Emotional Robot to Examine Different Play Patterns and Affective Responses of Children with and without ASD

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***Abstract*— Robots are often employed to proactively engage children with Autism Spectrum Disorder (ASD) in well-defined physical or social activities to promote specific educational or therapeutic outcomes. However, much can also be learned by leveraging a robot's unique ability to objectively deliver stimuli in a consistent, repeatable way and record child-robot interactions that may be indicative of developmental ability and autism severity in this population. In this study, we elicited affective responses with an emotion-simulating robot and recorded child-robot interactions and child-other interactions during robot emotion states. This research makes two key contributions. First, we analyzed child-robot interactions and affective responses to an emotion-simulating robot to explore differences between the responses of typically developing children and children with Autism Spectrum Disorder (ASD). Next, we characterized play and affective responsivity and its connection to severity of autism symptoms using the Autism Diagnostic Observation Schedule (ADOS) calibrated severity scores. This preliminary work delivers a novel and robust robot-enabled technique for (1) differentiating child-robot interactions of a group of very young children with ASD (*n=12)* from a group of typically developing children *(n=15)* and, (2) characterizing within-group differences in play and affective response that may be associated with symptoms of autism severity.**

Keywords*— *Socially assistive robots; Affective robots; ASD; Autism; Developmental ability; Mullen; ADOS

I. INTRODUCTION

Recent studies have explored the efficacy of employing robots for improving or augmenting traditional interventions for children with autism spectrum disorder (ASD) [1],[2]. Often, child-robot interactions are designed to target and improve specific deficits in social or communication skills over time through a series of structured or semi-structured activities. Much of this research has reported successful outcomes [3],[8],[10] in the form of increased adaptive behaviors. However, the potential for using robots to objectively elicit and record early behavioral manifestations of ASD, especially in very young children, has not been well studied.

Specific behavioral markers of autism including atypicalities in reactivity, social interest and affect, and delayed expressive and receptive language have been shown to be observable in children as young as 12 months [19]. Atypical response to the expression of fear and limited social orienting, joint attention, and attention to another's distress have also been reported in young children with autism [17],[18]. Further, response to emotional stimuli (affective response) is both early emerging and closely connected to the development of social and communicative ability [20],[21]. Our previous work explores the connection between affective response and developmental ability in typically developing (TD) children [5] and suggests that the ways in which children interact with an expressive robot may be indicative of their developmental ability. However, developing a child-robot interaction paradigm that is both viable and engaging for young children with autism presents as many opportunities as challenges.

Children with ASD are a diverse population, possessing a wide range of personal preferences, temperaments and skill. In this research, we accommodate a variety of preferred interaction styles and encourage spontaneous, child-directed play by eliciting responses to emotional stimuli in a supervised, free play setting. This paradigm affords self-expression for children of many skill levels by minimizing the amount of required facilitator-directed interaction. Nevertheless, free play scenarios involving young children and robots introduces a number pragmatic complexities.

Most robots are not designed to be dropped, thrown or kicked and can withstand only minimal physical manipulation. Further, data collection and analysis becomes increasingly complex as the frequency and variability of movement of study subjects increases. However, the opportunity to evaluate the validity of this novel child-robot interaction paradigm for identifying early emerging differences in this understudied population considerably outweighs these challenges.

In this study, we used an emotion-simulating robot to elicit play and affective responses from a group of preschool-aged children with ASD (with some children as young as 19 months of age). We captured data corresponding to child-robot play and video-recorded behavioral responses during the simulation of four emotions to evaluate: (1) the potential validity of employing an emotion-simulating robot to elicit play and affective response in a group of very young children with ASD, (2) between-group data to identify play and affective response patterns characteristic of the current study group with ASD compared to a previously studied TD group and, (3) within-group data to identify specific distinctions suggestive of autism severity. By analyzing characteristics of play with an expressive robot, we introduce a new perspective for learning about very young children with ASD and a new approach for potentially differentiating between this population and a group of typically developing children.

II. BACKGROUND

A. Robots for use in ASD studies

Structured and semi-structured interactions. Robots have been used as facilitators, mediators, coaches and tutors to improve motor imitation and turn-taking [6],[7],[8], social

Figure 1. Sphero the robot

interaction and communication [10],[11],[12] in children with ASD. Most interactive robot studies designed for children employ robots that are constrained to tables or pedestals or rely on structured interaction paradigms. In [6], the authors describe human-robot interactions in which a humanoid robot is situated on a table placed in front of the study subject and the robot and child engage in a series of motor imitation games. The research detailed in [8] features a less structured, but similar child-robot interaction design for engaging children in various activities. Other research includes a robot as a central component within a structured experimental space [12] to capture salient data pertaining to child-robot interactions and to afford the robot adaptability. Although it is often necessary for ensuring the safety of the children participating in the studies and for protecting the integrity of the robots with which they interact, directing and defining how children interact with a robot imposes considerable limitations on spontaneous play. Preserving opportunities for child-directed play is critical for eliciting natural early emerging social behaviors in very young children. This study is designed to maximize those opportunities.

Affective robot studies. Previous work with social and emotionally-expressive robots, highlights the considerable impact of affect expression on attention and ascription of intentionality during human-robot interactions [26],[27]. These studies report on research conducted with TD populations but may help elucidate potential key differences in behavioral response that may be elicited with a robot. Other work describes a distance-based measure for autonomously detecting and classifying positive versus negative robot interactions in a group of children with autism [28] and details individual differences in the reactivity of participants engaged in a child-robot interaction. Employing robots to deliver affective stimuli to learn more about the age at which socio-emotional differences may become observable in children with ASD offers many potential benefits [15],[38],[41].

B. Measuring affect response

Recognizing emotion effectively relies on the ability to discern facial, gestural and verbal expression, in oneself and in others, and to understand their social-contextual meaning [32],[33]. Observed affective responses are typically recorded via video and later manually coded using a variety of frequency measures including number of vocalizations, positive or negative facial affect, body postures and spatial proximity to an object or person of interest. Recently, automated techniques for detecting facial expression have been used to augment or replace the time-consuming process of manual video coding [24]. However, these tools are, as yet, not sufficiently robust for consistent and accurate affect detection in the general population, are less reliable for children, and are essentially ineffective for scenarios in which the individual is highly mobile. Additionally, compared to typically developing individuals, children with ASD tend to exhibit facial expressions differently [22] and use facial affect less frequently [23]. By identifying patterns of physical play that strongly correlate with observed affective response, this study delivers an additional measure for augmenting existing tools used in affect recognition and response detection.

C. Measuring developmental ability and autism severity

Many children with ASD have a higher frequency and more profound communication difficulties than their typically developing counterparts [13],[14]. Previous work establishes a link between verbal ability, responsiveness and social interaction in children with autism [29],[30],[31],[40] and the connection between social interaction and socioemotional ability [36]. These studies contribute to the fundamental motivation for this study.

One of the unique aspects of this work is the especially young age and early stage of development of the population studied. Much of the existing research conducted with interactive robots and young children with autism includes children 5 years of age and older [34],[35]. The distinct advantage of designing a free-play robot-interaction paradigm for very young children with a recent ASD diagnosis is the opportunity to collect early emerging behavioral differences in children who have received very little or no intervention. In so doing, we examine innate play and socioemotional processing less affected by typical interventions.

The Mullen Scales of Early Learning (MSEL) [25] is a widely used test of development for young children and was used in this study to explore the connection between play and affective response and development. The MSEL is a developmentally integrated behavioral assessment evaluating verbal and nonverbal developmental skills including (1) Visual Reception, (2) Fine Motor, (3) Expressive Language, and (4) Receptive Language. The Autism Diagnostic Observation Schedule (ADOS) [37], a widely-used semi-structured observation instrument for measuring communication, social interaction and play in individuals suspected of having ASD, was also used in this study. The ADOS consists of four modules, each one appropriate for the expressive language level and chronological age of the individual being tested. A key outcome measure of the ADOS is the calibrated severity score, designed to allow the comparison of autism symptoms severity across modules [9].

Figure 2. Top: Typically developing children respond to the robot's angry state. Bottom: Children with ASD respond to the robot's angry state.

III. METHODOLOGY

This study explores a novel, robot-enabled approach for eliciting and characterizing play and affective response differences between a group of TD children and a group of children diagnosed with ASD. Four emotions were simulated with a robot using multimodal stimuli to elicit child-robot and child-other interactions. Physical interactions and behavioral responses to the robot were recorded to characterize how children played with the robot during each emotion and to compare with data previously recorded from a group of TD children. Additionally, we collected frequency metrics to identify within-group play and affective response differences potentially indicative of autism severity. These two aims contribute to the evaluation of the viability of the proposed method as a technique for exploring early play and affective response differences between a group of typically developing children from a group of children with ASD.

In [5], we describe observable disruptions to children's play and social behavior immediately following the robot's transition from a positive to a negative affective state. However, based on known affect recognition and response difficulties characteristic of many very young children with ASD, we expected results from the current study group to reflect considerable differences, especially during pivotal transitions from positively valenced affective states to negatively valenced states. It is important to note that the primary objective of this study was not to evaluate whether children with ASD recognized each emotion, but rather to characterize how they responded to the presentation of different emotional stimuli, and to evaluate if and how their responses differed from a typically developing group of children.

A. Robot

A non-anthropomorphic, commercially-available robot named Sphero (Fig. 1) was selected for this study. On board sensors include a three-axis accelerometer measuring relative linear position on the x-, y- and z-axes and a gyroscope measuring rotational velocity on the x-, y- and z-axes. The robot is sufficiently robust to withstand moderate physical play, can sense and collect acceleration and angular velocity autonomously and features an array of LED lights to deliver multimodal stimuli. The combined effect of multicolor flashing and fading LEDs, custom-produced music and movement collectively contributed to the overall conveyance of emotion, agency and intentionality.

B. Participants

Twelve children with ASD, all males, with a mean age of 2.5 years, were recruited for participation in this study. Mean MSEL nonverbal developmental quotient (NVDQ; see IV.C) for this group was 77.9 and mean MSEL verbal DQ was 61.5. Additionally, data for fifteen typically developing children, 9 males, with a mean age of 3.9 years, were included to conduct comparative analyses. Mean MSEL NVDQ and VDQ for the TD group were both 111.5. Chronological age, NVDQ, and VDQ were entered as covariates in all analyses to control for these between group differences.

C. Study protocol

The protocol for this study is comparable to the procedure used to collect data from a typically developing group. A brief description is summarized here.

Experiment room. Upon arrival, each child and their caregiver were led to the experiment room by a facilitator and the caregiver was asked to passively observe the session. Throughout the interaction, the facilitator refrained from touching or attributing affect to the robot and elicited feedback from the child. Acoustic cues for each emotion were broadcast through four speakers in the test room.

Simulated emotions. Emotion simulation of happy, angry, fearful and sad states consisted of specific colors, sounds and movement shown to be associated with each emotion. As described in [5], affective sounds were validated *a priori* using Likert Scale feedback for the collective effect of sound, color and movement stimuli from a preliminary test group. A happy state was presented with bright flashing colors, melodic music in a moderate-to-high register and a child's giggle. The angry state featured dull, moderately flashing red lights, abrupt movements with sharp directional changes and dissonant music. The fearful state was simulated with intense, flashing white lights, fast movement with erratic directional changes and sharply-pitched music with minimal variance. Finally, sadness was achieved with dull blue lights, the sound of a child crying and slow rocking back and forth.

Activities. The 10-minute session was divided into four activities, with each individual activity lasting approximately 2.5 minutes. Activity One was presented to introduce each of the robot's affective states and consisted of the robot autonomously cycling through two 15-second iterations of each

emotion. Activity Two aimed to encourage child-robot interactions and explore the impact of a contingency with positive reinforcement on child-robot interactions and affective behavioral response. To this end, Activity Two featured the robot following the child around the room via tele-operation and transitioning to a happy state when touched. In Activity Three, the robot autonomously transitioned to an angry state upon sensing movement, using negative feedback instead of the positive reinforcement featured in Activity Two. In this contingent scenario, we examined the impact of causality and a negatively valenced emotion on play and affect responsivity. Finally, Activity Four featured the contingent expression of two affective states: sadness and happiness. This last activity was included to promote imaginative play, a sense of robot agency and began with the robot moving away from the child and transitioning to a sad state. Each time the child touched it, the robot transitioned to a happy state. All four activities were presented in the same order to control for the cumulative effect of negative affect across participants.

IV. DATA COLLECTION

Four fundamental types of data were collected to aid in the analysis of each participant's 10-minute session.

A. Accelerometer and gyroscopic signals

Signal data from an onboard accelerometer and gyroscope were recorded at a rate of 15 frames per second (fps) to capture information relating to physical play with the robot. The 3-axis accelerometer was used to capture proper acceleration across the *x, y, z,* axes in units of meters per second per second (m/s^2) while the gyroscope measured the angular velocity along 3 axes in degrees per second (deg/s).

B. Video

Two video cameras and a microphone were used to record information pertaining to physical interactions with the robot and behavioral responses resulting from emotion elicitation. The video cameras were installed on opposite walls in order to capture child-robot interactions from multiple viewpoints.

C. Mullen Scales of Early Learning (MSEL)

To assess developmental ability, each child received MSEL [24] prior to their participation in the study. Further, to account for elapsed time between MSEL administration and study participation (up to 12 months prior), a developmental quotient (DQ) was calculated, consisting of each participant's age equivalency (AE_{MESL}) at the time MSEL scores were recorded, divided by their chronological age (CA_{MSEL}) at the time of participation, to compare inter-subject developmental ability (Eq.1). Age equivalence (AEN) was also computed based on the DQ and CA (Eq. 2).

$$DQ = (AE_{MESL}/CA_{MESL})\times 100 \quad (1)$$

$$AEN = (DQ \times CA_{CURRENT})/100 \quad (2)$$

To properly evaluate the significance of results presented in Section VI, it is important to distinguish these two measures. AEN reflected age equivalence, while DQ scores represented relative performance differences.

D. Autism Diagnostic Observation Schedule (ADOS)

The Autism Diagnostic Observation Schedule (ADOS) is a standardized evaluation of social interaction, communication, play, and imaginative materials use for individuals suspected of having ASD [37]. The observational schedule consists of four 30-minute modules, each for use with individuals with differing levels of expressive language. A calibrated severity score (Overall-CSS) is based on percentiles of raw totals corresponding to each ADOS classification and provides a measure of autism symptoms that is independent of age and language ability [9]. Further, calibrated Social Affect (SA-CSS) and Restricted and Repetitive Behaviors (RRB-CSS) domain scores were computed to provide a clearer picture of separable components along the ASD dimension [39]. Together, these measures provide access to clinical features more specific to ASD than to other developmental disorders.

V. DATA ANALYSIS

Data collected during each session was analyzed to (1) compare ASD and TD group child-robot interactions, affective responses and developmental ability during emotion simulations and, (2) assess within-group measures of play, and affective response to explore the potential connection to autism severity. We expected that the ASD group's play patterns would reveal less discrimination between emotion states and exhibit less affective response than the TD group.

A. Child-robot interactions

Interaction measures of physical play such as kicking, picking up and holding the robot when considered within the context of an emotion simulation can reveal significant information about a child's evaluation of the robot. For example, a negatively-valenced emotion may elicit more touching or holding of the robot if the child evaluates the robot from a sympathetic viewpoint, if the child does not interpret the stimuli as negative or does not attribute the emotion to the robot. Alternatively, if the negative emotion elicits a sense of frustration or fear, the child may disengage or act aggressively toward the robot. To assess the extent of these responses, we compared the following child-robot interactions observed from both groups, along with behavioral responses.

Ultimately, five play activities were included in Video Coding Schema I: (1) Push, (2) Pick up, (3) Kick, (4) Drop and (5) Hold. For each of the first four variables and for each emotion, frequencies for each activity were recorded. For the "hold" variable start and end times were recorded to compute the total time a child held the robot.

B. Affective responses

Behavioral responses to the robot's emotion states were also manually coded from each video recorded session. A second coding schema, Video Coding Schema II was used to identify the following affective responses: (1) Robot verbalizations, (2) Other verbalizations, (3) Look at facilitator or caregiver for reassurance (not when speaking to or responding to caregiver), (4) Point at the robot, (5) Comfort seeking (6) Refer to robot as he/she/him/her, (7) Imaginative Play, and two qualitative measures: (8) Overall enjoyment and (9) Activity level.

TABLE I. PEARSON CORRELATIONS OF PLAY AND DEVELOPMENTAL ABILITY. *INDICATES SIGNIFICANCE $p<0.05$, **INDICATES $p<0.01$, +INDICATES TREND

Developmental DQ Scales	Happy-ASD	Happy-TD	Angry-ASD	Angry-TD	Sad-ASD	Sad-TD
Nonverbal	--	--	**Pick up (-0.581)*** **Hold (-0.717)****	**Pick up (-0.730)**** **Hold (-0.594)***	**Kick (0.579)***	
Verbal	**Hold (-0.613)***	**Hold (-0.548)***	**Pick up (-0.803)**** **Hold (-0.676)***	**Pick up (-0.540)***	**Hold (-0.536)+** **Kick (0.591)***	**Hold (-0.616)***

C. Analytical plan

To carefully explore our hypothesis pertaining to play and affective response differences, we focused our between-group analyses on measures that were correlated with ability in the typically developing population. Two types of close interaction (picking up and holding), a more aggressive form of play (kicking), and two social behaviors indicative of affective response (caregiver referencing and comfort-seeking) were evaluated within the context of each emotion. Additionally, we extracted these same measures of play and affective response to compute within-group correspondences and evaluate the relationship of play to ASD severity scores.

VI. RESULTS

Video recorded data was analyzed to quantify play types and affective responses occurring during each emotion simulation to examine ASD and TD between-group differences. Additionally, within-group statistical correlations between play, affective response, developmental ability and calibrated autism severity scores were analyzed to further inform the connection between response to an emotion-simulating robot, developmental ability and autism severity scores. First, we present between-group results in Subsection A in which we statistically correlate play, affective response and developmental ability (Table I) and include a comparative analysis to further describe observed differences between the ASD and TD groups (Figures 3, 4). Next, we include within-group statistical associations of play, affective response and measures of autism severity (Table II) to explore relative differences between individuals in the ASD group in Subsection B. These included picking up, holding and kicking, and caregiver referencing and comfort-seeking, within the context of happy, angry and sad states.

A. Between-group analysis of play, affective response and developmental ability

Affective responses and play manually annotated from video were analyzed for each emotion (Table I) and several significant correlations resulted. Differences in behaviors between groups were calculated with group x sought comfort more often *($p<0.05$)* when the robot was happy compared to a sad state. Mean group play frequencies and emotion linear mixed models controlling for chronological age, NVDQ, and VDQ (Table II).

Happy. When the robot was happy, children in both groups picked up *($p<0.01$)* and held *($p<0.01$)* the robot more and referenced their caregiver more often *($p<0.01$)*. Additionally, children in both groups kicked the robot more *($p<0.05$)* and comfort-seeking was considerably greater in the ASD group compared to the TD group, particularly in the average amount of holding observed (*m*=7.7, *s=5.4* vs. *m=4.0, s=3.3*, respectively) (Figs. 3, 4). Interestingly, holding was also negatively associated with verbal ability, perhaps contributing to comparatively more holding instances in the ASD group.

TABLE II. BETWEEN-GROUP EFFECTS

	Omnibus test p-values		
Behavior	**Group**	**Emotion**	**Interaction**
Pickup	**<0.01****	**<0.01****	0.46
Hold	0.029*	**<0.01****	**<0.01****
Kick	0.31	0.035*	0.78
Look at Caregiver	0.66	**<0.01****	0.28
Pointing	0.51	0.41	0.22
Seeking Comfort	0.10+	0.10+	0.28

Sad. Conversely, the frequency of holding the robot, caregiver referencing and comfort-seeking during its sad state was significantly less overall for both groups than when it simulated happiness, suggesting some level of affect responsivity and disengagement or disinterest. Given that the sad state was simulated for approximately the same amount of time as the other emotions, this may suggest that sadness caused some participants to disengage from play with the robot. Compared to children with ASD, TD children generally held the robot more often *($p<0.001$)* when the robot was sad (TD: *m=2.08, s=1.93,* ASD: *m=0.92, s=1.38*) although holding the robot in the sad state was negatively associated with verbal ability in the TD group. In a related way, it is worth noting that the four ASD participants with the lowest developmental scores collectively accounted for almost every instance of holding during the robot's sad state (10 of 11).

Higher verbal ability corresponded to less robot contact overall during the sad state for both groups but the few recorded instances of kicking were found to be associated with greater verbal and nonverbal ability in the ASD group. Only two instances of kicking were observed for each group. Accordingly, the two ASD participants who were among the highest scorers for developmental ability accounted for the only two instances of kicking. This comparison may address a fundamental discrepancy within the study group. Individuals with ASD and higher MSEL scores differed from their ASD peers with lower MSEL scores through their responses to sadness who may not have attributed emotion to the robot, instead treating it like an inanimate toy.

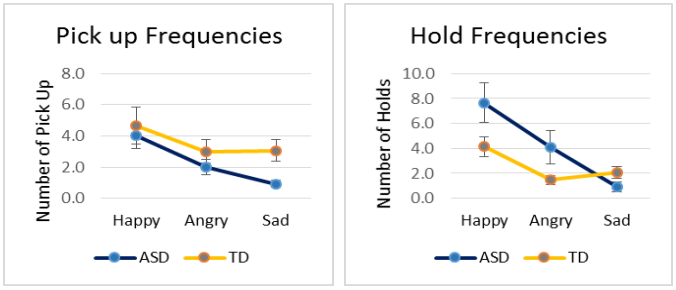

Figure 3. Average play frequencies for Pick up (left), Hold (right) by emotion for ASD, TD groups (±1SE)

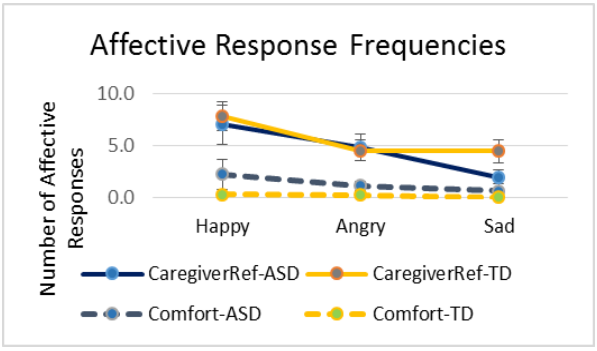

Figure 4. Affective response frequencies for ASD and TD groups

Angry. The angry state was also characterized by less interactive play, less caregiver referencing and less comfort-seeking compared to observations made during the happy state. Picking up the robot during anger was negatively correlated with both verbal and nonverbal ability in both study groups while holding the robot was associated with verbal and nonverbal ability for the ASD group, and nonverbal ability in the TD group. Since the robot had two conditions during which it transitioned from a neutral to an angry state: the first in which anger was simulated for 30 seconds without contingency and the second, during which the expression of anger was contingent upon child-initiated movement, it is possible that participants who did not recognize or enjoy the causal effect of their own actions did not find the robot as engaging. However, this may alternatively indicate that children with more developed socio-emotional ability may be averse to closely interacting with the robot during its angry state. This also suggests that children scoring higher on the MSEL may have attributed the negative affect to the robot and differentiated how they interacted with it based on this attribution more so than children with lower scores. Within-group holding frequencies during the angry state for ASD and TD groups were considerably different from each other (TD: *m=1.25, s=1.14,* ASD: *m=4.08, 4.54),* although the same results were not observed for picking up the robot, caregiver referencing or comfort-seeking. No significant between-group effects resulted for this emotion state.

Summary of between-group results. Contrary to our expectations, children with ASD showed a trend towards showing more comfort seeking behavior in general (TD: m=0.75, s=0.65, ASD: m=4.08, s=3.02; p=0.097). However, our findings provide additional evidence for the inverse relationship between developmental ability and physical play during the robot's simulation of happiness, anger and sadness. For both ASD and TD study groups, greater verbal and nonverbal developmental ability scores were negatively associated with picking up and holding the robot during these states and play frequencies further bolster this observation.

Evaluating these child-robot interactions, affective responses and their connection to developmental ability seems to indicate a compelling, emerging pattern. The initial and subsequent simulation of happiness, for many of the ASD and TD participants, elicited the most play with the robot and facilitated opportunities for interacting with the caregiver through visual referencing. With the introduction of negatively valenced emotions, individual differences in developmental ability seemed to contribute to a divergence in the group's play and affective responses. Developmental ability was significantly related to the amount of holding during each of the three emotions. Further, between-group effects also pointed to significant differences in the amount of holding during the robot's sad state (with the TD group generally holding the robot more) and more overall comfort-seeking in the ASD group. The relative developmental ability of participants seemed to contribute to how they evaluated the robot and consequently, how they interacted with it and their co-present caregiver. Significant differences could be attributed to a number of causes including: (1) the ASD group was not as perturbed by *recognized* negatively valenced emotions or, (2) the ASD group didn't attribute emotion to the robot. While validation of emotional stimuli was conducted *a priori* with a TD group, whether children with ASD assessed the robot's behavior as emotional was beyond the scope of this study. Developmental ability and autism severity are typically associated in the ASD population, thus correlations were also performed to assess within-group play and affective response related to autism severity domain scores.

B. Within-group analysis of play and affective response, suggestive of autism severity

We also computed pairwise correspondences between play and affective response and their relatedness to individual indicators of autism severity including social affect (SA-CSS), restricted and repetitive behaviors (RRB-CSS) and overall calibrated severity scores (Overall-CSS) (Table III). Correlations consistent with known communication difficulties for children with ASD resulted from our analyses as well as other less expected findings. For instance, greater anthropomorphism and verbalizations about the robot in both happy and angry states strongly correlated with developmental scores and negatively correlated with SA-CSS and Overall-CSS scores. This observation was expected since speech and mentalization are common deficits associated with autism.

The following results support other well-studied socio-emotional processing difficulties in children with ASD. Close, interactive play with the robot combined with less caregiver referencing during two particular emotions was significantly

TABLE III. PEARSON CORRELATIONS OF PLAY, AFFECTIVE RESPONSE, ADOS. *INDICATES SIGNIFICANCE $p<0.05$, **INDICATES $p<0.01$, +INDICATES TREND

ADOS Score	Happy	Sad	Angry	Fearful
SA-CSS_Severity	Verbalization-robot (-0.548)+ Verbalization-other (-0.585)*	Hold (0.593)*	--	Hold (0.639)*
RRB-CSS_Severity	Anthropomorphism (-0.608)*	Hold (0.504)+	Pick up (0.602)*	--
Overall-CSS Severity	Verbalization-robot (-0.686)* Anthropomorphism (-0.639)*	Hold (0.669)* Comfort (-0.695)*	Comfort (-0.616)*	Hold (0.556)+ Comfort (-0.673)*

associated with autism severity across the three ADOS indices evaluated. These differences are again especially apparent during the simulation of both anger and sadness.

Angry. Picking up the robot when it simulated anger was significantly correlated to greater severity in the RRB-CSS domain and evaluation of frequencies across participants reveals that the six individuals with the greatest RRB-CSS scores accounted for 16 out of the 24 total group instances (*m=2.67, s=1.37*). For comparison, the six participants with the lowest severity scores accounted for only 6 of the pick up events observed (*m=1.33, s=1.75*). For the duration of Activity Two, the robot transitioned to an angry state only when the child physically moved the robot. While many participants seemed to find the robot's angry simulation to be unpleasant and disengaged from play with it, others repeatedly engaged it. The significance of this correlation may suggest that children more severely affected by autism did not assess the robot's state as "angry" or unpleasant and instead enjoyed the causality of their engagement and the robot's response.

Sad. Greater SA-CSS and Overall-CSS severity scores were also positively correlated to holding the robot more frequently during the sad state. A detailed examination of this result in the context of frequencies reported in IV.A supports the idea that play and affective response may be associated with the severity score of ASD participants. The four participants who most frequently engaged in holding the robot during the simulation of sadness (10 of 11 instances, *m=2.5, s=1.29*) also had the highest severity scores. Further differentiating this subgroup from the other ASD individuals who held the robot during the sad state, the four individuals who accounted for the most holding, collectively only engaged in 1 instance of comfort-seeking compared to 7 instances among the remaining 8 participants. Moreover, these observations differ from the TD group. The number of holding instances in the TD group was accompanied by twice as many caregiver references whereas the five participants with the greatest severity scores in the ASD group had 10% fewer instances of caregiver referencing during the simulation of sadness. This is a particularly compelling finding supported by results from this study and is consistent with known difficulties in emotion recognition, recovery and response in children with ASD.

All. A negative correlation was also found between Overall-CSS severity scores and comfort-seeking behaviors during the simulation of all emotions. Out of a total of 49 comfort- seeking behaviors observed in the ASD group only 1 was reported for the four most severely affected participants. For comparison, the most severely affected participant accounted for the single comfort-seeking event while the participant with the lowest severity score accounted for 25. These differences support the important potential connection between response elicited by an affective robot and ASD severity scores.

VII. CONCLUSIONS

Leveraging the unique qualities of robust, simple robots to deliver affective stimuli in an objective way provides potential opportunities to augment our understanding of characteristic differences between very young typically developing children and children with ASD. This study contributes evidence supporting the potential validity of employing an emotion-simulating robot to elicit play and affective response across a broad and diverse population. While preliminary, this work describes differing patterns of play and affective response characteristic of interactions observed in an ASD study group and a previously studied TD group. This study included a small sample size, with a moderately-sized feature space and results may not be representative of the larger population. However, many correspondences remain significant even after Holm-Bonferroni adjustment for multiple comparisons. The current analyses also did not control for cognitive and verbal ability for within-group correlations.

We present a focused analysis of play and response describing within-group differences associated with severity of autism symptoms. Frequency changes of close, interactive play with the robot and caregiver-directed affective response, particularly between the robot's happy state and its angry and sad states, are an important and recurring theme observed in both groups studied. Comparative analyses of the ASD and TD study data, resulted in distinct characterizations of play and response that differed between groups. Examination of responses and ADOS scores in children with ASD also suggested that ASD severity may influence the magnitude of play and affective response differences observed between the two groups. Indeed, analyses presented is this work are consistent with existing studies on early behavioral differences in socio-emotional processing in children with ASD and support the potential viability of robots as a screening tool.

Eliciting and differentiating play and affective response patterns elicited with an emotional robot contributes to improved techniques for early ASD screening. A validated predictive model will potentially offer many additional benefits. Therefore, future work will analyze the impact of each stimuli independently to examine the individual role of sound, motion and color on affective response, include continued data collection and the development and validation of a probabilistic classification model trained using a larger set of data collected from TD and ASD groups of children.

VIII. ACKNOWLEDGMENTS

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REFERENCES

[1] Cabibihan, John-John and Javed, Hifza and Ang Jr, Marcelo and Aljunied, Sharifah, Mariam. "Why robots? A survey on the roles and benefits of social robots in the therapy of children with autism." International Journal of Social Robotics, vol. 5(4), pp. 593-618, 2013.

[2] Ricks, Daniel J. and Mark B. Colton. "Trends and considerations in robot-assisted autism therapy." IEEE International Conference on Robotics and Automation (ICRA), pp. 4354-4359, 2010.

[3] Greczek, Jillian and Amin Atrash, and Maja Matarić. "A computational model of graded cueing: Robots encouraging behavior change." HCI International 2013-Posters' Extended Abstracts. 582-586, 2013.

[4] Scassellati, Brian and Admoni, Henny, Matarić, Maja. "Robots for use in autism research."Annual Rev of Biomedical Eng. 14, pp. 275-294, 2012.

[5] Boccanfuso, Laura and Kim, Elizabeth S., and Snider, James C., Wang, Quan and Wall, Carla A., et al. "Autonomously detecting interaction with an affective robot to explore connection to developmental ability." Affective Computing and Intelligent Interaction, 2015.

[6] Ranatunga, Isura and Beltran, Monica and Torres, Nahum A and Bugnariu, Nicoleta and Patterson, Rita M and Garver, Carolyn and Popa, Dan O. "Human-Robot Upper Body Gesture Imitation Analysis for Autism Spectrum Disorders." Social Robotics, pp. 218-228, 2013.

[7] Srinivasan, Sudha M.. and Lynch, Kathleen A. and Bubela, Deborah J. and Gifford, Timothy D. and Bhat, Anjana N.. "Effect of interactions between a child and a robot on the imitation and praxis performance of typically developing children and a child with autism: A preliminary study." Perceptual and Motor Skills: vol. 116, pp. 885-904, 2013.

[8] Robins, Ben and Dautenhahn, Kerstin, Dickerson, Paul. "From isolation to communication: a case study evaluation of robot assisted play for children with autism with a minimally expressive humanoid robot." Int'l Conf. on Adv. in Computer-Human Interactions. pp. 205-211, 2009.

[9] Gotham, K. and Pickles, A. and Lord C. "Standardizing ADOS scores for a measure of severity in autism spectrum disorders." Journal of Autism and Developmental Disorders. (39), pp. 693–705, 2009.

[10] Feil-Seifer, David, and Mataric, Maja. "Robot-assisted therapy for children with autism spectrum disorders." Proceedings of the 7th International Conference on Interaction Design and Children. 2008.

[11] Boccanfuso, Laura, and O'Kane, Jason M.. "CHARLIE: An adaptive robot design with hand and face tracking for use in autism therapy." International Journal of Social Robotics 3(4). 337-347, 2011.

[12] Bekele, Ephrem T. and Lahiri, Uttama and Swanson, Amy R and Crittendon, Julie and Warren, Zachary E. and Sarkar, Nilanjan. "A step towards developing adaptive robot-mediated intervention architecture (ARIA) for children with autism." Neural Systems and Rehabilitation Engineering 21(2), pp. 289-299, 2013.

[13] Geurts, HM, Embrechts, M., "Language Profiles in ASD, SLI, and ADHD," Journal of Autism & Dev. Disorders 38(10),pp. 1931-43, 2008.

[14] Mitchell, Shelley, Brian, Jessica, Zwaigenbaum, Lonnie, Roberts, W., Zatmari, P., Smith, I., et al. "Early Language and Communication Development of Infants Later Diagnosed with Autism Spectrum Disorder." Jour. of Dev. & Beh. Pediatrics, 27(2), pp. S69-S78, 2006.

[15] Scassellati, Brian. "How social robots will help us to diagnose, treat, and understand autism." Robotics Research, pp 552-563, 2007.

[16] Feil-Seifer D, Matarić Maja. "Defining socially assistive robotics". International Conference on Rehabilitative Robotics pp. 465–68, 2005.

[17] Dawson, Geraldine and Toth, Karen and Abbott, Robert and Osterling, Julie and Munson, Jeff and Estes, Annette et al. "Early social attention impairments in autism: social orienting, joint attention, and attention to distress." Developmental Psychology, 40(2), pp 271, 2004.

[18] Dawson, Geraldine and Webb, Sara. J. and Carver, Leslie and Panagiotides, Heracles and McPartland, James. "Young children with autism show atypical brain responses to fearful versus neutral facial expressions of emotion." Developmental Science, 7, pp 340–359, 2004.

[19] Zwaigenbaum, Lonnie and Bryson, Susan and Rogers, Tracey and Roberts, Wendy and Brian, Jessica and Szatmari, Peter. "Behavioral manifestations of autism in the first year of life". Int'l Jour. of Developmental Neuroscience, 23(2–3), pp 143-152, 2005.

[20] Campos, Joseph J. and Campos, Rosemary G. and Barrett, Karen C. "Emergent themes in the study of emotional development and emotion regulation." Developmental Psychology 1989; 25(3): 394.

[21] Fasel, Ian, Deak, GO, Triesch, J., Movellan, J., "Combining embodied models and empirical research for understanding the development of shared attention," Development & Learning. pp 21-27, 2002.

[22] Faso, Daniel J., Sasson, Noah J., Pinkham, Amy E. "Evaluating Posed and Evoked Facial Expressions of Emotion from Adults with Autism Spectrum Disorder." Journal of Autism and Dev. Dis., pp 75-89, 2015.

[23] Gordon, Iris, Pierce, Matthew D, Bartlett, Marian S. and Tanaka, James W. "Training Facial Expression Production in Children on the Autism Spectrum". Jour. of Aut. & Dev. Dis.. pp. 2486-2498, 2014.

[24] Liu, Changchun and Conn, Karla and Sarkar, Nilanjan and Stone, Wendy. "Online affect detection and robot behavior adaptation for intervention of children with autism." Robotics, 24(4), 883-896, 2008.

[25] Mullen, E.M. Mullen Scales of Early Learning. Cranston, R.I.: T.O.T.A.L. Child. 1995.

[26] Nakata, Toru and Tomomasa Sato, Taketoshi Mori, and Hiroshi Mizoguchi. "Expression of emotion and intention by robot body movement." International Conference on Autonomous Systems. 1998.

[27] Breazeal, Cynthia, and Rodney Brooks. "Robot emotion: A functional perspective." Who needs emotions, pp. 271-310, 2005.

[28] Feil-Seifer D, Matarić MJ. "Automated detection and classification of positive vs. negative robot interactions with children with autism using distance-based features." Human-Robot Interaction, pp. 323-330; 2011.

[29] Hauck, Margaret, Fein, Deborah, Waterhouse, Lynn, Feinstein, Carl. "Social initiations by autistic children to adults and other children." Journal of Autism and Dev. Disorders, 25(6), pp. 579-595, 1995.

[30] Sigman, Marian and Ruskin, Ellen. "Continuity and change in the social competence of children with autism, Downs syndrome, and developmental delays." Monographs of the society for research in child development, 64(1), pp. 109-113, 1999.

[31] Stone, Wendy L. and Caro-Martinez, Lourdes M. "Naturalistic observations of spontaneous communication in autistic children." Journal of Autism and Dev. Disorders, 20(4), pp. 437-453, 1990.

[32] Bauminger, Nirit. "The facilitation of social-emotional understanding and social interaction in high-functioning children with autism: Intervention outcomes." Journal of Autism and Developmental Disorders, 32(4), pp. 283-298, 2002.

[33] Buitelaar, J. K. and Van der Wees, M. and Swaab-Barneveld, H. and Van der Gaag, R. J. "Verbal memory and performance IQ predict theory of mind and emotion recognition ability in children with autism spectrum disorders and in psychiatric control children." Journal of Child Psychology and Psychiatry, 40, pp. 869–881, 1999.

[34] Duquette, Audrey, Michaud, François and Mercier, Henri. "Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism." Autonomous Robots 24(2), pp. 147-157, 2008.

[35] Robins, Ben and Dautenhahn, Kerstin and Te Boekhorst, R. and Billard, Aude. "Robotic assistants in therapy and education of children with autism: can a small humanoid robot help encourage social interaction skills?" Univ. Access in the Info. Soc. 4(2), p.105-120, 2005.

[36] Lopes, Paulo N. and Salovey, Peter and Côté, Stéphane and Beers, Michael and Petty, Richard E. "Emotion regulation abilities and the quality of social interaction." Emotion 5(1), pp. 113, 2005.

[37] Lord, Catherine, et al. "The Autism Diagnostic Observation Schedule—Generic: A standard measure of social and communication deficits associated with the spectrum of autism." Journal of Autism and Developmental Disorders 30(3), pp. 205-223, 2000.

[38] Mundy, P. "Joint attention and social-emotional approach behavior in children with autism." Dev. & Psychopathology, 7(01), pp 63–82, 2005.

[39] Hus, V, Gotham, K., & Lord, C. "Standardizing ADOS Domain Scores: Separating Severity of Social Affect and Restricted and Repetitive Behavior" Jour. of Autism & Dev. Disorders, 44(10), pp 2400–12, 2012.

[40] Klin, A. "Attributing social meaning to ambiguous visual stimuli in higher-functioning autism and Asperger syndrome: The social attribution task." Journal of Child Psych & Psychiatry, *41*(7), pp 831–846, 2000.

[41] Carter, E.J, Hyde, J. "Designing Autism Research for Maximum Impact." Human Factors in Computing Systems, pp 2801-2804, 2015.