Understanding Agency in Interactions Between Children With Autism and Socially Assistive Robots

Elaine Schaertl Short and Eric C. Deng
Interaction Lab
Department of Computer Science
University of Southern California
David Feil-Seifer
Robotics Research Lab
Department of Computer Science & Engineering
University of Nevada, Reno
and
Maja J. Matarić
Interaction Lab
Departments of Computer Science, Neuroscience, and Pediatrics
University of Southern California

Socially assistive robotics (SAR) has increasingly been shown to have potential as a tool for social skills therapy for children with autism, a developmental disorder associated with atypical social development. This work presents the results of a study of robot agency on child-robot interactions involving children with autism. We describe the development of a SAR interaction scenario with both agent-like and object-like robot behaviors and present the results of a pilot study of six children with autism interacting with a humanoid robot with the full controller, as well as three types of control: a non-humanoid "box" robot with similar behavior (reduced morphological agency), a humanoid robot with random behavior (reduced behavioral agency), and a robotic toy (reduced morphological and behavioral agency). We find that the children can be divided into two groups depending on their reaction to the robot; for some children, the robot was an engaging object that elicited social behavior by providing novel and appealing sensory experiences (primarily bubble-blowing), while for other children, the robot was an agent and elicited social behavior through agent-like actions such as autonomous movement. We found that the first group had small differences between robot conditions and vocalized most with the bubble-blowing toy, while the second group vocalized most with the humanoid robots and looked less at the humanoid portion of the robot with reduced behavioral agency.

Keywords: socially assistive robotics, autism spectrum disorders

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1. Introduction

A growing body of evidence demonstrates the potential of socially assistive robotics (SAR) as a tool to support social skills therapy for children with autism,[1] a developmental disorder characterized by atypical social behavior that affects as many as 1 in 68 children in the United States alone (Centers for Disease Control and Prevention (CDC), 2014). Although prior work has often focused on a limited number of participants with narrow inclusion criteria (Begum, Serna, & Yanco, 2016), taken in aggregate, this body of work includes a wide diversity of robot morphologies, robot behaviors, and child developmental profiles. Nearly all these studies show positive child-robot interactions, and several include positive therapeutic outcomes (Scassellati, Admoni, & Matarić, 2012).

In this work, we study the role that a robot's *agency* plays in interactions with children with autism. We develop and compare a set of four variations on a SAR system with both object-like and agent-like properties: the full system with contingent behavior and humanoid appearance (high level of agency), a version that has reduced *behavioral* agency (random behavior), a version that has reduced *morphological* agency (non-humanoid appearance), and a completely non-agent-like toy. We performed a within-subjects study of these robots, motivated by the following research questions:

- How do the robot's behaviors affect children's vocalization (a proxy for social/agent-like interaction)?
- How does the morphological and behavioral agency of the robot affect children's social (measured by vocalization) and non-social (measured by button-presses) interactions with the robot?
- Do some children have more object-like or more agent-like interactions?
- What patterns in children's behavior are seen in object-like interactions? What patterns are seen in agent-like interactions?

Qualitative analyses suggest that, based on the differences in child reactions to the robot, interactions can be classified as agent-like or object-like. Based on these differences, we conducted an exploratory quantitative analysis and found that children with agent-like interactions have a positive reaction to the high-agency robot, spending more time looking at the humanoid torso, vocalizing more with the robots with high agency of some type, and speaking more in response to autonomous robot movement. We also found that children with object-like interactions reacted similarly to all high-agency robots, including vocalizing most with the non-agent-like toy, spending more time pressing a bubble-triggering button, and vocalizing more in response to bubble-blowing behavior than autonomous movement. This suggests that in addition to the properties of predictability and simplicity that previous work has identified, another strength of robots for use with children with autism is their ability to act as positive interaction partners for children with a wide range of degrees of orientation toward social behavior by acting as either interesting objects or agents.

2. Background and Related Work

Autism is a broad category of developmental conditions resulting in a variety of atypical behaviors in social interaction and communication (Wetherby, Prizant, & Hutchinson, 1998). Some differences

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[1] The terms autism spectrum disorder (ASD) or autism spectrum condition (ASC) emphasize the heterogeneity of the condition or indicate atypical presentations of autism; in this work, we use the term "autism" to include the full spectrum of abilities and difficulties exhibited by this population.

seen between typically developing children and children with ASD include reduced vocal expressions, anticipatory gestures, social reciprocity, facial expressions, affection, and eye contact (American Psychiatric Association, 2013; Szatmari, Archer, Fisman, Streiner, & Wilson, 1995). Common therapeutic interventions aimed at helping children with autism to navigate the social world include many hours of intensive practice of social skills and related foundational behaviors (e.g., applied behavior analysis (Anderson & Romanczyk, 1999; Foxx, 2008), pivotal response training (Pierce & Schreibman, 1995), or the Early Start Denver Model (Dawson et al., 2010)). One challenge common to all these interventions is maintaining engagement over the many hours of practice they require, particularly given that the interaction may not have any inherent appeal for the child.

Table 1: Robot type and child characteristics for a selection of studies of HRI with children with autism.

Robot	Agency	Description of Target Users
FACE	High; android robot that expresses emotions	"The children with autism had been diagnosed using ADI-R and ADOS-G, [...] as high functioning autism" (Pioggia et al., 2007)
Kaspar	Low; robot is directly controlled by user	"a six year old girl with severe autism," "a child with severe autism," "a 16-year old teenager with autism who is not tolerating any other children in any play or other task oriented activities" (Robins, Dautenhahn, & Dickerson, 2009)
Keepon	Intermediate; robot has a simplified body and simplified social behavior	"At CA 1:11 (chronological age of 1 year and 11 months), her mental age (MA) was estimated at 0:10 by Kyoto Scale of Psychological Development", "MA 1:7 at CA 3:1; no apparent language", "MA/cognition 3:2 and MA/language 4:3 at CA 4:6" (Kozima, Nakagawa, & Yasuda, 2007)
Nao	Intermediate to high; robot speaks, blinks eyes, and plays a song game (Shamsuddin et al., 2012), or robot imitates child behavior (Tapus et al., 2012)	"K can be classified as having high-functioning autism" (Shamsuddin et al., 2012); "cognitive abilities are equivalent of a 3 year old child and his language abilities of a 2 year old child"; "language abilities are equivalent to those of a 2 year old child, and his cognitive level of a 3-year old"; "language abilities are equivalent to those of a 1 and a half year old child, and his cognitive level of a 2 year old"; "severe mental retardation and he is nonverbal" (Tapus et al., 2012)
Pleo	Intermediate to high; dinosaur robot reacting to participants' prosody	"ASD and control groups were well matched on verbal and cognitive abilities, with all participants having Verbal and Performance (or nonverbal) IQ above 70" (Kim, Paul, Shic, & Scassellati, 2012)
Probo	High; social robot engaging in social storytelling	Participants with "moderate autism" and " lack of initiation or appropriate social response in a given social situation; [...] some reading prerequisites (ability to open and browse a book, previous experience with story books); [...] ability of recognizing emotions" (Vanderborght et al., 2012)
QueBall	Low; spherical mobile robot	"One agitated autistic child"; "Several severely autistic children" (Salter, Davey, & Michaud, 2014)

In contrast, technological interventions have been consistently found to hold a great deal of appeal for children with autism and allow them to maintain a "spirit of play" (Colby, 1973) while building social and communicative skills (Moore, McGrath, & Thorpe, 2000; Sansosti & Powell-Smith, 2008; Swettenham, 1996; Tanaka et al., 2010; Wainer & Ingersoll, 2011). As the field of computing has advanced, robots have become an increasingly accessible technology, and research in the fields of socially assistive robotics (SAR) (Feil-Seifer & Mataric, 2012), autism therapy, and social communication in autism (Anagnostou et al., 2014; Kitzerow, Teufel, Wilker, & Freitag, 2015) has provided evidence that the technological affinity of children with autism extends to robots as well as computers (Scassellati et al., 2012). Furthermore, as rule-based systems that can be built to be consistent and predictable, both robots and computers may be appealing to children with ASD who dislike change and surprises (Sigman et al., 1999). This aversion to unpredictability may explain the draw of technology and the positive interactions seen with children with autism and further supports using robots as assistive partners (Chen & Bernard-Opitz, 1993; Jordan, 1998).

While robots show promise as therapeutic tools for children with autism because of their appeal alone, they contrast with purely computer-based interventions in that they are technological artifacts that can also act as embodied agents. That is, robots in interactions with humans can function as social agents as well as mechanical artifacts, depending on both their behavior and appearance. A body of research in human-robot interaction (HRI) has examined the ways in which robot designers can affect users' perceptions of robots' agency. *Agency*, the capacity or perceived capacity of individuals to act as independent entities (Pickering, 1993), includes a number of types; in this work, we focus on exploring morphological and behavioral agency. *Morphological agency* refers to attributes of an agent in relation to its physical form; work in socially interactive robots has resulted in four values for robot morphology: anthropomorphic, zoomorphic, caricatured, and functional (Fong, Nourbakhsh, & Dautenhahn, 2003). *Behavioral agency* discusses the components of an agent's agency related to its actions and demonstrated abilities and advises the human user's role in the interaction (Scholtz, 2003). A combination of the affordances of the robot's embodiment, or morphological agency, with initial demonstrations of ability, or behavioral agency, are likely strong predictors for what type of interaction the system will have with users. Designing systems that look like familiar social agents, such as humans or animals, and behave the way that those familiar social agents behave, will likely result in agent-like interactions, and vice versa. These perceptions may not always function on the conscious level: Takayama (2009) found that people react to robots as if they are agents, even though upon reflection they do not always attribute agency to those robots. Perceived agency also depends on the robot's behavior; Levin, Adams, Saylor, and Biswas (2013) developed a model of how people conceptualize agency that takes into account how perceptions of the robot's agency can vary with its behavior. Researchers have found that perceptions of robot agency are sensitive to manipulation by such means as having a robot cheat at a game (Short, Hart, Vu, & Scassellati, 2010) and changing robot size (Lucas, Poston, Yocum, Carlson, & Feil-Seifer, 2016), movement patterns (Avrunin, Hart, Douglas, & Scassellati, 2011), or gaze behavior (Srinivasan & Murphy, 2011).

Consequently, robots have great potential as untiring social partners whose behavior can be tuned to best benefit each user. However, when developing SAR systems for children with autism, researchers must consider that one common atypical pattern of development is a substantial delay in performance on tasks designed to measure theory of mind, "the ability to infer other persons' mental states and emotions" (Brüne & Brüne-Cohrs, 2006). This has led some researchers to claim that theory of mind is absent or severely impaired in children with autism (Baron-Cohen, Leslie, & Frith, 1985), although subsequent research suggests that only the magnitude of the delay is unique to this population (Yirmiya, Erel, Shaked, & Solomonica-Levi, 1998), and more recent work has found that deaf children of hearing families perform similarly on these theory of mind tasks (Peterson & Siegal, 2000). Another typical characteristic of children with autism is a decreased incidence of symbolic and pretend play (Baron-Cohen, 1987), especially in spontaneous and open play scenarios (Jarrold, Boucher, & Smith, 1996). While there is not a clear difference between symbolic and functional play, and when researchers explicitly elicit pretend play, less of a difference is seen between children with autism and children with typical development (Jarrold, 2003), this pattern may still affect how children with autism interact with robots in play scenarios.

Because of these developmental differences, we expect that children with autism may perceive robot agency differently than children with typical development. A critical component, then, of developing SAR-based therapeutic interventions for children with autism is understanding how they perceive and relate to robots, particularly when researchers expect that robots will function as *agents*, entities with goals, mental states, and the capacity for independent action.

In research into SAR for children with autism, the agency of the robot has not previously been explicitly manipulated, but the robots used have varied widely in anthropomorphism and behavior. A number of studies of human-robot interaction with children with autism are summarized in Table 1. In many cases, more anthropomorphic robots with more agent-like behavior are matched to users with a higher level of social capability. For example, the study with QueBall (Salter et al., 2014) focused on the effect of the robot on children with a high level of difficulty with social interaction, while the study with the FACE robot (Pioggia et al., 2007) included participants with "high functioning autism." A few studies, such as with the Keepon robot (Kozima et al., 2007) or Nao robot (Tapus et al., 2012) included participants with a wider variety of comfort levels with social interaction. These studies showed positive human-robot interactions across participants but with interactions with very different characteristics: for example, in the work by Tapus et al., the nonverbal child's "attention was focused on the Nao robot, while ignoring the behavior of the experimenter," while one of the more verbal children "rapidly understood that the interaction partner was mirroring his actions and manifested vocalizations and positive affect as a consequence" (Tapus et al., 2012).

To focus on this underexplored problem, we explicitly manipulated the agency of the robot with regard to both its morphology and behavior and performed a within-subjects comparison of children's behavior and the characteristics of their interactions with robots of different agency.

3. Interaction and Robot Design

This section describes the development of the interaction scenario used in this work. Across existing clinical approaches and exploratory interviews with parents, teachers, and treatment professionals for children with autism, we found support for the notion of a robot with both object-like and agent-like characteristics. We then integrated the sensing and actuation capabilities of the robot with the envisioned characteristics of the robot to develop an interaction scenario that leveraged the capacity of the robot to bridge object-like and agent-like roles.

3.1 Interaction Scenarios with Children with Autism

We define the specifics of the robot's behavior within an interaction scenario. The scenario is based on activities drawn from existing clinical approaches to therapeutic and diagnostic interactions with children with autism, as well as a series of unstructured interviews we conducted with relevant stakeholders, including individuals with autism, teachers, and other professionals who work with children with autism.

The interaction scenario was designed to work within the capabilities and limitations of an autonomous socially assistive robotto support the long-term goal of robots that support social partners, teachers, or other treatment professionals. We chose not to use a teleoperated system using the Wizard-of-Oz approach (Steinfeld, Jenkins, & Scassellati, 2009) to ensure that the behavior and

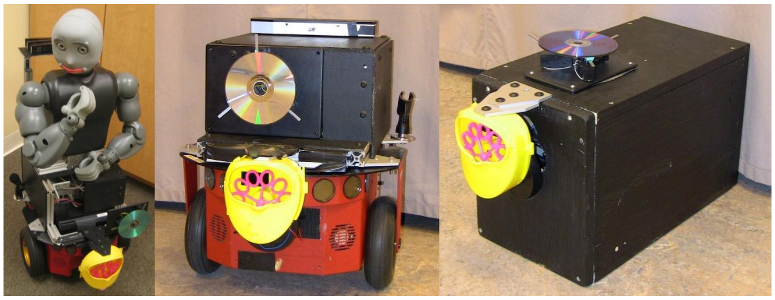

Figure 1. The three robot embodiments used in this work. Left: mobile humanoid robot. Center: mobile box robot. Right: non-mobile toy.

errors were consistent with an autonomous robot and not with human sensing capabilities and limitations. This choice removes the subjectivity of human feedback that might confound results or limit the value of the study insights to future work on autonomous systems. A human was in the loop for only one aspect of the robot's behavior: because of the acoustics of the room, a human operator was needed to perform voice activity detection. Given a large labeled dataset of speech in the targeted environment, however, this task is well within the capabilities of modern computer systems, and the operator was instructed to respond to all vocalizations, just as an autonomous system would.

Our approach is informed by the Autism Diagnosis Observation Schedule (ADOS), a leading method for diagnosing ASD in children through direct observation (Lord et al., 2000). The ADOS uses a series of structured probes to examine the reactions of children with autism. The method consists of a set of social-communicative sequences that include both structured and unstructured interactions. It is divided into four modules that vary based on speech patterns in individuals, with Module 1 consisting of situations for those who do not consistently use phrase speech and Module 4 outlining situations for verbally fluent children and more complex questions about daily life (Lord et al., 2000). A robot could be used in an object-like way in the ADOS diagnosis context by engaging in repeatable standardized nonsocial behavior, or it could serve in a more agent-like role by providing standardized social behavior. In this work, the social probes used in the ADOS, such as bubble play and saying a person's name, serve as guidelines for interaction scenarios used in the human-robot interaction design.

Another existing clinical approach that informs this work is the Developmental, Individual Difference, Relationship-based (DIR) Model, known as DIR/floortime therapy. In this approach, a therapist interacts with a child on the floor and uses the child's existing social behaviors to develop new social behaviors and skills (Wieder & Greenspan, 2003). However, a central deficit shared by children with autism is a difficulty with self-initiation of social behavior, possibly because of motivational issues (Koegel, Carter, & Koegel, 2003). Given the anecdotal evidence that children with autism exhibit more social behavior when a robot is present, a robot might be used to augment interventions by addressing reduced self-initiation of behavior. An increase in proactive social behavior toward an agent-like robot would give interventionists more behaviors to build on. The open-ended, child-centered approach to interactions informs the human-robot interaction scenarios developed in this work.

Additionally, through a series of unstructured interviews with individuals with autism, teachers, therapists, diagnosticians, and researchers experienced with autism, we found significant interest in using a robot in the context of autism therapy for children. This interest persisted even when the technological limitations of the state-of-the-art in robotics were described. Interviewees envisioned several different scenarios for the robot, depending on their area of expertise, that spanned the agency spectrum of the robot, from object to agent. Most teachers preferred an agent-like robot that operates during free-play sessions, but not during teaching portions of a school day, acting as a social mediator or play partner. Intervention specialists, in contrast, envisioned an object-like robot used during a treatment session, acting as an object of interest or a behavior reinforcer, the way a toy is used in contemporary therapeutic approaches.

The behaviors specific to autism are currently difficult to reliably observe autonomously and non-invasively, so the interaction scenario is limited to social phenomena that the autonomous SAR system is able to observe. Despite this limitation, an unstructured child-robot interaction is achieved and allows the child to express the desired range of social behaviors. Some activities identified in the interviews and existing clinical practice, such as bubble play, lend themselves to a robot in an object-like role, while other activities require the robot as a social agent. Thus, the behavior of the robot in this work intentionally spans a variety of levels of agency, from behavior reinforcer to social interaction partner, allowing us to study the role of agency.

Our interaction scenario design also followed the following recommendations from the autism therapy constituencies we interviewed:

- Encourage/facilitate proactive social interaction;
- Allow the interaction to be started/stopped in response to the child's behavior; and
- Offer opportunities to exercise critical social skills.

Based on the combined insights about the intervention interaction structure described above, we developed two scenarios that together govern the robot's behavior:

- **Use of Social Space:** This behavior is motivated by an adaptive physical education program for elementary school students and requires a mobile, embodied system. The robot and the child interact by maintaining suitable personal distance: when the child moves too close to the robot, the robot backs away, and when the child moves too far from the robot, the robot moves closer to the child. When the robot is not facing the child, it turns to face the child. Social skills that might be observed in this scenario include child vocalizations, responsive movement, and social gestures.
- **Bubble Play:** This behavior is based on a Module 1 task of the ADOS and involves a robot acting as a reinforcing object. The robot uses a computer-controlled device to blow bubbles from a brightly-colored toy component mounted on it. The robot is programmed to blow bubbles in response to the child's social behaviors (more agent-like) or in response to the child pressing a button on the robot (more object-like, but addressing contingency and providing reinforcement). Social skills that might be observed in this scenario include child vocalizations, initiation of behavior, and pointing.

3.2 Autonomous System Implementation

This section describes the robot's behavior, as well as the sensing and computing tools that enabled the autonomous child-robot interaction.

3.2.1 Robot Behavior To study how the agency of the robot's behavior affected the interactions, we combined the social orientation and bubble-play behaviors into a single SAR system, affording a wide variety of levels of agency in its interaction capabilities. We then varied the embodiments of the robot to enable the study of how the robot's appearance of agency (or lack thereof) affected the interaction (see Fig. 1), including one robot with humanoid appearance and two with reduced morphological agency:

- Humanoid robot: A humanoid robot torso mounted on a mobile base, approximately one meter tall in total. The torso made simple gestures and used synthesized speech or pre-recorded phrases, with simple utterances such as "Ow!" and "Woo-hoo!" The behavior of the mobile base is described below.
- Box robot: A non-humanoid mobile base that navigated around the environment, responded to the child's behavior, and activated the bubble blower in response to button presses and controller rules.
- Toy: A non-mobile toy equipped with a bubble blower and a button for activating the bubbles. The toy was placed on a table during the interactions to ensure that it was easy to reach. This morphology was used to ensure that the affordances of the toy matched its behavior; without wheels, it was clear that the toy was non-mobile.

Based on the DIR/floortime intervention, we aimed to encourage proactive social interaction by providing social reward/engagement in response to the child's social behaviors, including appropriate use of space (Hall, 1966). To that end, we developed a set of rules for robot behavior as follows:

- The robot socially orients to the child by default;
- If the child is more than 1m from the robot, the robot waves at the child and then gestures to the child to "come here";[2]
- If the child is more than 1m from the robot for longer than 10 seconds, the robot approaches the child;
- If the child approaches the robot, the robot makes an approving vocalization;
- If the child moves away from the robot, the robot makes a disappointed vocalization;
- If the child moves behind the robot, the robot does nothing; this creates a safe zone where the child can be ignored by the robot;
- If the child presses the button on the robot, the robot blows bubbles;[3] and
- If the child makes a vocalization, the robot blows bubbles.

These rules, designed under the advisement of autism clinicians, aimed to motivate specific social behaviors by the child: use of social space and vocalizations. As noted earlier, because of the acoustics of the room, a supervised approach was used to control the robot's behavior in response to child vocalizations: An operator pressed a button whenever the child vocalized. However, the

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[2] This behavior was not implemented for the box robot.

[3] As mentioned above, this was the only behavior implemented on the bubble-blowing toy.

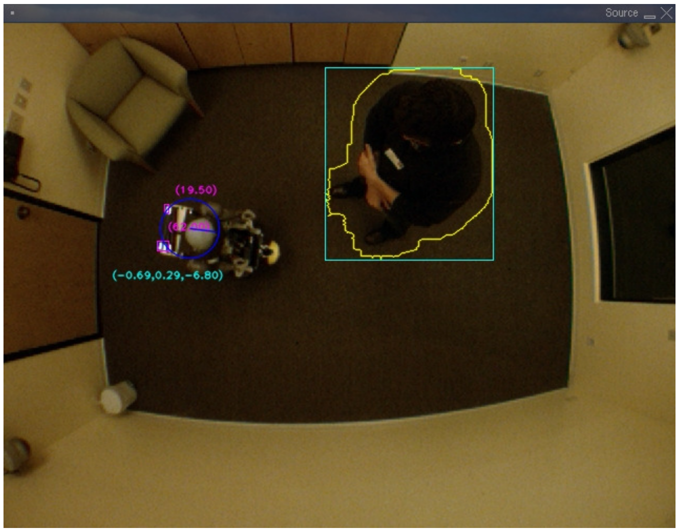

Figure 2. A view from the overhead camera with annotation about the pose of the robot and of the participant.

operator's behavior was constrained to model existing autonomous methods for detecting vocalization, which would not distinguish whether a vocalization was directed at the robot, self-stimulation behavior, echolalic behavior, directed at the parent, etc. Accordingly, the operator assumed that all observed vocalizations were social and directed at the robot. Thus, both social and non-social vocalizations were "rewarded" with bubbles. Previous work has shown that there are different types of vocalizations in populations with autism, including non-communicative vocalizations, echolalic responses, and vocal stereotypies (Ahearn, Clark, MacDonald, & Chung, 2007), but qualitative, observation-based analysis of the children's behaviors in our study indicated that nearly all vocalizations were, in fact, social and directed at the robot. Rewarding all vocalizations is a potential limitation of the work, but it did not affect user behavior in the context of this study.

To create a robot that differs from the humanoid robot in *behavioral* agency in the same way that the box robot differs from the humanoid robot in *morphological* agency, a random controller was implemented for the humanoid robot. In this controller, the robot executed the above behavior repertoire randomly rather than in response to the child's behavior. The toy served as a highly object-like control, with neither morphological nor behavioral agency: Its only behavior was to blow bubbles in response to a button press.

3.2.2 Overhead Interaction Toolkit To enable the social orientation activity, the robot required accurate sensing of people and obstacles in the environment. To achieve this, we designed and developed the overhead interaction toolkit (OIT) to allow the robot to navigate autonomously in a small environment and to socially orient to participants. The OIT tracks the positions of the child and robot, along with any other participants in the session, such as a parent or peer. These tracked positions were initially used for navigation and obstacle avoidance and, in later work, for interpreting social behavior.

We equipped the experiment space with an overhead camera to detect the positions of the child, parent, robot, and other obstacles in the room. Given *a priori* information about the layout of the room, this sensor was sufficient for the robot to maneuver autonomously in the experimental space and to sense movement-based actions of the participants that triggered robot behaviors.

The robot was equipped with infrared (IR) emitters that emitted two different-sized light regions so that the system could observe both the position and orientation of the robot. IR was chosen because it is visible to the overhead camera but invisible to the human participants in the interaction.

The child and parent wore differently colored shirts to facilitate real-time person tracking. The system used background subtraction to locate the experiment participants in the image. Given that the camera was mounted to the ceiling and the experiment room was windowless, the background of the image (the floor) was mostly static (a small amount of image static occurred as a result of normal camera operations, but it could be filtered out). Therefore, the experiment participants could be found as foreground blobs in the image. The shirt colors allowed us to reliably distinguish the parent from the child and to thereby reliably detect and track the child's behavior.

Each video frame, collected at 15 frames per second, served as a single sample for detecting the locations of the interaction participants and deciding on an appropriate robot action. Processing each frame required a very small portion of the frame interval to compute, leaving additional time for behavior classification, supporting real-time robot response.

4. Methodology

To examine the effects of the robot's level of morphological and behavioral agency on the interactions with participating children with autism, we created a four-way within-subjects experiment design, with the following conditions presented in a randomized order:

- **"MB"**: High morphological agency, high behavioral agency; the full robot system described above (left image in Fig. 1)
- **"Mb"**: High morphological agency, low behavioral agency; the randomly behaving full humanoid robot (left image in Fig. 1)
- **"mB"**: Low morphological agency, high behavioral agency; the non-humanoid mobile base with contingent behavior (center image in Fig. 1)
- **"mb"**: Low morphological agency, low behavioral agency; a robotic toy (right image in Fig. 1)

Based on the idea that more agency in the robot will lead to more agent-like child-robot interaction with more attention to the robot's head and less interaction with the button and bubbles, we developed the following hypotheses:

- **H1**: Participants will speak the most in the MB condition, followed by the Mb and mB conditions, and the least in the mb condition.
- **H2**: Participants will orient their head pose toward the robot's head more in the MB condition than the Mb condition.
- **H3**: Participants will press the button the most in the mb condition, followed by the mB and Mb conditions, and the least in the MB condition.
- **H4**: Participants will interact with the bubbles the most in the mb condition, followed by the mB and Mb conditions, and the least in the MB condition.

4.1 Participant Selection

The study participants included nine boys and one girl between the ages of 5 and 9 years (mean age = 7.2 years), recruited from Autism Speaks' Autism Genetic Resource Exchange (AGRE) (Geschwind et al., 2001). The AGRE program provides bio-materials and phenotype and genotype information of families with two or more children (multiplex) with autism to the scientific community. Participants were eligible for inclusion in the study if they had been diagnosed with autism by AGRE researchers using a combination of the Autism Diagnostic Observation Schedule (ADOS) (Lord et al., 2000) and Autism Diagnostic Inventory (ADI-R) (Lord, Rutter, & Couteur, 1994). Additional inclusion criteria included being between the ages of 5 and 10 and having a minimum verbal ability determined either with a score above 2.0 years of age on the communication sub-scale of the Vineland Adaptive Behavior Scale (Sparrow, Balla, & Cicchetti, 1984) or using either Module 2 or Module 3 of the ADOS evaluation.

Recruitment fliers were sent to eligible families in the Los Angeles area. Interested families responded by phone and email. Of the 65 families who were sent a flier, 10 responded (12.3%), and 10 children from seven families participated in the study. Because the AGRE database consists of multiplex families, multiple siblings from four of the participating families participated in the study. Of the ten overall participants, there were four sets of siblings (A-G, D-C, F-J, I-H). Vineland and ADOS functional scores were available for the participants and were used as exclusion criteria, but they were deemed too old for functional comparison.

Of the ten participants in the study, four had an aversive reaction such as tantrums or requesting not to interact with any of the robots, requiring ending the sessions early, and were excluded from the analysis.[4] This analysis focuses on the six participants who had a positive reaction to the robot, labeled A-I. Details can be found in Appendix: Participant Details. Most interactions for a given participant pair (parent and child) took place on a single day, except for three participants who returned on a second day to interact with the the box robot and repeat the toy conditions because of experiment logistics. Before the experiment, informed consent was obtained from parents, and verbal assent was obtained from the children, per a protocol approved by the university Institutional Review Board.

4.2 Measures and Data Coding

During the experiment, an experimenter watched through a one-way mirror from the observation room, and video footage was captured for post-experiment analysis. The data from this experiment were human-coded for two robot behaviors, nine child behaviors, and one parent behavior, some of which had sub-codings (e.g., child head orientation to parent vs. child head orientation to robot; see Table 2). A single primary coder annotated all video data, and a second coder was used for reliability analysis on a randomly chosen selection of 14 of the 38 sessions. We treat each annotation as a binary variable in 250 millisecond time steps, taking the OR of annotations in the step (i.e., if any part of the time step is annotated as true, the step is labeled as true) and use this smoothed data to calculate Cohen's κ. Because of the highly unbalanced nature of these annotations (events occurred as little as 5-10 percent of the time in many cases), chance agreement is extremely high, artificially depressing κ. Therefore, we take values of 0.6 or higher as acceptable. The remaining behaviors resulted in low coder agreement, either because they appeared extremely infrequently in the data [child posture (sitting/standing/kneeling), affect (positive/negative/neutral), and avoidance (of the robot/parent)] or because our coders were unable to detect the feature in the available data (child movement target, which we found to be indistinguishable in a small space; child gesture, which was found to be indistinguishable from playing with the bubbles and stereotyped movement).

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[4] Prior work has focused on detecting such aversive reactions automatically (Feil-Seifer & Mataric, 2012).

Table 2: Agreement Values for Relevant Features

Feature	Cohen's κ	Percent Agreement
Robot Moving	0.61	91.2
Robot Blowing Bubbles	0.90	95.9
Child Vocalization	0.79	92.4
Parent Vocalization	0.73	95.5
Child Touching Button	0.72	95.8
Child Head Toward Any Part of Robot	0.65	82.5
Child Interacting with Bubbles	0.77	92.7
Child Head Toward Humanoid Part of Robot (Humanoid Conditions Only)	0.70	94.7
Child Movement Target	*Low Agreement: space too small*	
Child Gesture	*Low Agreement: indistinguishable*	
Child Affect	*Low Agreement: low incidence*	
Child Posture	*Low Agreement: low incidence*	
Child Location	*Low Agreement: space too small*	
Child Torso Orientation	*Low Agreement: space too small*	

4.3 Materials

This experiment explored interactions with three different robot embodiments in the same physical space. The experiment used three different robot embodiments: a humanoid torso on a mobile base, a mobile base, and a toy, all equipped with a bubble blower and button. The humanoid robot and the mobile base used the same differentially steerable mobile base platform, a Pioneer 2DX, about 0.3 meters tall. The humanoid version had a Bandit torso mounted on top of the base; the torso features two 6 DOF arms, a 2 DOF neck, and an expressive face with actuated lips (1 DOF) and eyebrows (1 DOF); Bandit is approximately 1 meter tall, excluding the mobile base. Both robots were equipped with identical bubble blowers and speakers The toy embodiment was stationary and consisted of just a bubble blower with a button.

4.4 Experimental Protocol

During an introductory period, a clinical psychologist and an experimenter greeted each child and parent participant pair and reviewed informed consent and assent forms with the parent while the child adjusted to the environment (see Fig. 3). Next, a “feet-wet” period of approximately five minutes commenced, in which the child and parent were given a demonstration of each of the robot's interaction behaviors by the experimenter. This ensured that the robot's behavior did not later surprise the child (minimizing novelty) and allowed for comforting if the child became upset with the interaction. The parent was told that there was a chair available for sitting down, but if the child wanted to involve the parent in the interaction with the robot, that was allowable.

The experimental session followed the “feet-wet” period and consisted of a five-minute interaction between the child and one of the four conditions described above. If the child became upset, became anxious, or ceased interacting, all robot motion was stopped and the experimenter reentered the experiment space and attempted to calm the child and reengage them with the robot, if possible. If that was not possible, the experimenter removed the robot from the room and the session was terminated. Sessions presented to each child and parent were separated by breaks during which the parent and child left the room and the experimenter prepared the next session and changed the

Figure 3. The experiment room as seen from the observation room, through the one-way mirror (dimensions 9 feet by 12 feet by 10 feet high).

robot embodiment as needed. The experiment ended when the participants had seen all conditions or declined to continue.

5. Results

We provide a qualitative analysis of participant behavior and then, based on those observations, divide the participants into two groups. We then analyze the differences and similarities in interaction patterns between the two groups in the interaction outcomes and show that these patterns can be interpreted as either more object-like or more agent-like interactions with the robot.

5.1 Qualitative Results

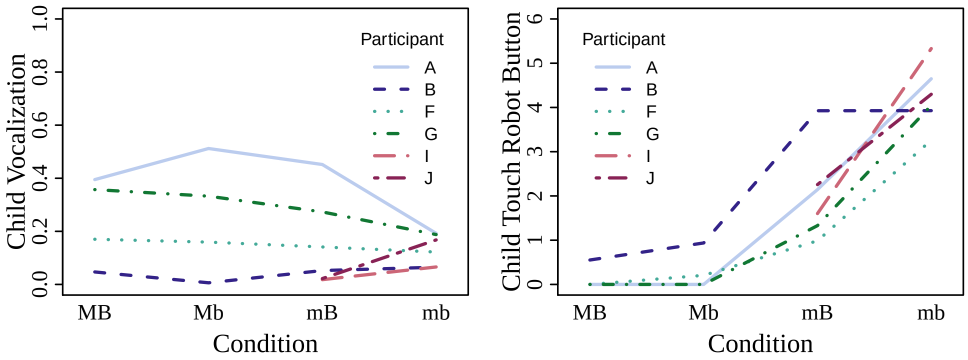
To provide a qualitative understanding of the interactions, a coder wrote a description of the child's behavior in each 30s interval, starting at the beginning of the interaction. We observed the following patterns in the child-robot interactions:

5.1.1 Participant A Participant A was one of the participants with an agent-like interaction with the robot. A spoke to all the mobile robots, giving them names and trying to get them to play games.

MB: In this condition, Participant A spoke frequently to the robot (there was speech in every 30-second interval). A specifically asked the robot what games it could play, suggested that they play "tag," and tried to encourage the robot to play the game throughout the interaction (because of the robot's social spacing, it never got close enough to "tag" A).

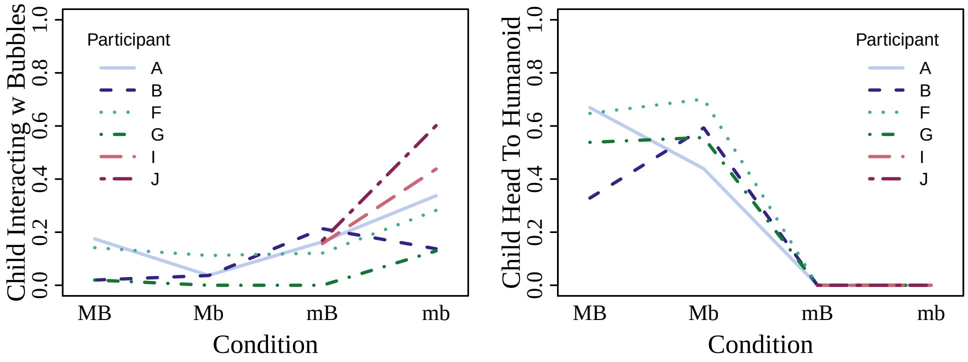
Mb: A saw the low behavioral agency condition after the high behavioral agency condition and continued to try to get the robot to play "tag". A discussed the robot's behavior with their parent and tried to start a dance contest with the robot. Toward the end of the session, A expressed some frustration with the robot's lack of response to the rules they tried to set out, saying to the parent, "Now I guess I know what it feels like when you have to teach a little kid."

mb: A spent most of the session with the low morphological and behavioral agency robot playing with the bubbles, speaking less to the parent and not at all to the robot. When A did speak to



(a) Proportion of time spent vocalizing

(b) Number of button presses per minute



(c) Proportion of time spent interacting with bubbles

(d) Proportion of time with head oriented to the humanoid portion of the robot

Figure 4. Outcomes by individual and condition.

their parent, they focused on the properties of the robot as an object, saying things like “What are the holes for?” and “That’s it, it just blows bubbles?”

mB: A gave the low morphological and high behavioral agency robot a name (“Bebe”), and asked the parent what the robot’s gender is. A also asked whether the robot “play[ed] with” the robot from the Mb and MB conditions and again tried to play “tag” with the robot.

5.1.2 Participant B Participant B had an object-like interaction with the robot, focusing on touching the robot and pressing the button to trigger the buttons. B spoke very little to the caregiver or the robot.

MB: Participant B spent the interaction touching the robot and pressing the bubble-triggering button. B spoke only three times during the interaction, twice to say something unintelligible and once to say, “Hi” to the robot. However, B expressed enjoyment during the interaction with frequent laughter while playing with the bubbles.

Mb: In this condition, B pressed the button again but spent most of the time touching the robot. B continued to touch the robot, even when the robot said, “Ouch” and tried to move away.

mb: B pressed the button on the toy repeatedly throughout the five-minute interaction and had little speech, except for asking the caregiver for help with the robot toward the end when it ran out of bubble fluid.

mB: In this condition, B repeatedly mimicked the robot's vocalizations. B also spent about half the interaction playing with the bubbles.

5.1.3 Participant F Participant F had an agent-like interaction with the robot, spending most of the time trying to command the robot. F did not like the humanoid as much as the non-humanoid mobile robot but demonstrated positive behavior with both.

MB: F continued to try to instruct the robot and was excited whenever the robot did as asked, exclaiming, "He's listening, Daddy!" whenever the robot's behavior aligned with the command. However, F did not want to get too close to the robot, moving away and saying, "He looks creepy" when it approached.

Mb: In the low behavioral agency condition, F tried to command the robot with phrases such as "Turn!" or "Blow bubbles!" (only the latter resulted in the requested behavior). F touched the robot's face several times and stood very close to it. Toward the end, F stated, "This one scares me; the other two doesn't [sic]" but was again excited when F asked the robot to move and it did.

mb: F pressed the button and played with the bubbles in this condition but focused on talking with the caregiver about the bubbles and other equipment in the room such as the microphones.

mB: In this condition, F got down on their hands and knees to try to talk to the robot, including asking it, "Are you scared?" when it attempted to put appropriate social distance between it and F by backing up. F played with the bubbles occasionally when the robot blew bubbles in response to speech but was focused on trying to get the robot to interact.

5.1.4 Participant G Participant G also had an agent-like interaction with the robot, expressing concern for its well-being and trying to give it commands. G enjoyed playing with the bubbles and tried to trigger them with speech with the humanoid robots and by pressing the button on the non-mobile bubble-blowing toy.

MB: In this condition, G spent much of the time trying to get the robot to make "the train sound." When this failed, G asked the robot to blow bubbles and was pleased to succeed at that. At one point, the robot backed into a wall, and the child asked, "Are you okay?" several times.

Mb: G began the session trying to get the robot's attention, saying, "No, don't look at Mom, look at me. Over here!" In this condition, the child also asked the robot to blow bubbles and was pleased when by chance the robot did as it was told.

mb: With the robotic toy, G was excited to play with the bubbles, saying, "Yay! Bubble time!" repeatedly and pressing the button throughout the session. However, G also spent part of the session looking at himself in a mirror in the room and ignoring the robot.

mB: G began the session by trying to get the robot to move according to directions ("Can you get closer to me, please?") and telling it to blow bubbles (which was successful because of the robot's contingent behavior). G gave the mobile robot a name and gave it requests by name, including asking it to play "chase."

5.1.5 Participant I Participant I had an object-like interaction with the robot. This participant enjoyed the bubbles and spent most of the time with the humanoid robot and with the low morphological and behavioral agency robot pressing the button to trigger the bubble blower. In the condition with the non-humanoid robot, participant I played with the robot by moving around as well as by pushing the button.

MB: Participant I spent the entire session with the humanoid robot pressing the button and playing with the bubbles. They also made three unintelligible comments during the session but did not otherwise speak.

Mb: *Participant I did not interact with the low behavioral agency, high morphological agency robot.*

mb: Participant I spent the session pressing the button, playing with the bubbles, laughing, and dancing.

mB: In this session, participant I spent most of the interaction looking at the robot as it moved around and then moving around to cause it to follow the child, saying, "I'm making the robot follow me." In the last two minutes of the session, the participant pressed the button and played with the bubbles repeatedly.

5.1.6 Participant J This participant refused to interact with the humanoid robot and had an object-like interaction with the non-humanoid mobile robot. They were focused on pressing the button to trigger the bubbles and watching the mobile robot move.

MB: *Participant J refused to interact with the humanoid robot.*

Mb: *Participant J refused to interact with the humanoid robot.*

mb: Participant J expressed enjoyment about the bubbles, laughing and saying, "Yay!" while playing with the bubbles. J also told the caregiver, "I think it's cool" and asked how much time was left to play with the robot.

mB: In this condition, J pressed the button on the robot repeatedly, playing with the bubbles and watching the robot move around. J again asked the caregiver repeatedly how much time was left.

5.1.7 Other Participants **Participant C** had a negative reaction to the robot and had to terminate participation early. **Participant D** enjoyed the bubbles but had a negative reaction to the robot, trying to hide from it, and terminated participation early. **Participant E** enjoyed playing with the bubble toy but avoided the robot entirely and terminated participation early. **Participant H** had a negative reaction to the robot and had to terminate participation early.

5.2 Quantitative Analysis

The qualitative analysis suggested that although Participants A, B, F, G, I, and J all had positive interactions with the robot, these interactions had very different qualities, with participants A, F, and G treating the robot more like an agent and participants B, I, and J treating the robot more like an object or an intruiguing toy. Based on these observations, we developed several additional hypotheses for testing in an exploratory quantitative analysis:

- **H5**: The robot's bubble-blowing behavior is a more object-like behavior and will result in less speech for participants with agent-like interactions and more speech for participants with object-like interactions.

Table 3: Mean and standard deviation of the number of button presses per minute.

Condition	Mean	SD
MB	0.68	1.22
Mb	0.29	0.45
mB	2.04	1.04
mb	4.24	0.70

- **H6**: The robot's movement behavior is a more agent-like behavior and will result in more speech for participants with agent-like interactions and less or equal speech for participants with object-like interactions.
- **H7**: Participants with object-like interactions with the robot will orient more toward the bubbles and the robot's base (from which the bubbles are blown), while participants with agent-like interactions will orient more toward the robot's torso.
- **H8**: Participants with object-like interactions with the robot will press the button on the robot more than participants with agent-like interactions in the conditions with higher agency.

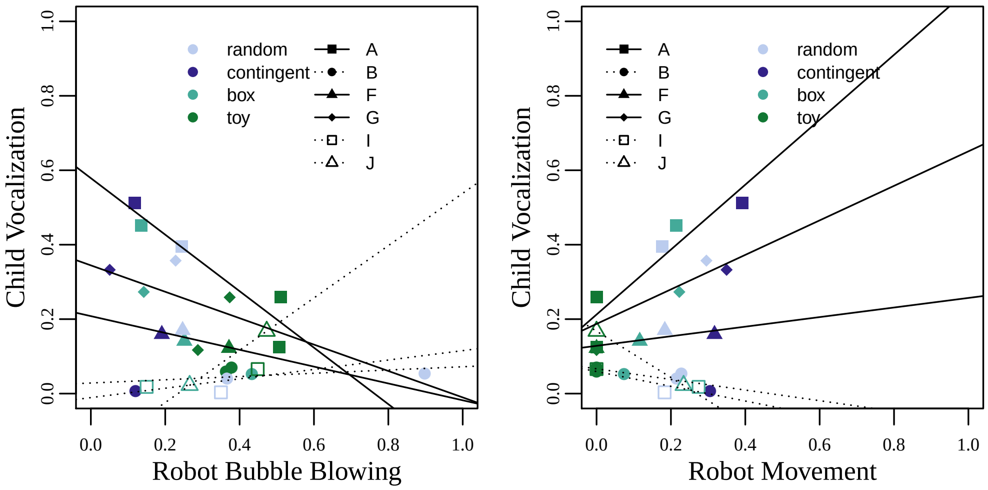
5.3 Participant Sub-Groups: Object-Like and Agent-Like Interactions

Dividing the children into two subgroups based on the qualitative analysis of their behavior, we conducted an analysis to begin to understand how children with autism might react to socially assistive robots. We examined the correlations between participant behavior and robot behavior, aggregating across conditions. Fig. 5(a) shows the correlation between the proportion of time that the participant vocalized and the proportion of time the robot was blowing bubbles. Although there was an overall significant negative correlation of -0.398 between bubbles and speech ($p < .05$), we found a significant interaction between participants and the correlation ($p < .01$), with three participants having a negative correlation and three participants having a positive correlation. This supports the division of participants into two groups and is consistent with the interpretation that for some children the robot was an engaging object that provided an interesting sensory experience (that is, the bubbles) that could encourage speech, while for other children, the sensory experience of the bubbles was a distraction from the social interaction but robot movement encouraged speech.

Next, we compared the difference in the probability that a child will stop speaking within 1.5 seconds of the robot blowing bubbles and the probability that a child will start speaking in the same timeframe. We find a statistically significant correlation with overall speech ($p = 0.01233$), including a crossing of the zero point, indicating that for some children, bubbles increased speech while for others, they decreased speech (Fig. 5(c)). A similar interaction effect was found in the correlation between robot movement and child speech ($p < .05$), as shown in Fig. 5(b), with the same participants who had a negative correlation between bubbles and speech having a positive correlation between robot movement and speech, and vice versa. That is, for talkative participants, the robot's bubble-blowing behavior interrupted the flow of the interaction, while for the less talkative participants, the bubble-blowing behavior encouraged additional interaction.

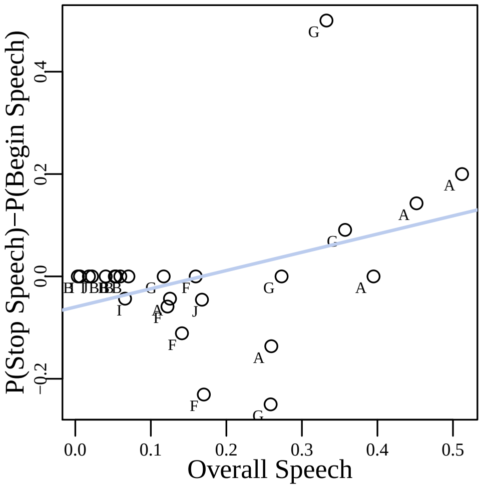
5.4 Group Differences in Outcomes of Interest

Throughout this section, we focus on patterns in the variables of interest; we do not focus on statistical significance, given that dividing the participants into two groups results in only three participants per group. However, we find a consistent pattern in the trends across several variables of interest



(a) Proportion of time spent vocalizing compared to proportion of time bubbles were blown, with linear regressions per participant.

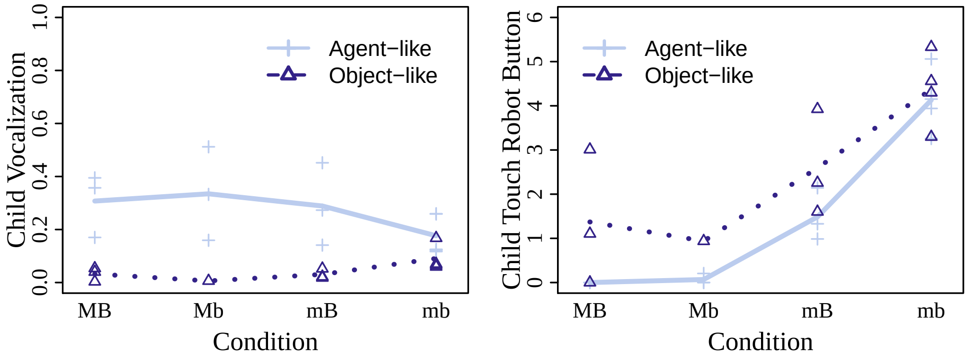
(b) Proportion of time spent vocalizing compared to proportion of time robot was moving, with linear regressions per participant.



(c) Relationship between overall child speech and the difference in the probability that child began speech versus ended speech after the onset of robot bubble blowing.

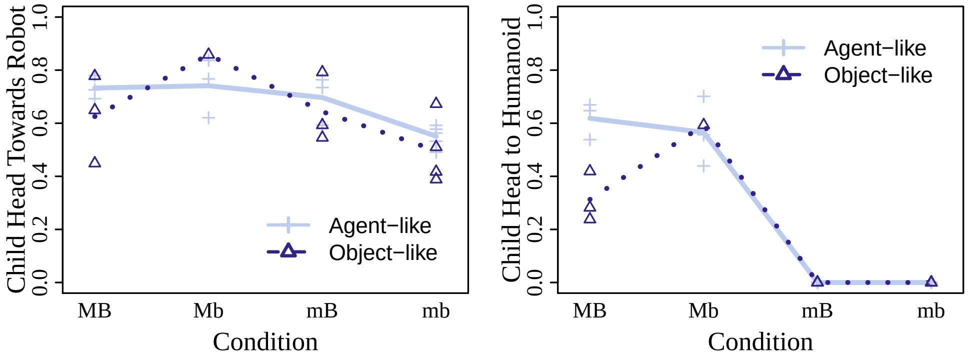
Figure 5. Correlation analysis of child speech and robot behavior, showing differences between agent-like and object-like interactions.

in the differences between the two groups. As shown in Fig. 5(a), the three participants in the agent-like interaction group were also the three participants who consistently vocalized more in the interaction, more clearly shown in Fig. 6(a). We also observe that the agent-like interaction participants pressed the button fewer times per minute than the participants with object-like interactions (Fig. 6(b)), consistent with them treating the robot as an agent and interacting with it via speech rather than via mechanical means (i.e., by pressing the button). We note that these group differences



(a) Proportion of time child spent vocalizing.

(b) Number of times per minute the child pressed the bubble-triggering button.



(c) Proportion of time child spent with head oriented to the robot.

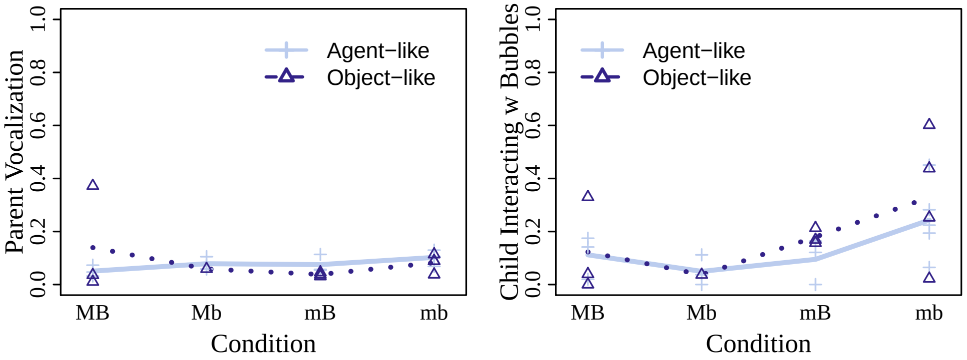
(d) Proportion of time child spent with head oriented to the humanoid portion of the robot.

Figure 6. Child vocalization, button-pressing behaviors, and head orientation, separated into object-like and agent-like interaction groups.

disappear in the mb condition, where the interaction "partner" can only be interpreted as an object. Consistent with our observation that children with object-like interactions were still interested in the robot, we observe limited differences between the groups in children's head orientation to the robot overall (Fig. 6(c)). Finally, we find that in the humanoid robot conditions, the participants with agent-like robot interactions spent more time with their heads oriented toward the humanoid portion of the robot than the participants with object-like interactions (Fig. 6(d)), particularly in the MB condition. To check that the differences between these groups were not caused by the bubbles having a different level of appeal or by the parents' behavior, we examined the differences in the proportion of time spent vocalizing by the parents (Fig. 7(a)) and the amount of time the child spent interacting with the bubbles (Fig. 7(b)) and found limited or no differences between groups.

5.5 Combined Results

Aggregating results by condition across participants reveals no significant differences in the proportion of the interaction that the children spent vocalizing, one of our primary outcome measures (Fig. 4(a)). However, using a one-way within-subjects ANOVA, a significant difference across conditions



(a) Proportion of time parent spent vocalizing.

(b) Proportion of time spent interacting with the bubbles.

Figure 7. Parent vocalization and child interaction with bubbles, separated into object-like and agent-like interaction groups.

in the number of button presses per minute was found ($F(3, 12) = 26.76, p < .001$; Fig. 4(b)). A pairwise t-test with Bonferroni correction revealed significant differences between the mb condition and all other conditions at the $p < .001$ level (with effect sizes of 0.87 for MB, 0.96 for Mb, and 0.78 for mB conditions) and between the mB and Mb conditions at the $p < .05$ level (with an effect size of 0.74). There was also a difference between the mB and MB conditions with $p = .10$ and a medium effect size of 0.51, suggesting that with additional participants, this difference might be significant. Means and standard deviations can be found in Table 3. The proportion of time spent interacting with bubbles and the proportion of time spent with head oriented to the robot's head both had no significant primary effect of condition. However, as shown in Figures 4(a), 4(b), 4(c), and 4(d), there was substantial individual variation in these measures, which, combined with the qualitative results in Section 5.1, suggests that children's treatment of the robot was more a function of the individual child than of the robot's features.

6. Discussion

In this work, we presented an autonomous SAR system for interacting with children with autism and used the system in a study of robot agency and children with autism. We did not find support for our hypothesis that greater agency in the robot would lead to greater vocalizations (H1) or attention to the robot's head (H2) for children with autism. We found some support that the button was most appealing in the mb condition (H3), with button presses increasing from the MB to the Mb, mB, and mb conditions, although we did not see a significant difference in interaction with the bubbles between conditions (H4).

Based on the qualitative analysis, the participants were divided into two groups, and an exploratory analysis was conducted providing preliminary evidence for a spectrum of interpretations of a socially assistive robot among children with autism. Half the children in the experiment both spoke *more* as a function of the robot's movement and spoke *less* as a function of the robot's bubble-blowing behavior, a pattern that can be classified as an "agent-like" interaction (H5 and H6). The other three children in the experiment exhibited the opposite pattern, speaking *more* as a function of bubble-blowing and *less* as a function of movement, a pattern that can be classified as an "object-like" interaction (H5 and H6). Further analysis of the data indicates the following trends about agent-like interactions: 1) participants spoke more overall (suggesting that this pattern might be correlated with overall social motivation); 2) they pressed the robot's button fewer times (H7); and 3) they spent more time looking at the humanoid portion of the robot (rather than other parts of the robot) (H8).

The results suggest that participants with an object-like interaction pattern also found the robot appealing: Both groups exhibited head orientation to the robot about 70% of the time, equal to or more than the time of their head orientation to the bubble-blowing toy. Finally, the differences between the groups are minimized in the mb condition, a result that is consistent with the claim that these group differences are driven by differences in the interpretation of the robot's agency for the robots with both agent-like and object-like features, given that the toy is nearly impossible to interpret in an agent-like manner.

Based on qualitative observations of the data, and given that the children with agent-like interactions with the robots had consistently greater vocalization than the children with object-like interactions, these differences in interactions may be driven by varying baseline levels of social motivation among the participants. However, even children with lesser inclination to interact socially with the robot exhibited a high level of attention toward the robot (Fig. 6(c)). We also find limited differences between the two conditions with higher morphological agency compared to the mB condition, suggesting that interpretations of agency in this group of participants may have been driven by morphological differences in the robots rather than behavioral differences. The primary differences in the reduced behavioral agency (Mb) condition were driven by the children with object-like interactions with the robot, who focused on button-pressing in the MB condition. In this case, although the behavior was intended to be more agent-like, the children were focused on the mechanical button-bubbles connection rather than the agency of the robot.

For designers of SAR systems and researchers in SAR for children with autism, these results provide important insights for future work. For scenarios where children's enjoyment of interactions (as measured by responsiveness and positive affect) is most important, these outcomes may be maximized when the behavioral and morphological agency of the robot is matched to the developmental level of the target sub-population of children with autism. If the goal is to provide children with autism opportunities to develop their social skills, a robot with flexibly agent-like and object-like features might provide children with opportunities to engage with it in the manner most comfortable to them, while also providing socially challenging interactions within their zone of proximal development. These semi-social interactions might give children the opportunity to experiment with new social behaviors in a positive interaction with a robotic interaction partner that will neither judge them nor unexpectedly exhibit the complex social behaviors that come naturally to human interaction partners. The agent-like or object-like features of a robot might also be changed over time to provide scaffolding toward more complex social interactions. Finally, future research in SAR for children with autism that enables autonomous characterization of how agent-like or object-like a child's interaction with the robot might provide important input for decision-making in autonomous SAR systems.

Challenges inherent in performing studies involving children with autism are well established. This study, like most, features a small number of participants and a limited amount of total interaction time with those participants (Scassellati et al., 2012). Consequently, data analysis takes an exploratory approach toward examining patterns in the data rather than focusing on statistical rigor. We posit that the results serve as evidence for the importance of discussing child-robot interactions in terms of how object-like or agent-like the children's treatment of the robot is, rather than as evidence for drawing strong conclusions about the effects of the particular robot morphologies included in this pilot study. Other limitations of the study include the use of head orientation as an imperfect proxy for attention; future work would benefit from modern gaze-tracking hardware. Additionally, in the high behavioral agency condition, the robot responds to any child speech, without regard for content. Thus, although this condition involved a robot with *higher* behavioral agency than the other conditions, the robot did not have the highest possible level of behavioral agency: With a more sophisticated natural language processing system or a more constrained interaction, a robot might be able to behave in ways more contingent on the content of the children's speech. Finally, despite rigorous initial diagnoses, more current information about each child's developmental profile was not available, making it impossible to perform pre/post-behavior comparisons and correlate the discovered trends with historic data, as would be desirable.

Finally, ethical issues may be raised by studies that involve interaction between children with autism and robots. Therapists and parents might be wary of child-robot interaction replacing human-human interaction, while activists in the autism community might question whether it is necessary to "normalize" behavior. In this context, we situate our results within a developmental perspective on child behavior: A SAR system may serve as a comfortable interaction partner for a child with a low level of interest in other people. Gradually increasing SAR system agency over time and incorporating human interaction partners into triadic interactions can facilitate the development of social skills in ways that are most natural for each child. Thus, we find in these results an encouraging middle ground in which a robot can provide scaffolding to a child's natural development in the social environment.

7. Conclusion

This work presented a study of robot agency in interactions with children with autism. A SAR system with both object-like and agent-like features was developed and studied with a cohort of children with autism. A full system with high behavioral and morphological agency was compared to three controls: a robot with reduced behavioral agency (a randomly behaving humanoid robot), a robot with reduced morphological agency (non-humanoid mobile robot), and a fully object-like robotic toy. In addition to expected differences in children's behavior with the toy versus the robots, participants could be divided into two groups based on the patterns in their vocal responses to robot behavior. Additional analysis of participants in these two groups showed differing patterns in their vocalization, button presses, and head orientation to the robot's head with the robots with various levels of morphological and behavioral agency, and those patterns are consistent with more object-like interactions in one group and more agent-like interactions in the other group. We observed that participants' reactions to the conditions in this study appeared to be driven by their interpretation of the robot's agency more than the intended levels of agency. However, despite these between-groups differences in the specifics of the human-robot interaction, participants in both groups showed a high level of interest in interacting with the robot.

Researchers and therapists may be able to harness the flexibility of the robot's role to scaffold children toward more frequent positive social interactions with other people, while maintaining an enjoyable and engaging interaction for the children themselves. This work also showed that an interactive agent is more capable of engaging children in agent-like social behavior than traditional toys, which further validates the usage of socially assistive robots for social skill therapy with children with ASD. Future work would include developing systems that facilitate this scaffolding, as well as characterizing participants to predict what level of robot agency will result in the most productive and positive interactions for specific users.

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Elaine Schaertl Short (corresponding author) and Eric Deng, University of Southern California, Los Angeles, 90089, USA. Emails, respectively: elaine.g.short@usc.edu, denge@usc.edu; David Feil-Seifer, Department of Computer Science & Engineering, University of Nevada, Reno, Reno, 89557. Email: dave@cse.unr.edu; Maja Matarić Departments of Computer Science, Neuroscience, and Pediatrics, University of Southern California, Los Angeles, 90089, USA. Email: mataric@usc.edu

Appendix: Participant Details

Ages of the children and a description of the sessions of the six participants included in this study (A, B, F, G, I, J). Of the ten overall participants, there were four sets of siblings (A-G, D-C, F-J, I-H). Sessions included in this analysis: participants with positive reactions to the robots.
*: Robot malfunction that ended the session prematurely.

ID	Age (yrs)	Condition	Session Time (s)
A	9.4	MB	343
		Mb	273
		mb	309
		mb (d2)	297
		mB (d2)	308
B	5.8	MB	326
		mb	303
		Mb	320
		MB	116
		mb (d2)	255
		mB (d2)	321
F	6.3	mB	244*
		mb	295
		Mb	292
		MB	299
G	9.4	mb	289
		Mb	297
		MB	334
		mB (d2)	316
		mb (d2)	274
I	6.6	MB	316
		mb	304
		mB	300
J	5.3	mb	297
		mB	307