Potential Clinical Impact of Positive Affect in Robot Interactions for Autism Intervention

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***Abstract*—While interactive technologies frequently are designed to be enjoyable, there are particular reasons to prioritize this for technologies intended to support autism interventions. Most broadly, enjoyment of activities or materials used in interventions has been associated with heightened improvements in the behaviors targeted by the interventions. In the largest group study to date of school-aged children with high-functioning autism (*N*=24), we present evidence of more positive affect elicited with a robot than with an adult, during matched triadic interactions designed to facilitate social and conversational interaction with a clinician. Robot-mediated increases in positive affect were found to be associated with production of spoken language directed to the clinician during robot interaction. We further found that robot-mediated increases in positive affect were associated with greater autism severity, particularly in the social affect domain, and with lower nonverbal IQ. Our findings suggest that robots may have a unique advantage in interventions for children with autism spectrum disorders by eliciting more positive affect, and that we should explore robot support for interventions with lower-functioning, affected individuals.**

Keywords—human-robot interaction; autism; affect; enjoyment; engagement; group study

I. Introduction

Interactive technologies are often designed for application to education, entertainment, healthcare, or social networking. For any interactive technology we evaluate how effectively they serve their intended application. For example, we measure whether users' learning improves when interacting with an educational technology. In addition, for all applications, we design for enjoyment. Common sense tells us that people engage with objects and activities that they enjoy, given that most technological interactions depend on the user's voluntary engagement.

Recently there has been a surge in the design of interactive systems for use by individuals with autism spectrum disorders (ASD). Such systems include innovative augmentative and alternative communication devices, video modeling of behaviors, covert auditory coaching, virtual reality social skills interventions, e.g., [1]–[4], and interactive robotic supports for communication and social skills interventions targeting behaviors such as joint attention, e.g., [5]–[11]. Beyond universal reasons to design for users' enjoyment, applications intended to support interventions for children with ASD have additional specific reasons to prioritize users' enjoyment. This paper discusses the important roles positive affect can play in communication and social skills interventions for children with ASD, and describes our evaluations of positive affect during interaction with a social robot, as well as the import of our findings to the design of robot interactions for autism intervention.

A great deal of past and ongoing effort has gone into developing interactive systems that can automatically detect and respond to users' affective states, often with the goal of responding to changes in affect to improve the user's experience or to facilitate the user's engagement in a task, e.g., [12]–[15]. Alternatively, recent evidence indicates that an interactive system's expression of emotion can influence or facilitate users' engagement in, or understanding of, interactive tasks, e.g., [16]–[18]. Among affective computing systems specifically designed for use by individuals with autism, automatic detection of emotion or autonomic arousal have targeted applications including systems that are responsive to the user's emotional state, support for the science of developmental disorders, and support for individuals with ASD during social interactions by labeling others' emotions [19]–[21].

In contrast to automatic emotion detection and expression of emotion by an interactive system, in this paper, we are highlighting a different focus on affect: that of designing an interactive system for the user's enjoyment. Enjoyment is not a new priority in HCI and much attention to enjoyment in interactive systems derives from video game design, e.g., [22], [23]. We raise design for enjoyment here because it deserves special emphasis with respect to applications for ASD.

Many children with ASD receive intense behavioral interventions to improve a variety of skills associated with communication and social interaction. When designing for interventions for children with autism, we may want to prioritize the user's positive affective state for two particular reasons. First, expression of affect is sometimes itself a target for intervention for some children with ASD. Directed or

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communicated expression of positive affect can be considered a social or communicative skill in its own right, and expression of positive affect has been found to be coordinated less frequently with eye contact and other communicative behaviors, in lower functioning affected children [24]. Among high-functioning children with ASD, some have difficulty expressing positive affect in speech prosody [25] and they direct or communicate their affective state—that is, they coordinate positive affective expressions with eye contact or vocalization—less well than their peers with typical development [26], [27]. As a result, some interventions specifically target the expression or communication of positive affect, particularly in the context of social or communicative exchange [24], [28].

Second, and more broadly, whether or not expression of positive affect is itself the target of an intervention, within the context of communication or social skill interventions targeting any specific behaviors, it has been argued that positive affect is critical to maintain a child's engagement during intervention [29]. This is consistent with theories of motivation in learning in general [30]. There is also evidence that the use of materials and activities which a child enjoys or prefers—that is, *intrinsic reinforcers*—can improve the effects of treatment [31], [32]. Therefore, interactive technologies intended to support communication or social skill interventions for ASD have good reason to prioritize their target audience's enjoyment, as doing so may make interventions more effective.

There is evidence that some individuals with ASD have strengths or special interests in interacting with mechanical, physical, or technological systems, or respond more often correctly or appear more engaged during tasks administered using a computer [33]–[36], which forms some of the motivation to develop technological supports for intervention. However, it is important to note the abilities and interests vary with vast heterogeneity among individuals with ASD. Identifying relationships between strong response to technological interventions and heterogeneous developmental or clinical profiles may help us to refine our designs to fit those profiles.

Among HRI studies of individuals with autism, there have been anecdotal reports of enjoyment in small-number case studies, e.g., [7], [37], [38], and anecdotal reports of enjoyment among larger numbers of children with ASD engaged in an educational computer game, e.g., [39]. These reports are limited by their small numbers or anecdotal qualities, the latter of which makes it difficult to compare with other investigations. In contrast, an investigation of responses of 22 children with ASD to a multi-touch screen-based technology used novel as well as previously used questionnaires to confirm users' enjoyment of the technology [40], establishing the feasibility of the multi-touch screen's use in interventions for children with ASD [41].

In the present study of a group of school-aged children with ASD (*N*=24), the largest sample to date, we examine their enjoyment of interaction with a social robot, during a brief task designed to elicit behaviors commonly targeted in communication and social skills intervention. Our study is unique in that (1) we use direct observation of participants' behaviors to gauge enjoyment, and (2) we compare positive affect during interaction with the robot against a benchmark of interaction with an adult, and (3) we examine relationships between positive affect and a potential intervention target behavior—spoken language, as well as with clinical developmental characterizations. Finally, because this is a group study, we can make modest claims about the generality of our findings to other children with ASD.

Fig. 1. Top: Triadic interaction among a participant (center-back of image), the confederate (left), and the robot (center-front); the adult interaction partner secretly controlled the robot from the corner of the room (right). Bottom: Matched triadic interaction with the confederate and adult interaction partner (right).

A recent study of a cohort of high-functioning school-aged children with ASD sought to measure the potential utility of robots within communication and social skills interventions, by comparing participants' social behaviors during interaction with a robot against those with an adult interaction partner or an asocial touchscreen computer game [42]. It was found that participants directed more spoken language to a clinician while interacting with a robot than during a matched interaction with another adult. This finding of robot-mediated increases in directed spoken language suggests that robot interactions may be useful for conversational interventions for high-functioning children with ASD, providing a measure of validity or efficacy with respect to the robot interaction's intended purpose.

In the present study, we sought to further gauge the potential clinical utility of social robot interaction for communication and social skills intervention for ASD, by comparing affective valence during interaction with the robot versus with the adult interaction partner. We excluded comparison with the computer game because its asocial design elicited few affective expressions. Comparison against response to interaction with an adult offers measurement against a baseline involving a common interventional interaction partner—that is, a clinically trained adult.

II. Methods

A. Participants

Twenty-six children with previous diagnoses of ASD and high functioning participated in our experimental protocol. All received extensive cognitive, social cognitive, and other developmental assessments by a team of expert clinicians during their participatory visits. Two participants were excluded from analysis—one whose speech was difficult to comprehend, and one whose autism diagnosis was not confirmed during evaluation. Of the 24 participants included in analysis, all had fluent speech, full-scale IQs above 70 ($M = 94.2$, $SD = 11.7$, $min = 72$, $max = 119$; measured using Differential Abilities Scales (DAS-II; [43] or the Wechsler Scale for Children—IV (WISC-IV; [44]). All included participants received clinical best estimate confirmation of their ASD diagnoses, with support from the Autism Diagnostic Observation Schedule—Generic (ADOS-G; [45] and Autism Diagnostic Interview—Revised (ADI-R) [46], both gold-standard diagnostic instruments. Ages ranged from 4.6 to 12.8 years ($M = 9.4$, $SD = 2.4$); 3 participants were female. Further details are available in [42].

B. Interaction Design for Rich Social Interaction and Enjoyment

In randomized crossover design, participants completed 6-minute, triadic interactions with a confederate—a researcher who guided interactions—and either a robot or adult interaction partner (see Fig. 1). Given our ultimate goal of comparing social behaviors elicited during a therapy-like robot interaction against behaviors expressed during interaction with an adult, our highest priorities in designing both interactions were (a) seamless, rich social interaction; (b) engaging, enjoyable interaction; and (c) tight, parallel matching between robot and adult interactions.

C. Experimental Procedures

The robot and adult interactions were closely matched and were semi-structured in order to elicit participants' mentalizing about the robot or adult interaction partner's attentional and affective states, turn-taking with the robot or adult interaction partner to construct a structure out of building block toys, and either petting the robot or performing a secret handshake with the adult. These social behavioral probes were chosen to reflect deficits that might be targeted in interventions for children with high-functioning ASD.

The robot and adults' actions and vocalizations were moderately constrained to a pre-determined set of behaviors, and were delivered according to a tightly controlled interactive script. The robot and adult's behaviors were expressed using non-verbal but affectively expressive prosodic vocalizations, head turns, and hand gestures to indicate joy, excitement, disappointment or dislike, as well as attention to particular objects. The confederate suggested activities or asked questions of the participants, and offered increasingly restrictive, supportive prompts a pre-determined number of times, before suggesting an answer to a question or demonstrating a suggested action. Moderate constraints placed on the adult interaction partner's vocalizations did not impede conversational interaction; these constraints are described in greater detail below in Section II.E.

Fig. 2. The dinosaur robot Pleo was controlled using Wizard of Oz hidden, remote, manual control and expressed affective and attentional states using pseudo-verbal vocalizations, head movements, and body movements.

D. Robot and Robot Control

We modified the commercially marketed, toy dinosaur robot Pleo [47] (see Fig. 2) to play pre-recorded, synchronized motor and audio behaviors, triggered through the robot's infrared receiver by a television remote control. To elicit rich social behaviors, we designed the robot's behaviors so that participants would think of it as an autonomous, social partner, understanding of language, and emotionally expressive—something between a pet and a taciturn peer. To endow the robot with an appearance of autonomy, we used Wizard of Oz remote, manual control of the robot [48], [49]. That is, unknown to participants, the robot's behaviors were controlled by the adult interaction partner, who sat back apparently observing in a corner of the room, triggering the robot's behavior by hiding the remote control under a clipboard. Only one participant voiced strong suspicions of manual control and at the conclusion of all experimental conditions discovered the remote control. To further express autonomy, the robot continuously performed varying idling behaviors, shifting its body weight, looking around the room, occasionally muttering or humming to itself. In order to instill a belief that the robot was capable of rich social interaction, the robot expressed positive (e.g., excitement and joy) and negative (disappointment or dislike) affect and attention to particular objects using pseudo-verbal vocalizations (e.g., "Ooooohh!" to indicate interest in an object, and, "Awwww" to indicate disappointment), head turns, body movements. We chose pseudo-verbalizations instead of speech because we lacked an interface for spontaneous unplanned speech production. Therefore, we designed the robot to pre-emptively avoid children's asking the robot to express thoughts beyond its affective or attentional state. To make the interaction more enjoyable, we chose a cartoonish vocal character, designed a happy dance to express elation, and offered participants a chance to pet the robot and designed flexibility into the structure of interactions, to allow participants opportunities to engage the robot beyond the structured probes.

E. Adult Interaction Partner Behavior

To control between-condition variability, the adult interaction partner used limited speech to express affect and attention (e.g., "That one!" to indicate interest in an object, "Cool!" to indicate excitement), only using explicit affective labels to confirm a statement made by the participant or confederate (e.g., "Yeah, I wanted to keep building with the blocks."). In other words, the constraints placed on the adult interaction partner's speech were: (1) to avoid touching or naming an object until the participant or confederate had explicitly identified it, and (2) to avoid labeling her emotional state until the participant or confederate had explicitly named it. The adult interaction partner used gesticulated excitedly to match the robots broader and faster motor actions.

F. Ratings of Affective Valence

The primary dependent variable in the present study was affective valence, as judged grossly over the entirety of the robot and adult interactions, separately. Two independent raters reviewed video recordings of each 6-minute interaction and produced a Likert scale rating from 1 to 5, corresponding to intense negativity (i.e., frustration, discomfort or unhappiness), mild negativity, neutral affect, mild positivity (i.e., enjoyment or happy excitement), or intense positivity for most of the interaction. Inter-rater reliability was high (*ICC*=.841 and .846, for robot and adult conditions, respectively). Inter-rater averages were ultimately used as the measure of affective valence.

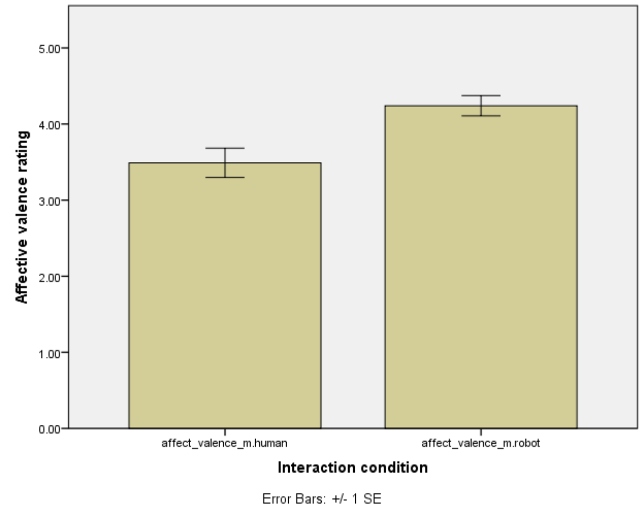

Fig. 3. Bars show mean affective valence ratings over a cohort of children with ASD (N = 24), during adult (left) and robot (right) interaction conditions. Affective valence was rated grossly over the 6-minute duration of each interaction, on a Likert scale from 1 to 5, 1 representing intensely negative affect; 3, neutral; and 5, intensely positive.

III. RESULTS

Paired t-tests revealed that affect was more positive during the robot than the adult condition ($t[23] = 5.1$, $p < .001$, $d = 0.93$). This difference is illustrated in Fig. 3. Number of utterances directed to the confederate during the robot interaction was related to more positive affect during the robot than adult interaction ($r[22] = .53$, $p < .01$).

More positive affect during robot than adult interaction was inversely associated with nonverbal IQ (higher IQ scores indicate greater cognitive ability; $r[22] = -.47$, $p < .05$) and associated with ADOS calibrated severity score (higher ADOS calibrated severity scores indicate greater autism symptom severity; $r[22] = .43$, $p < .05$), and more specifically with ADOS calibrated severity score in the social affect domain ($r[22] = .46$, $p < .05$).

IV. DISCUSSION

A group of high-functioning children with ASD exhibited more positive affect during interaction with the robot than with an adult, in matched conditions eliciting communication and social skills targeted in interventions. More positive affect during robot interaction was associated with the amount of confederate-directed spoken language produced during the robot interaction, as well as with lower non-verbal cognitive ability and higher autism severity.

More positive affect, or greater enjoyment, during the robot than the adult interaction suggests that robots may have an advantage over humans as intrinsic reinforcers, or preferred interaction partners, for facilitating interaction with a clinical confederate guiding an intervention-like protocol. Given associations between use of intrinsic reinforcers with greater improvements during intervention, the present findings suggest a potential advantage that robots may have for interventions.

The present measures of positive affect during interaction with the robot are consistent with previous findings of highly positive affect during a different, rich social interaction between the same robot Pleo and another cohort of school-aged children with high-functioning ASD [50], which lends further support to the possibility that robots may be intrinsically reinforcing for many children with autism. We caution, however, that we have reported positive affect ratings in terms of group means, and that given broad heterogeneity encountered among individuals with autism, this finding should not be expected to apply to all children with ASD universally.

Interestingly, our findings suggest that robots may be especially reinforcing for children who are more severely affected and who have lower nonverbal IQ. This may indicate that human-robot interactions may be of particular benefit to younger or lower-functioning children.

Together, the present evidence supporting robots' role as potential intrinsic reinforcers, and previous findings of robot-mediated increases in confederate-directed spoken language [42], suggest the potential for robots to be useful facilitators of intervention for children with ASD. This is further supported by the relationship found between spoken language production during interaction with the robot and more positive affect during the robot interaction. We studied only children with high functioning ASD, primarily because we expected that lower functioning children who, by definition, have greater difficulty with language and lower cognitive functioning, would be more difficult to restrict to largely non-tactile interaction with the robot. For younger or lower-functioning children, we suggest that more robust robotic platforms should be used. This is an important area for future investigation.

Use of hidden, manual Wizard of Oz robot control presents a significant limitation to the deployment of designs like ours. We chose WOz control only because state of the art computational perception of human behaviors and robotic object manipulation are not yet accurate or reliable enough to support naturalistic, relatively unconstrained, conversation- and shared-object-based social interactions of the type we sought to probe. We expect that as automation of perception, robotic object manipulation, and robust, reliable device design improve, we will be able to apply *autonomous*, rich, engaging robot interactions to autism intervention. The present study serves as supportive evidence that such efforts, especially in automatic social behavior perception and robust design, should continue, particularly with consideration to behaviors unique to children with autism. This view is further developed in [53].

Although our study examines human-robot interaction, given evidence of facility or special interest in devices and technologies [33], [51], [52], other, non-robot technologies may also serve as intrinsic reinforcers for children with ASD. In other words, because many individuals with ASD may have a special affinity for various technologies, they may particularly enjoy interactions with a technology, and this in turn may impact the benefit they gain from those interactions. Therefore, we suggest that designers of any interactive technology for individuals with ASD measure their users' affective responses, and consider possible relationships to other measures of usability or clinical efficacy, as well as to heterogeneous characteristics of the users.

Finally we stress that our findings speak to the potential benefit of robot interactions as facilitators of interaction with a clinician, not with the technology itself. We suggest that when designing for children with ASD, technologists take care to differentiate between encouraging interaction with the technology itself, and facilitating more adaptive interaction with other people.

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