiated their responses by property type. These patterns can be interpreted most clearly in the context of the interaction of stimulus and property type.

As Figure 2 illustrates, both typically-developing participants and participants with ASD provided consistent yes responses to all types of questions about the child. Participants strongly endorsed the physiological ($M = .96$, $SD = .12$), perceptual ($M = .99$, $SD = .03$), cognitive ($M = .98$, $SD = .06$), and social-emotional ($M = .95$, $SD = .08$) properties for the child, and did so at equivalent levels.

Responses to questions about the dog were more mixed. Participants provided frequent yes responses to questions about both the physiological ($M = .95$, $SD = .12$) and perceptual ($M = .96$, $SD = .08$) properties of the dog, relatively fewer yes responses to questions about the dog's cognitive properties ($M = .80$, $SD = .30$), and even fewer yes responses about the dog's social-emotional properties ($M = .66$, $SD = .17$). Pairwise comparisons indicated significantly lower levels of yes responding for the social-emotional properties than the physiological or perceptual properties ($ps < .01$).

Finally, in response to questions about the robot, both typically-developing participants and children with ASD provided relatively fewer yes responses overall. Unlike for the child and dog, participants' responses to questions about the robot fell midway between yes and no: physiological ($M = .40$, $SD = .19$), perceptual ($M = .58$, $SD = .25$), cognitive ($M = .55$, $SD = .30$), and social-emotional ($M = .56$, $SD = .26$). Pairwise comparisons also indicated significantly

lower levels of yes responding for the physiological properties than for all other questions types (all ps < .05). Notably, responses to questions about the robot did not differ significantly between typically developing children and children with ASD.

Discussion

The purpose of the current study was to investigate how children with ASD and a comparison group of typically developing children interpret social robots and the extent to which their beliefs about social robots differ from their beliefs about standard living things – specifically, people and animals. Results revealed that both typically developing children and children with ASD showed different patterns of beliefs about the social robot, dog, and child. Children responded yes to the vast majority of the questions about the child in all four categories: physiological, perceptual, cognitive, and social-emotional. For the dog, children showed high levels of yes responding for both physiological and perceptual properties, with relatively lower levels of yes responding for cognitive and social emotional properties. These findings demonstrate that both typically developing children and children with ASD have accurate and fairly sophisticated knowledge about the properties of human and animal category members.

Children's responses to questions about the social robot showed a different pattern. Both typically developing children and children with ASD provided fewer yes responses for the social robot overall, showing average responses midway between yes and no for all of the target properties. These findings are consistent with prior research with typically developing children showing that they are confused by social robots, and tend to categorize social robots somewhere in between the categories of animate and inanimate (Kahn et al., 2012; Saylor et al., 2010).

Surprisingly, results showed no significant main effects or interactions involving participant group suggesting that typically developing children and children with ASD

performed equivalently in the current study. We had predicted two possible patterns of

responding for children with ASD. First, we predicted that participants in the ASD group may be

less likely to differentiate between the cognitive and social-emotional properties of the child,

dog, and robot given their reduced sensitivity to social and animacy cues (Castelli et al., 2002;

Klin, 2000; Rutherford et al., 2006). Our second prediction was that participants with ASD may

give more "no" responses to the perceptual, cognitive, and social-emotional properties of the

robot because of their tendency to categorize robots as being similar to machines (Peca et al.,

2014). However, our findings did not match either of these predictions. The results did not reveal

any significant differences between the participant groups of typically developing children and

children with ASD.

There are several potential explanations for these null findings. First, our failure to reveal

differences between typically developing children and children with ASD may have been due to

the small sample size. Because we had so few participants in both groups, this may have

prevented us from detecting any true significant effects.

Second, the absence of effects based on participant group may have been due to age

differences. The typically developing children in the current study were significantly younger

than the children with ASD—between the ages of 6 and 7, as compared to between the ages of 7

and 10. We deliberately chose to sample younger typically developing children because of the

developmental delays associated with ASD. However, had the typically-developing participants

been age matched to the participants with ASD, it is likely that they would have provided more

"no" responses to questions about the robot, given that older children tend to be less confused

about the attributes of social robots (Kahn et al, 2012; Melson et al, 2009). Future research

should examine beliefs about social robots in typically developing children and children with ASD from a broader range of ages.

A third possible explanation for the lack of participant group differences is that the participants with ASD in the current study were all fairly high-functioning. All of the children with ASD were able to verbally express themselves and had received high quality educational services from the staff at the Centennial School. Given that these children attend a specialized school that provides specific interventions for students with ASD and explicitly teaches social skills, these participants may have been more attentive and responsive to social cues than the general population of individuals with ASD might be. Thus, it is important to extend this study to a broader sample of children with ASD showing varying levels of functioning.

Finally, it is possible that the absence of differences in beliefs between typically developing children and children with ASD is not due to study limitations but rather reflects the true state of children's conceptual knowledge. Children with ASD may share the same basic concepts of people, animals, and social robots as their typically developing peers. If this is the case, the differences between typically developing children and children with ASD may not be about conceptualization of entities but rather more narrowly about social interactions with them. Future research with a larger sample of children of varying ages and levels of severity of ASD symptoms is needed to explore this possibility.

The findings from the current study also raise important questions about the use of social robots as a therapeutic tool for children with ASD. Previous research has shown that social robots are effective at eliciting social behaviors in children with ASD and thus have been recommended for therapeutic purposes (Kozima et al., 2009; Robins et al., 2005; Sartorato et al., 2017; Scassellati et al., 2012; Stanton et al., 2008). However, the findings of the current study

suggest that social robots alone may not be an effective therapy for children with ASD. Our results demonstrate that children with ASD view social robots, such as Keepon, as very different from people. Thus, the skills and behaviors learned in the context of interactions with social robots may not necessarily translate to interactions with people. Although this method of therapy may be a good starting point for teaching social skills, it is important to consider the generalizability of these skills and work with social robots will likely need to be supplemented by additional therapies to achieve optimal outcomes.

In conclusion, although much is still unknown about ASD including how to most effectively intervene to treat the accompanying social deficits, the results of the current study provide important initial insight into how children with ASD think about the social robots commonly used in therapy. Results reveal that, like typically developing children, children with ASD are able to clearly distinguish social robots from other living entities, such as animals and humans. However, more research is needed to determine how best to use social robots for eliciting social behaviors from children with ASD and how to encourage the generalizability of those social behaviors to human social interactions.

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Arlington, VA: American Psychiatric Publishing.

Cabibihan, J. J., Javed, H., Ang, M., & Aljunied, S. M. (2013). Why robots? A survey on the roles and benefits of social robots in the therapy of children with autism. *International journal of social robotics*, *5*(4), 593-618.

Castelli, F., Frith, C., Happé, F., & Frith, U. (2002). Autism, Asperger syndrome and brain mechanisms for the attribution of mental states to animated shapes. *Brain*, *125*(8), 1839-1849.

Johnson, C. P., & Myers, S. M. (2007). Identification and evaluation of children with autism spectrum disorders. *Pediatrics*, *120*(5), 1183-1215.

Kahn Jr, P. H., Kanda, T., Ishiguro, H., Freier, N. G., Severson, R. L., Gill, B. T., ... & Shen, S. (2012). "Robovie, you'll have to go into the closet now": Children's social and moral relationships with a humanoid robot. *Developmental psychology*, *48*(2), 303.

Klin, A. (2000). Attributing social meaning to ambiguous visual stimuli in higher-functioning autism and Asperger syndrome: The social attribution task. *The Journal of Child Psychology and Psychiatry and Allied Disciplines*, *41*(7), 831-846.

Kozima, H., Michalowski, M. P., & Nakagawa, C. (2009). Keepon. *International Journal of Social Robotics*, *1*(1), 3-18.

Melson, G. F., Kahn, P. H., Beck, A., Friedman, B., Roberts, T., Garrett, E., & Gill, B. T. (2009). Children's behavior toward and understanding of robotic and living dogs. *Journal of Applied Developmental Psychology*, *30*(2), 92-102.

Michalowski, M., Machulis, K., Gasson, M., & Hersan, T. (2013). *Hack "My Keepon" With an*

    Arduino Brain | Make:. *Make: DIY Projects and Ideas for Makers*. Retrieved 2 December

    2017, from https://makezine.com/projects/make-35/my-franken-keepon/

Newschaffer, C. J., Croen, L. A., Daniels, J., Giarelli, E., Grether, J. K., Levy, S. E., ... &

    Reynolds, A. M. (2007). The epidemiology of autism spectrum disorders. *Annu. Rev.*

    Public Health, *28*, 235-258.

Peca, A., Simut, R., Pintea, S., Costescu, C., & Vanderborght, B. (2014). How do typically

    developing children and children with autism perceive different social robots?.

    Computers in Human Behavior, 41, 268-277.

Ricks, D. J., & Colton, M. B. (2010, May). Trends and considerations in robot-assisted autism

    therapy. In *Robotics and Automation (ICRA), 2010 IEEE International Conference*

    on (pp. 4354-4359). IEEE.

Robins, B., Dautenhahn, K., Te Boekhorst, R., & Billard, A. (2005). Robotic assistants in

    therapy and education of children with autism: can a small humanoid robot help

    encourage social interaction skills?. *Universal Access in the Information Society*, 4(2),

    105-120.

Rutherford, M. D., Pennington, B. F., & Rogers, S. J. (2006). The perception of animacy in

    young children with autism. *Journal of autism and developmental disorders*, *36*(8), 983-

    992.

Salter, G., Seigal, A., Claxton, M., Lawrence, K., & Skuse, D. (2008). Can autistic children read

    the mind of an animated triangle?. *Autism*, *12*(4), 349-371.

Sartorato, F., Przybylowski, L., & Sarko, D. K. (2017). Improving therapeutic outcomes in

   autism spectrum disorders: Enhancing social communication and sensory processing

   through the use of interactive robots. *Journal of Psychiatric Research.*

Saylor, M. M., Somanader, M., Levin, D. T., & Kawamura, K. (2010). How do young

   children deal with hybrids of living and non- living things: The case of humanoid

   robots. *British Journal of Developmental Psychology*, *28*(4), 835-851.

Scassellati, B., Admoni, H., & Mataric, M. (2012). Robots for use in autism research. *Annual

   review of biomedical engineering*, *14*, 275-294.

Severson, R. L., & Carlson, S. M. (2010). Behaving as or behaving as if? Children's

   conceptions of personified robots and the emergence of a new ontological

   category. *Neural Networks*, *23*(8), 1099-1103.

Stanton, C. M., Kahn, P. H., Severson, R. L., Ruckert, J. H., & Gill, B. T. (2008, March).

   Robotic animals might aid in the social development of children with autism.

   In *Human-Robot Interaction (HRI), 2008 3rd ACM/IEEE International Conference

   on* (pp. 271-278). IEEE.

Thill, S., Pop, C. A., Belpaeme, T., Ziemke, T., & Vanderborght, B. (2012). Robot-assisted

   therapy for autism spectrum disorders with (partially) autonomous control: Challenges

   and outlook. *Paladyn*, *3*(4), 209-217.

Weisman, K., Dweck, C. S., & Markman, E. M. (2017). Rethinking people's conceptions of

   mental life. *Proceedings of the National Academy of Sciences*, *114*(43), 11374-11379.

Weitlauf, A. S., McPheeters, M. L., Peters, B., Sathe, N., Travis, R., Aiello, R., ... & Warren, Z.

   (2014). Therapies for children with autism spectrum disorder.

Table 1. Questions by property type.

Property Type	Question
Physiological	Can Keepon/this dog/this kid get hungry?
	Can Keepon/this dog/this kid feel pain?
	Can Keepon/this dog/this kid get sick?
	Can Keepon/this dog/this kid go to the bathroom (pee or poop)?
	Can Keepon/this dog/this kid feel tired?
Perceptual	Can Keepon/this dog/this kid see things?
	Can Keepon/this dog/this kid hear sounds?
	Can Keepon/this dog/this kid smell things?
	Can Keepon/this dog/this kid taste food?
	If you touch Keepon/this dog/this kid, can Keepon/this dog/this kid feel it?
Cognitive	Can Keepon/this dog/this kid remember things?
	Can Keepon/this dog/this kid think?
	Can Keepon/this dog/this kid learn new things?
	Can Keepon/this dog/this kid make choices?
	Can Keepon/this dog/this kid want things?
Social-Emotional	Can Keepon/this dog/this kid feel love?
	Can Keepon/this dog/this kid understand how you feel?
	Can Keepon/this dog/this kid feel embarrassed?
	Can Keepon/this dog/this kid feel lonely?
	Can Keepon/this dog/this kid know what's nice and what's mean?

Figure 1. Image of My Keepon, the social robot used in this study.

Figure 2. Mean responses (± SE) to the test questions by participant group, stimulus, and

property type.