
Toward Socially Assistive Robotics For Augmenting Interventions For Children With Autism Spectrum Disorders

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Summary. Children with Autism Spectrum Disorders (ASD) have communication deficits and difficulties with social interaction. A lack of social behavior can hamper therapeutic interventions and can diminish the ability to learn social skills. Robots have been shown to provoke proactive social behavior in children with ASD. We are developing robot systems capable of acting as catalysts for social behavior in the context of ASD therapy. We present an experiment design for evaluating the effects of a socially assistive robot in a therapeutic setting and results of a pilot experiment with children with ASD interacting with such a robot.

1 Introduction

Socially Assistive Robotics (SAR) focuses on providing aid to the user through social rather than physical interaction [10]. Applications for SAR include rehabilitation assistance for repetitive tasks such as those in post-stroke recovery [40], exercise therapy for Alzheimer’s Disease and other cognitive disabilities [41], companionship roles in nursing homes [43], and social mediation for children with Autism Spectrum Disorders (ASD) [6, 25, 28, 32, 37].

SAR systems thus have the potential to assist a broad spectrum of activities and serve in a variety of roles. In all cases, the physical robot fills both a social and a task-specific role. In the case of assisting physical rehabilitation, task-specific evaluation usually involves in-place models, such as rehabilitation exams [46] and physiological tests [7, 43]. In the case of assisting social interaction [12] and communication, evaluation experiments are often more complex to design. This paper describes a SAR system designed for facilitating and training social interaction, and it includes an experimental design used to evaluate its effectiveness with the intended beneficiary population.

We present an approach for developing SAR systems for use as part of an intervention for children with ASD, a population that has deficiencies in many types of social behavior. This approach is rooted in DIR/Floortime therapy

(DIR: Developmental, Individual-Difference, Relationship-Based), a flexible, individualized intervention approach designed for children with autism, which involves a human therapist playing with the child on the floor, and using the child’s existing social behaviors to new new social behaviors and skills and increase circles of communication [16]. We propose to use a robot to augment DIR/Floortime therapy as a means of addressing the reduced self-initiation of behavior that commonly occurs in children with ASD [23].

Socially assistive robots have been shown to have promise as potential assessment and therapeutic tools, because children with ASD express an interest in interacting socially with such machines [17, 37, 45]. Our work is motivated by the fact that SAR may hold significant promise for ASD intervention. In this paper, we describe an assistive Human-Robot Interaction (HRI) intervention design. We then demonstrate the effects of a SAR system in an experiment with children with ASD.

2 Background and Related Work

2.1 Socially Assistive Robotics

Socially Assistive Robotics (SAR) has a wide range of application domains. Social robots have been used in the common areas of nursing homes, aiming to increase socialization among residents [1, 18, 43]. SAR has also been used in rehabilitation robotics, where it has been shown that assistance primarily through social interaction may have therapeutic benefit. Our group has developed SAR systems to augment rehabilitative care for post-stroke [9, 30], where a robot verbally encourages a user to keep to a therapy regimen consisting of functional arm exercises, and post-operative cardiac care [19], where a robot reminds a patient to perform spirometry breathing exercises, and exercise therapy for elderly residents of a nursing home [41] as part of a preventative care regimen for elders with Alzheimer’s. Other rehabilitation projects have explored using a robot as a means of motivating rehabilitation through mutual storytelling that involves expressive movements as a means to keep a repetitive exercise regimen appealing to children [27, 35]. The results of other research groups that use robots as therapeutic agents for children with ASD present a promising case for future research of ASD and robotics [26, 28, 32, 36, 37].

2.2 Experiment Designs for Socially Assistive Robotics

SAR is a new field with little common practices. We present a brief review of relevant studies using human-robot interaction and socially assistive robots, including feasibility studies, user studies, behavior studies, surveys, and ethnographies, respectively.

Feasibility studies are common in robotics. The primary goal of such studies is to design systems and verify that they works as intended. One example is Breazeal et al. [5], where the authors built a robot capable of reasoning about joint intentions, and verified that it exhibited collaborative behavior as an entity capable of recognizing joint intentions should. Other examples from our

work in socially assistive robotics include a feasibility study for a post-stroke rehabilitation robot [31] and a post-operative cardiac recovery robot [19]. In all these studies, the systems were validated, not to assessed clinical tools for specific health outcomes.

Another way to evaluate SAR systems is through user studies. Such studies are long-term evaluations of how a single user, or a small group of users, interacts with an intervention tool [2]. One example is the study a single user’s experiences with a service robot in an office setting [38]. The study provided insights for interface design and common failure points for such a system.

Behavior studies are used to show how a user’s behavior changes when a robot is present. Typically a behavior study is used to show comparative differences between two or more conditions. One example is Breazeal [3], which evaluated the smoothness of interaction between different strategies of turn-taking behavior. Behavior studies in the SAR context have been used to demonstrate the effects of embodiment [21, 34, 44] and robot behavior [40] on a user.

One means of assessing the properties of a SAR system is to ask users directly. Surveys have been used to evaluate SAR features such as likability, engagement, and responsiveness [4, 44]. There has been little work to date to make a common survey for assistive robotics, or for robotics in general. So far, in most cases survey are particular to the type of robot being used and the domain that the robot is used in.

Ethnographies are an effective means for determining the effects that a deployed robot has on a user population. Like user studies, they involve tracking human-robot interactions over time. However, unlike user studies, they involve entire user populations rather than individual users. Ethnographies have been used in to assess the effects of robots in eldercare [14], home [13], and hospital [33] settings.

2.3 Autism Spectrum Disorders

ASD includes autism, Asperger’s, and other pervasive developmental disorders (PDD). Children with ASD exhibit some or all of a range of symptoms, from a lack of basic social skills (joint attention, speech, play, etc.), overly focused or isolated areas of interest, to problematic repetitive behaviors [15, 42]. A lack of socialization and relationship-forming typically results. Most children with ASD require care into adulthood [8]. While there is no single standard for care of children with ASD, a therapeutic intervention generally involves modifying the behavior of caregivers in order to encourage children to initiate and respond to essential social behavior, such as social orienting and joint attention [20, 39, 47]. Such therapy can involve the use of other people known to the child as well as other objects, such as toys, in order to create social situations [16].

2.4 Socially Assistive Robotics for ASD

Several projects are exploring ways of using socially assistive robots as agents for therapeutic interaction in ASD, toward deployment in intervention settings. Dautenhahn [6] uses simple mobile robots to help guide children with ASD toward more complex social interactions. Results have shown that children with autism proactively interact with simple robots and that such robots can mediate joint attention [36]. Studies have also shown that a simple robot can have a positive effect on gaze and physical contact behavior when acting as a social mediator [32, 45]. Storytelling robots have been used for therapeutic applications as well [28]. Finally, a cartoon-like robot is being used as part of a long-term study in a day care center [24, 26]. Most encouraging about these efforts is that children with ASD are often motivated to exhibit proactive social interaction such as joint attention when a robot is present [36].

Our work with children with ASD leads to an approach that utilizes feasibility studies to determine if a robot can behave appropriately in experimental settings, and behavior studies to verify hypotheses regarding properties of the robot that facilitate improved social interaction for users with ASD. Section 4 describes an experiment design that meets these criteria, described in detail in the next section.

3 Robot-Augmented ASD Intervention Approach

Mounting evidence [36, 37, 45] supports the findings that children with autism who are otherwise asocial display social responses and engage in social interactions with robots and exhibit more proactive social interaction. We thus designed a robot-augmented ASD therapy approach based on the DIR/Floortime intervention.

As noted above, DIR/Floortime therapy is a semi-structured play intervention in which a therapist uses a child’s existing social skills as a basis to develop new social behaviors [16]. The standard use of other people and toys as part of DIR/Floortime sessions allows for the introduction of a robot in place of a toy as part of the therapy process. In that context, robots with appropriate behaviors can serve to motivate proactive interaction and mediate joint attention between the child and a peer or an adult [36].

We designed the Behavior-Based Behavior Intervention Architecture (B³IA) as part of a larger research project that aims to create a methodology, approach, architecture, and supporting algorithms for HRI-based intervention methods, and, more specifically, to enable principled evaluation of SAR systems in the context of ASD [11]. Due to the nature of an autonomous behavior intervention system in a therapeutic setting, the control architecture of such a system has additional requirements beyond those typically found in other autonomous robot systems. The architecture must facilitate the robot’s ability to:

1. Sense the actions of the child and understand his/her approximate meaning in the given social context;

2. Act autonomously for designated interaction scenarios;
3. React not merely to the immediately sensed situation, but also to the interplay of interaction over time;
4. Evaluate the quality of human-robot interaction over a specified period of time.

In B³IA, a robot observes the behavior of the child through a collection of sensors that may be on-board, in the environment, and/or worn by the child. Using the structure inherent in existing assistive therapies, the designer of the a robot’s architecture is able to craft the actions of the robot as well as the response to sensed behaviors of the child using established diagnostic guidelines [29]. The details of B³IA are given in [11].

While there is evidence that the presence of a robot has an effect on a child’s social behavior, there are no data yet on whether the behavior of the robot itself has an effect on the child. Thus, the specific research aim that serve as a foundation for a robot control architecture for use in ASD intervention is:

- **Specific Aim:** Determine if the behavior of the robot has an effect on the social behavior of the child.

We phrase this as a testable hypothesis:

- **H1:** A child interacting with a contingent robot (one that responds to the child’s behavior) will exhibit more social behavior than when interacting with a random robot (one that responds randomly).

The motivation for exploring this hypothesis is simple. Studies to date that have employed robots with children with ASD have not yet tested whether the behavior of the robot was in itself responsible for the resulting observed behavior of the child, or if similar behavior might have been elicited by a toy or otherwise. To properly test if the robot’s behavior is the cause of the child’s response, and to what degree, a control experiment is necessary, which compares contingent to non-contingent (i.e., random) robot behavior.

We developed an experimental scenario to test this core hypothesis, compatible with DIR/Floortime therapy, and suitable for evaluating the control architecture. In order to implement an experiment, a familiar and relevant scenario is necessary. The scenario we selected is based on the use of bubbles as part of ASD diagnosis. We developed Bubble Play, a a computer-controlled bubble-blower that can be mounted on the robot, and equipped the robot with two large colorful buttons, as shown in Figure 1(b). When the child pushes one of the buttons, the robot blows bubbles while turning in place. When the child does not push one of the buttons, the robot does nothing (no bubbles, no turning). The simplicity of the scenario has several benefits. Chief among them is its reliability, and lack of intimidating effect. We found that more complex social behaviors, especially when displayed on a humanoid robot, require some habituation [11]. While the study of just such behaviors on more complex robots is the focus on our ongoing work, it is inappropriate for testing the core hypothesis, as it introduces undesirable uncontrollable parameters into



(a) Robot used in the experiments (b) Interaction with the robot (c) Interaction with the humanoid robot

Fig. 1. The robot in an experimental setting. The bubble-blowing robot (left) is known to be less intimidating than a humanoid robot (right).

the experiment. Finally, since this scenario is part of the Autism Diagnostic Observation Schedule (ADOS), a common Autism diagnostic instrument, there are very well-known criteria for evaluating the social interaction of a child during the scenario [29].

The intended role of the robot is as a catalyst for social interaction, both human-robot and human-human, thus aiding human-human socialization of ASD users, rather than as a teacher for a specific social skill. This allows for the scenario where the robot is not specifically generating social behavior or participating in social interaction, but instead where robot behaves in a way known to provoke human-human interaction. The Bubble Play scenario is designed to facilitate (and increase) just such interaction. Bubble play, when performed by a human companion (therapist or parent), is known to provoke social interaction between the child and the person operating the bubble blower [29]. Thus using the robot as a substitute is ideally suited for evaluating the specific social benefit of the robot, and thus addressing the intended hypothesis, above.

4 Experimental Validation

We conducted experiments with children with and without ASD in order to verify that the robot is effective as part of the described intervention design. Our priority as discussed in Section 3 is to demonstrate that the robot’s behavior has an effect on the child. In addition, we wish to demonstrate that the robot acting contingently based on the actions of the child has a positive effect on his/her social interaction. Finally, we wish to demonstrate that the robot can observe (and potentially analyze) collected social interaction data as a necessary prerequisite for more complex autonomous social behavior.

As described above, the purpose of the validation experiment that we conducted was to determine whether or not the behavior of the robot has an effect on the child’s behavior. To test the hypothesis, we created two experimental conditions, *contingent* and *random*. In the *contingent* condition, the robot behaves as described in Section 3. When one of the two buttons is pushed, the robot turns in place and blows bubbles. When the buttons are not pushed,

the robot does nothing. In the *random* condition, the robot executes the same actions (turning and blowing bubbles), but at random intervals and not in response to the child’s interaction with the buttons, if any. No specific action occurs when either button is pushed.

If there is a measurable difference between the contingent and random conditions, then we can conclude, for those two conditions, that the behavior of the robot has an effect on the resulting social behavior of the child with ASD. If the contingent condition elicits more social interaction than the random condition, we can infer that the robot behaving contingently with the child would be more effective as part of an intervention than a randomly behaving robot. For the pilot experiments, we recruited four participants (3 ASD, 1 typically developing) ranging in age from 20 months to 12 years old. The pilot experiment produced a series of qualitative and quantitative observations of the child’s social skills, which included vocalizations, initiation of behavior, social orienting, and pointing.

4.1 Potential Confounding Factors

An experiment of this type has several potential confounding factors that could affect the results. First, the novelty of the robot can potentially have a significant effect on the social behavior of the child. Second, the novelty of the Bubble Play scenario can also have an effect on the social behavior of the child. Children with ASD typically have a different reaction to new situations than typically developing children [22]. As this is a single-session repeated-measures study, we needed to determine what effect, if any, novelty has on the child’s behavior. In addition, we had to separate the effects that the robot had on the child’s behavior from the Bubble Play scenario’s effect on the child’s behavior. To assess and address the effects due to novelty, we created an experimental design that provides conditions for comparison, described in the next section.

Finally, there is a risk that the child may not interact with the robot, regardless of the circumstances/experimental design and scenario. Earlier pilot results have shown that when the robot is deemed intimidating, the child may not interact socially at all [11]. As noted above, we choose the Bubble Play scenario in part to address this confounding factor. Our experience suggests that the simpler the robot (mechanical-looking over humanoid; no speech interaction; predictable movements), the less initially intimidating it is for children with ASD.

4.2 Presentation Order

We used an experimental condition presentation order that addresses several known challenges, including novelty and individual differences among participants. To establish a partial baseline of the child’s behavior, the child, and any interaction partners (e.g., parents) involved in mediated experiments are

observed for 5 minutes before and after the control and experimental conditions are presented, without the robot in the room. This no-robot (NR) period serves to observe pre-existing social behaviors and rule out behavior changes as a result of growing comfort in a new situation.

Sequence A	FW	NR	I1	I2	NR	R1	R2	NR
Sequence B	FW	NR	I2	I1	NR	R2	R1	NR

Table 1. The sequence of condition presentation. Key: FW: feet wet, NR: No-robot; I1,2: Initial Presentation; R1,2: Repeat Presentation

Each experiment session consists of a sequence of presentations of a scenario (see Table 1). To address the novelty factor, each experiment consists of three phases: the “feet wet” (FW) phase, the “initial phase” (I), and the “repeat phase” (R). In the FW phase, the experimenter introduces the robot, and shows its capabilities and intended function. The initial phase presents the scenarios. Data are gathered during this phase to study the novelty effects of a robot on a participant. Following the initial phase, the experimental conditions are presented again in the repeat phase. This phase is thus less tainted by novelty. The same observations are used as in the initial phase; we seek comparative differences between the conditions rather than novel social effects in response to the robot. In the repeat phase, the experimental conditions are presented in the same order as in the initial phase.

There are many reasons to be concerned that novelty can have an effect on the results of our experiment. In order to examine the effects that novelty does have on our results, we present each experimental condition twice. We can then compare I1 to R1 and I2 to R2 to see if there are any significant differences between a first and second presentations of a robot. We can also look at all four trials (I1,I2,R1,R2) for a trend over time. In addition, we can compare the three no-robot presentations to see a trend over time. This can be used to observe if there is a change as the child acclimates to the experimental setting.

To determine the effect that the robot has, we can either compare the robot to a non-autonomous toy (such as a truck, a ball, a bubble blower, etc.) or to a human given interaction rules similar to the robot. This is done during the NR conditions. We can compare NR to I1, I2, R1 or R2 to determine the improvement from no-robot to robot conditions.

4.3 Analysis

During each session, video data are collected from multiple eye-level cameras. The video data are annotated by human observers, coding for the following specific social behaviors:

- Speech/vocalizations
- Gestures (pointing, waving, etc.)

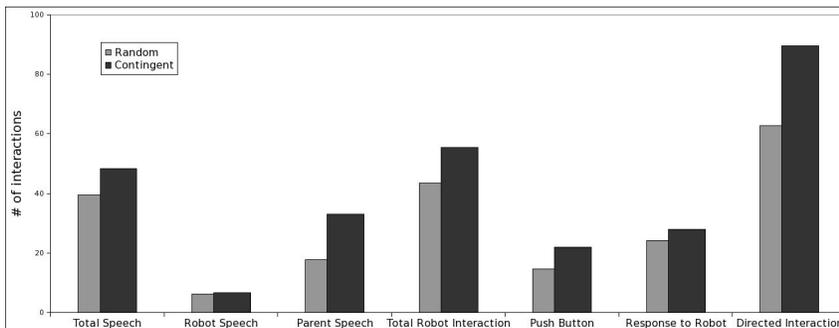


Fig. 2. Preliminary results of the experiment

- Movement toward/away from/in front of person/robot
- ASD-stereotypical behavior (hand flapping, etc.)
- Joint attention/eye contact with parent/robot
- Actions to control robot (button pushes, gestures for robot to imitate, etc.)

For each presentation we annotated the video recordings for the above behaviors, including the target of the social behavior as well as whether the behavior is proactive or in response to the parent or robot. We then, through an algorithmic process, compute information about the quantity and quality of interaction during the presentation. We compare quantity and quality values between conditions.

For direct scenario comparisons, we use an ANOVA for repeated measures. There are many explanatory factors that can affect the amount of social interaction observed as well as any change in the amount of social interaction between conditions. These factors include: age, severity of social deficit due to ASD (measured using diagnostic instruments, such as ADOS), and the social behavior of the participant when the robot is not present (measured using the NR condition). Differences among these predictor effects might explain any trends observed in the data. Future work will use the ANCOVA (analysis of covariance) to determine what percentage of any correlations can be explained by predicting factors.

5 Results

Each of the four participants interacted with the robot in the Bubble Play scenario described in Section 3. One ASD child had to withdraw due to an equipment malfunction. Three participants (2 male/1 female; mean age, 6 years) participated in the study.

5.1 Quantitative Results

We found that the behavior of the robot affects the social behavior of a child (both human-human interaction between the child and the parent present, and human-robot interaction between the child and the robot): social behavior

with a contingent robot was greater than with a random robot. Total speech went from 39.4 to 48.4 utterances, robot speech from 6.2 to 6.6 utterances, and parent speech from 17.8 to 33 utterances. Total robot interactions went from 43.42 to 55.31, with button pushes increasing from 14.69 to 21.87 and other robot interactions going from 24.11 to 28. Total directed interactions went up from 62.75 to 89.47. Generally, when the robot was acting contingently, the child was more sociable. This increase is reflected in the observed number of social actions. These results demonstrate that the robot’s behavior is, at least in part, responsible for the child’s resulting social behavior, and that the contingent robot behavior has a positive effect on the amount of social behavior that the child exhibits. The data therefore support the hypothesis.

Effect size (calculated using Cohen’s d) ranged from .5 (medium) to .8 (large) and above. For these effect sizes, and for an ANOVA to achieve .8 power, we need a participant pool of at least 35 participants. This power analysis is done using data from only three participants, so its predictive value is low. Doing an *a priori* power analysis assuming large and medium effect sizes for an ANOVA, we will need between 31 and 67 participants to achieve a power of .8.

We are currently conducting a study verifying these results in a larger population. If the larger study results are consistent with the reported pilot results, they will further underscore the importance of robot control architecture development, since the behavior of the robot is a part of the observed social effects.

5.2 B³IA Performance

In Section 3, we outlined four requirements for a robot-augmented intervention. The reported experiment was too simple to properly test the B³IA architecture, although it showed that, for the very simple Bubble Play scenario, the robot met requirements 1 and 2. The activity history component of the architecture was, in this experiment, limited to sensing pushes of the buttons, and the actions that the robot took (blowing bubbles, turning in place, no actions). We also compared video annotations to the automatic recording of social behavior that the B³IA architecture is designed to collect. The two annotations, the robot-collected and the human-annotated, were consistent. Given the simplicity of the robots’ and the child’s behavior repertoires, it is not surprising, though it is reassuring, that the recognized information matched with human annotations of the child’s activity during the experiment. We compared video annotations

For each presentation we annotated the video recordings for social behavior (including speech, gestures, movement, and physical contact), noting the target of the social behavior as well as whether or not the behavior is proactive or in response to the parent or robot. We are currently developing an algorithmic process to compute the quantity and quality of interaction during the presentation. This will fulfill the fourth requirement of the architecture.

6 Summary and Future Work

The experiments presented in this paper use the B³IA architecture in a very simple ASD intervention setting, and demonstrate that the robot's behavior has a social impact on the child. Our current work involves using the B³IA activity history in an off-line fashion to develop a measure of the quality of social interaction for a fixed time-period. These measures are useful for both ASD assessment and intervention. When calculated in an on-line fashion, such a measure of quality can be a component of the robot's action selection mechanism.

The current interaction evaluation system will be augmented with input from autism specialists to better evaluate the quality of interaction. The eventual goal of this evaluation is to produce human-readable output that a human intervener could use to monitor the progress of a robot-assisted intervention so that the intervener could personalize the intervention to suit the unique needs of the child. We will explore appropriate data-mining techniques for human-readable measures.

The understanding of design properties of a robot intervention such as contingency of behavior is important for creating an effective autonomous robot-assisted intervention for children with ASD. Our ongoing work involves a larger study which will examine the core hypothesis in more detail. A longitudinal version of the study will also include an examination of the effects of the robot's form; we plan to use a mobile robot vs. a humanoid, hypothesizing that the former is more readily acceptable to ASD children but the latter is more conducive to training human-human social skills. The results from these experiments, will serve to define guiding principles for developing socially assistive robot systems targeted for ASD intervention.

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