Autonomously detecting interaction with an affective robot to explore connection to developmental ability

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***Abstract*—This research employs an expressive robot to elicit affective response in young children and explore correlations between autonomously-detected play, affective response and developmental ability. In this study, we introduce a new, affective interface that combines sound, color, movement and context to simulate the expression of emotions. Our approach exploits social contingencies to emphasize the importance of situational cues in the proper interpretation of affective state. We studied a group of young children at various ages and stages of cognitive development, to: (1) evaluate the efficacy of using captured motion data to autonomously detect physical patterns of play while interacting with a robot, (2) examine relationships between physical play patterns and observed affective response and, (3) explore associations between developmental ability and play or affective response. This pilot study demonstrates that aggregate patterns of physical interaction with a robot are distinguishable through autonomous data collection. Further, statistical analyses demonstrates that developmental ability may be directly related to how a child interacts with and responds to an affective robot.**

Keywords— Affective robots; Affective response; Non-humanoid robots; Child Development; Play.

I. INTRODUCTION

Free play is an important part of development [1]. It is considered by many to be the leading source of development during a child's preschool years [2]. Deploying technologies, like robots, in the context of natural play is especially attractive because it increases opportunities for conducting studies in diverse settings and across broad populations. Further, employing technology to capture information indicative of child development is advantageous because child responses can be elicited and data can be collected in an objective, repeatable way. However, few robots are robust enough to survive in natural, unstructured play scenarios with young children. Consequently, there are few existing studies describing interaction paradigms suitable for unstructured play with robots, and no studies, to our knowledge, that use autonomously-collected child-robot physical play to correlate a child's affective response with development.

Affect responsivity, or response to emotional stimuli, is early emerging in child development and intimately related to social and communicative ability [32],[33]. However, little is known about the age at which differences in affect responsivity become observable. Non-humanoid robots can enact simple social scenarios and elicit affective response without the added complexity of language, facial expression or body posture and may appeal to children even in very early stages of development. Further, recording *how* children interact with and respond to an emotion-simulating robot can provide critical insights into how robots might be employed to elucidate emerging developmental differences in children.

In this pilot study, we evaluate the utility of operating a robot in an unstructured play environment with young children, to (1) characterize physical interactions, (2) identify overt behaviors that indicate the child's affective response and (3) examine possible relationships between physical play, observed affective behaviors and developmental ability. Results from this research support the feasibility of this new interaction design for measuring emotion response and suggest that the presented paradigm is a promising framework for use with young children with a range of developmental ability.

II. BACKGROUND

A. Interaction Design

User design studies emphasize the value of designing a developmentally appropriate user interface for young children interacting with technologies [18],[19]. In recent studies, interface designs focus on actively including children during iterations of the planning and development process [20],[21]. The novel interaction model presented in this study delivers a

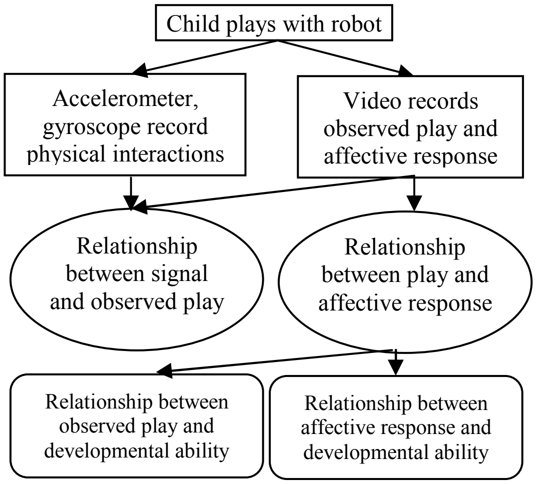

Figure 1. Child-robot interactions (row 1) provide accelerometer, gyroscopic and video observations (row 2), to analyze relationships between play, affective response and development (rows 3-4).

developmentally appropriate and engaging interface where feedback collected from children in preliminary trials informed iterative changes incorporated in the pilot study. Child-robot interactions are alternately promoted and discouraged through the expression of positively and negatively valenced emotions, delivered contingently to encourage engagement during each activity [33]. Nonlinguistic child vocalizations are also incorporated in each social scenario enactment to promote anthropomorphism of the robot [34] and to further explore how developmental ability contributes to overall child responsivity.

B. *Affective Response*

Human-computer studies, particularly those concerned with affective human-computer interaction (HCI) and human-robot interaction (HRI) studies, have explored the role of affect in natural interactions [14],[15],[16],[17]. The ability to accurately recognize a user's affective state in order to direct the course of interactions further advances the potential of robots to better assist their human counterparts [36]. Typical measures of emotional state have included vocalizations, facial expressions and body postures. However, accurately detecting affective expression in young children remains a challenge due to sometimes very subtle and inconsistent expression of emotion [30]. Thus, autonomously detecting play patterns correlated with observed affective responses may provide a more stable measure of affect recognition and response.

C. *Developmental Ability*

Studying how children respond to the elicitation of affect, within the natural context of free play, may also ultimately provide significant insight into how play activities are correlated with developmental ability [31]. Additionally, by capturing video of affective responses in young children engaged in free play, we can explore correlations between features of physical interactive play and other nonverbal cues with the recognition of emotion and developmental ability [32]. In so doing, we may further our understanding of affect recognition and emotion responsivity to different emotions in young children. Specifically, we aim to study how changes in interactive play, such as robot manipulation, parent referencing, engagement level and comfort-seeking behaviors, change depending on the emotion being simulated by the robot.

III. APPROACH

The objectives of this study are to (1) assess the feasibility of using autonomously-detected robot motion to detect child-robot interaction patterns during the robot's simulation of four emotions, (2) examine correlations between autonomously-detected patterns of play and observed affective response and, (3) evaluate correlations between patterns of physical play, affective response and developmental ability.

Figure 2 - Sphero the robot.

Figure 3 – Child engaged in free play with the robot (left). Child creating social story (right).

A. *Robot*

The robot used for this study is Sphero (Figure 2), a commercially-available, non-anthropomorphic robot with a three-axis accelerometer measuring relative linear position on the x-, y- and z-axes, a gyroscope measuring rotational velocity on the x-, y- and z-axes and LED lights. Robot selection was motivated by four primary considerations: (1) robustness, (2) ability to act as a multimodal stimulus (e.g., color and movement), (3) minimal cost, and (4) capability to autonomously sense acceleration and angular velocity. While exceptionally minimalistic, colorful lights, sounds and movements helped to convey emotion, agency and intentionality and contributed to the robot's entertainment value.

B. *Participants*

Consent was obtained from the caregivers of fifteen participants between 2 and 6 years of age (age_{mean}=3.3 yrs, males=9, $\text{NonverbalDQ}_{\text{mean}}$=45.54, $\text{VerbalDQ}_{\text{mean}}$=46.15). A wide age range was selected to ensure data were collected from children across a broad developmental spectrum. Prior to the study, each child received the Mullen Scales of Early Learning (MSEL) [35], an assessment of developmental ability. The MSEL is a developmentally integrated behavioral assessment evaluating verbal and nonverbal developmental skills. Five scales include: (1) Gross Motor, (2) Visual Reception, (3) Fine Motor, (4) Expressive Language, and (5) Receptive Language.

Since gross motor skills were not assessed for all participants, Gross Motor scores were excluded in the current analyses. Further, because some children received the Mullen up to 12 months prior to study participation, a developmental quotient (DQ), consisting of the their chronological age (CA_{MSEL}) at the time MSEL scores were recorded, divided by the child's age equivalency (AE_{MESL}) was calculated to compare the developmental ability of each child (Eq.1).

$$\text{DQ} = (\text{AE}_{\text{MESL}}/\text{CA}_{\text{MESL}})\times 100 \quad (1)$$

$$\text{AEN} = (\text{DQ} \times \text{CA}_{\text{CURRENT}})/100 \quad (2)$$

Finally, an age equivalent (AEN) was determined using the DQ score and the child's chronological age at the time of their participation (Eq.2). While AEN reflects age equivalence, DQ scores reveal *relative* performance differences.

C. *Simulating Four Emotions*

To simulate each affective state, a custom combination of three stimuli were implemented. First, a set of synthesized music was produced and light displays were developed based on the acoustic and visual properties previously shown to evoke or represent feelings of anger, happiness and fear [22],[23],[24],

[25],[26],[27]. Acoustic stimuli were validated via survey in which a Likert scale was administered to gauge the strength of all emotions for each piece of music. Second, non-linguistic vocalizations corresponding to each emotion state were added as augmentative sound cues. Finally, although the attribution of emotion to movement is not as well-developed in young children as it is in adults, we used motion artifacts believed to be indicative of emotion in the studied populations to inform movement for each affective state [28],[29].

The attribution of a particular emotion to each acoustic stimuli was validated via survey in which a Likert scale was used to indicate the strength of all four emotions for each sound. Further, preliminary testing with a small group of children was used to collect feedback for the combined effect of acoustic, light and movement properties. Features used to simulate each emotion are described below:

Happy. Bright, colorful lights with high intensity and slowly changing color. Melodic music with frequent, smooth changes in pitch in a moderate-to-high register and a child's giggle. Moderately fast movements and a curved path, mostly restricted to circles and s-shapes.

Fearful. High intensity, rapidly flashing white lights. Music is marked by a fast tempo, sharp pitch and minimal pitch variance. Fast movements, erratic direction changes with no pauses between directional shifts.

Angry. Dull, moderately fast flashing red lights. Loud, short-burst, low pitch music featuring sharp pitch variance and musical dissonance. Abrupt movements characterized by fast acceleration and deceleration, sharp directional changes and short pauses between directional shifts.

Sad. Dull, slowly flashing blue lights. A nonlinguistic audio cue, consisting of a young child crying was selected. Movement characterized by a slow rocking back and forth.

In addition to four emotions, the robot produced an “ouch” sound after detecting a collision, but only when not actively simulating an emotion. The “ouch” sound was omitted during emotion expressions in order to easily discern which emotion or vocalization contributed to a child’s affective response.

D. Study Protocol

A facilitator greeted each child and caregiver and led them to the experiment room. The experiment room was an 8x8 interaction space equipped with two video cameras, a microphone and four speakers, one mounted in each ceiling corner. The facilitator remained present for the 10-minute interaction to elicit feedback from the child and the caregiver was asked to be a passive observer. The child was not provided any instruction prior to the session. During the course of the interaction, the facilitator refrained from touching the robot and from using any terminology ascribing affect to the robot. A second facilitator remained behind a two-way mirror to tele-operate the robot for two of the four activities and to troubleshoot in the event of a malfunction. Each activity lasted approximately 2.5 minutes and all four activities were presented in the same order. Although activities were initially randomized in the preliminary protocol, early testing revealed children were quite sensitive to negatively valenced emotions, especially when presented consecutively. While most children recovered from one activity featuring negative affect (when followed by a positively valenced activity), a series of negatively valenced activities often led to complete disengagement. In order to conduct a full study and control for the cumulative effect of negative affect across participants, we alternated activities featuring negatively and positively valenced emotions and kept the order of activities consistent. A brief description of each activity is provided below.

1) Activity one. Introducing the robot

The first activity was used to introduce the robot's various sounds, colors and movements during the simulation of each emotion. The robot initially transitioned from idle to a happy state. Two cycles of the happy state were completed before the robot transitioned to an angry state. In this way, the robot autonomously cycled twice through each emotion, for a total of approximately 2.5 minutes. At the completion of Activity one, the robot returned to an idle state.

2) Activity Two. The robot wants to play

This second activity was actuated by a facilitator using the tele-operated mode. The robot elicited child interactions by following the child around the room and simulating a happy state or playing a cheering sound when the child touched or picked it up (Figure 3). This activity lasted 2.5 minutes and encouraged the child to interact with the robot by delivering positive reinforcement via contingency and movement. Following 2.5 minutes, the robot assumed an idle state.

3) Activity three. The robot prefers to be alone

The third activity featured another contingency-based scenario. However, instead of using positive reinforcement, the robot simulated anger to discourage the child from touching or picking up the robot. Upon sensing movement, the robot autonomously transitioned to an angry state. Using this contingent scenario, we explored the role of causality and the impact of a negatively valenced emotion on responsivity to affective expression. Activity three lasted for three minutes after which the robot again returned to an idle state.

4) Activity four. The robot becomes happy when touched

At the outset of Activity Four, the robot moved away from the child and transitioned to a sad state. When the child touched or picked up the robot, the robot changed to a happy state. This final activity lasted 2.5 minutes and was designed to promote imaginative play and to convey a sense of intentionality and agency by delivering emotions within a contingency-based condition and simple social context (Fig 3).

IV. DATA COLLECTION AND ANALYSIS

Each child's 10-minute session with the robot was recorded using data captured by the robot’s 3-axis accelerometer and 3-axis gyroscope, as well as the room’s 2 video cameras and microphone. The accelerometer measured proper acceleration across three axes and in units of meters per second per second (m/s^2). The gyroscope measured angular velocity along three axes in degrees per second (deg/s). This technique produced six time-series signals per participant and per emotion (or 360 signals, total), each uniquely representing the acceleration or rotational velocity along a particular plane. Analyzing translation or rotation along individual plane(s) was key to characterizing play patterns since each simulation produced a unique signal defined by motion across a distinct set of axes. For consistency across experiments and for ease of analysis, signal data were down-sampled to 3 samples per second (sps).

Video cameras in the interaction space were positioned at opposite ends of the room to capture interaction from a forward-facing viewpoint. Because the duration of each simulated emotion varied during contingency-based activities and Activity One was primarily intended to allow the child to acclimate to the robot's sounds, colors and movement, 30-40 second clips occurring after Activity One were selected to evaluate play activities for each emotion. If an uninterrupted 30-second segment was not available, a video clip corresponding to that emotion from Activity One was used.

A. Autonomously Detecting Play Patterns

Time-stamped data relating to the robot's active affective state, color, sound and activity were recorded to quantify the frequency and type of child-initiated physical play during each emotion and within different social contexts. The collective impact of these analyses was the ability to identify the aggregate impact of play activities observed via video on each input signal to ultimately be able to autonomously deduce how a child was interacting with the robot without requiring human observation. Video Coding Schema I (below) provides a detailed description of the types of child-robot interactions that were manually coded from collected videos.

Video Coding Schema (I) – Characterize physical play with robot during a 30-second emotion simulation. Five play activities were included in Video Coding Schema I: (1) Touch, (2) Pick up, (3) Kick, (4) Throw and (5) Hold. For each of the first four variables, a number corresponding to the frequency of that activity was recorded for each emotion segment. For the "hold" variable a start and end time were recorded to compute the total time a child held the robot.

First, each input signal was pre-processed with a low-pass Butterworth filter to reduce noise artifacts. Next, signals collected at higher sample rates were down sampled and four signal features were computed including, absolute mean peak amplitude (PA_{mean}), maximum peak amplitude (PA_{max}), peak frequency (PF) and root mean square error (RMSE). In order to compute RMSE, baseline values recorded during the unimpeded simulation of each of the four emotions were recorded *a priori* for subsequent comparison with each corresponding input signal. PA_{mean} and PA_{max} analyses were performed to examine potential correlations between signal features and high-impact play activities such as throwing and kicking and movement-restricting play such as holding. PF was computed to detect play activities that constrained or otherwise changed the frequency of robot-produced movement.

B. Correlating Patterns of Play to Affective Response

Specific measures of affective response including verbalizations, caregiver or facilitator referencing and caregiver or facilitator comfort-seeking were collected. To evaluate social play, imaginative social story production and vocalizations as well as measures of intentionality, anthropomorphism and agency were also coded. While Video Coding Schema I was developed to code child-robot play actions during a 30-second emotion simulation only, Video Coding Schema II was designed to quantify the frequencies of physical robot interactions, social play and affective responses over the entire session and is described below:

Video Coding Schema (II) – Characterize overall play activities, affective responses during 10-minute session. Thirteen play types were defined in this schema. Frequency metrics included: (1) Touch, (2) Pick up, (3) Kick, (4) Hold, (5) Verbalization about robot, (6) Other verbalization, (7) Look at the facilitator or caregiver, (8) Point at the robot, (9) Seek comfort from facilitator or caregiver, (10) Call the robot he/she/him/her, (11) Imaginative Play, and two qualitative measures: (12) Overall enjoyment and (13) Level of activity.

Interaction measures such as touching, kicking, picking up and holding the robot when analyzed in the context of an emotion simulation can reveal important information about a child's evaluation of a scenario. 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. Alternatively, if the negative emotion elicits a sense of frustration, anger or annoyance, the child may disengage or act aggressively toward the robot. To further explore these relationships, we compared robot-directed physical events (e.g., kicking) with social and communicative events (e.g., comfort seeking) from Video Coding Schema II.

C. Correlating Affective Response to Developmental Ability

Video-coded affective responses and scores from four MSEL scales were used to perform analyses correlating affect responsivity to developmental ability. Composite scores from these scales provided general characterizations of each child's developmental profile. Additionally, individual scale scores afforded a detailed analysis describing how developmental categories may influence intensity and/or nature of emotion-specific responsivity. We were particularly interested in examining possible correlations between a child's developmental abilities and differential affective responses to negatively- and positively-valenced emotions. Exploring changes in physical play immediately following transitions between valenced emotions were of particular interest, tapping into questions regarding hyposensitivity or hypersensitivity to emotional information. Beyond exploration of overall response to each emotion, our investigation presents a detailed analysis of the potentially selective relationships between observed emotions, affective responses, and developmental skills.

V. RESULTS

A. Signal-to-play.

The simulation of each emotion produced movements which varied in terms of acceleration, rotation and duration. We compared individual signal features from unimpeded simulations with input signals to identify deviations stemming from child-initiated interactions. While throwing strongly correlated with lower peak frequencies along the y-axis for accelerometer and gyroscopic values when the robot simulated

TABLE I – AGGREGATE SIGNAL-TO-PLAY CORRELATIONS FOR EACH EMOTION. DIRECTION OF EACH CORRELATION IS INDICATED IN PARENTHESES.

	Happy	Angry	Sad	Fearful
Touch	--	AX: RMSE(+0.69) GZ: PA_{mean}(+0.61) AZ: PA_{mean}(-0.62)	GX: PA_{mean}(-0.72)	--
Throw	AY:PF(-0.59) AX: PA_{mean}(+0.60) AZ: RMSE(-0.62) GX: PA_{mean}(-0.77) GY: PF(-0.63)	AY: PA_{mean}(-0.74) GX: PA_{max}(-0.79)	--	--
Pick up	AY: PA_{mean}(+0.66) GX: PA_{mean}(-0.61)	--	GY: RMSE(+0.66)	GZ: PA_{mean}(-0.62)
Kick	AZ: PA_{max}(+0.78)	GX: PA_{mean}(-0.60) GY: PA_{mean}(-0.72) GY: PA_{max}(+0.86) AZ: PA_{max}(+0.66)	--	--
Hold	AY: PA_{max}(+0.60) GX: PA_{mean}(-0.67)	AY: PA_{mean}(-0.90) GX: PA_{max}(+0.65)	GY: PA_{mean}(+0.60) GZ: PA_{mean}(+0.63)	AX: PA_{mean}(+0.87) AY: PA_{mean}(+0.61) AZ: PF(-0.80) GX: PF(-0.78) GY: PF(-0.75) GZ: PF(-0.73) GX: PA_{mean}(-0.82) GY: PA_{mean}(-0.65)

a happy state, throwing the robot during the simulation of anger was strongly associated with changes in mean amplitude along the accelerometer y-axis values.

A correlation matrix featuring 24 signal feature/signal pairs (4 signal features for each of 6 signals), for each emotion was computed. Out of 20 possible unique play action-emotion pairs, 13 play actions showed significant correlations with a distinct signal component (Table 1). There were no cases in which the correlated signal characteristics could not be used to disambiguate the play action-emotion pair. Seven play activities were not strongly correlated with a particular signal component during a specific emotion. One reason for the lack of correspondences may be the limited number of samples collected for a particular play activity during an emotion. For example, only one kicking instance was recorded compared to 85 instances of holding when the robot simulated sadness.

There were also very few instances of child-robot interactions during the robot's fearful state. The few examples that were collected of a child holding the robot during the fear state (which is characterized by fast, frequent movements and rotation) resulted in a strong correlation in every axis of signal data. However, the collected number of samples did not influence all correspondences. Although an almost equal number of samples were collected for touching the robot when it simulated anger and happiness, significant correlations were only determined for touching the robot when it simulated anger. This phenomenon may be due to the specific nature of movement related to the emotion and the degree to which the child's touch obstructed the robot's movements.

B. *Play-to-Affective Response.*

Analyses were also performed on video-coded data to determine if significant correlations existed between play activities with the robot and observable indicators of affective response (Table 2). We evaluated: (1) the relationship between anthropomorphizing the robot and specific play actions in each affective state, (2) the association between verbalizations and play activities, particularly during negatively valenced emotions, (3) the correlation between comfort-seeking behaviors and each negatively valenced emotion, and (4) the relationship between enjoyment and child-robot interactions.

A correlation matrix with play and affective response variables revealed that anthropomorphizing the robot was directly related to an increase in certain play actions, but not with others. For example, a significant positive correlation was found between increased robot anthropomorphizing and longer time spent holding the robot, irrespective of which emotion was being simulated. Further, referring to the robot as he/she/him or her was strongly correlated with caregiver referencing when the robot simulated a fearful or angry, but not a happy or sad state. These observations suggest that a child who anthropomorphizes the robot may engage in more physical interactions overall and may respond to certain negatively-valenced emotions by seeking additional caregiver support.

Similarly, greater verbalizations about the robot were correlated with greater caregiver referencing during angry, sad or fearful states. In the same respect, the number of times the child picked up the robot and the amount of time the child held it after the "ouch" sound cue was played, was positively correlated with the number of verbalizations about the robot. Alternatively, an increase in other verbalizations was positively correlated with increased touching during angry, fearful and pain states but also correlated with a greater incidence of kicking the robot when sad, angry and fearful. These relationships indicate that the number and nature of child verbalizations may vary based on the robot's affective state.

Other interesting relationships also emerged. Comfort-seeking behaviors, in the form of caregiver referencing and child-initiated physical contact with the caregiver, were directly related to the number and nature of physical interactions with the robot during negatively valenced emotions. In particular, the amount of time a child picked up or held the robot when it expressed anger or pain, was directly related to the number of times s/he sought reassurance during that state.

Finally, we evaluated the association between overall enjoyment and play activities during each emotion. In our study, the perceived level of overall enjoyment was strongly positively correlated with the amount of time the child held the robot when it simulated sadness and happiness but negatively associated with the number of times the child kicked the robot soon after it expressed pain. Overall, statistical variances in the child-initiated physical interactions with the robot suggested that play, verbalizations and comfort-seeking behaviors may be directly associated with the perceived agency of the robot.

C. *Play and Affective Response-to-Developmental Ability.*

Measures of developmental ability were also correlated to affective response in order to evaluate the strength of their relationship in the context of this study (Table 3). Two primary themes characterized the nature of the association between developmental ability and affective response. The first theme related to proactive behaviors often associated with sympathy.

The incidence of higher receptive language DQ scores was associated with a greater frequency of picking up the robot after

TABLE II. PEARSON CORRELATIONS OF AFFECTIVE RESPONSE TO CHILD-ROBOT INTERACTIONS. *INDICATES SIGNIFICANCE OF P<0.05, **INDICATES P<0.01.

Affective response	Happy	Sad	Angry	Fearful	Pain
Anthropomorphizing	Hold (0.606)*	Hold (0.572)*	Hold (0.599)* Caregiver Ref (0.869)**	Hold (0.577)* Caregiver Ref (0.749)**	--
Verbalization (robot)	--	Caregiver Ref (0.700)**	Caregiver Ref (0.871)**	Caregiver Ref (0.801)**	Pick up (0.550)* Hold (0.570)*
Comfort-seeking	--	--	Pick up (0.559)* Hold (0.548)*	--	Hold (0.538)*
Enjoyment	Hold (0.723)**	Hold (0.730)**	--	--	Kick (-0.628)*
Verbalization (not about robot)	--	Kick (0.853)**	Touch (0.731)** Kick (0.557)*	Touch (0.800)** Kick (0.633)*	Touch (0.749)**

TABLE III. PEARSON CORRELATIONS OF PLAY, AFFECTIVE RESPONSE TO DEVELOPMENTAL ABILITY. *INDICATES SIGNIFICANCE OF P<0.05, **INDICATES P<0.01.

Developmental Scale	Overall child enjoyment	Sad	Angry	Fearful	Pain
Recep. language	Enjoy-DQ (-0.638)*	Hold-DQ (-0.616)*, AEN(-0.574)*	Pick up-DQ (-0.591)*, Kick-AEN (-0.561)*	--	Pick up-DQ (0.631)*
Visual receptivity	--	Hold-AEN(-0.519)*	--	Touch-DQ (0.549)*	Touch-DQ (0.535)*
Fine motor	Enjoy-DQ (-0.639)*	Hold-AEN (-0.550)*	Pick up (-0.785)**	--	--
Nonverbal	Enjoy-DQ (-0.534)*	Hold-AEN(-0.553)*	Pick up-DQ (-0.730)**, Kick-AEN (-0.514)*	--	Kick-DQ (0.523)*
Verbal	Enjoy-DQ (-0.623)*	Hold-DQ (-0.616)*, AEN(-0.549)*	Pick up-DQ (-0.540)*, Kick-AEN (-0.544)*	--	Kick-DQ (0.542)*
Mental age	Enjoy-DQ (-0.607)*	Hold-DQ (-0.546)*, AEN(-0.556)*	Pick up (-0.681)**	--	Kick-DQ (0.562)*

"ouch" verbalizations. Similarly, higher visual reception and fine motor DQ scores were related to increased robot touching when it simulated fear or pain. Collectively, children who scored higher on the MSEL exhibited behaviors that may indicate sympathy or empathy for the robot during a negative affect other than anger or sadness.

Secondly, children with higher MSEL scores may have actively avoided interacting with the robot when it simulated certain negatively valenced emotions. More specifically, although fear and pain may have elicited a sense of sympathy, anger and crying may have elicited something quite different. Higher fine motor, rceceptive language, nonverbal, verbal and mental age DQ scores were all correlated to a lower incidence of picking up the robot when it was angry while lower expressive language, verbal and mental age AEN scores indicated a higher incidence of kicking the robot when in the angry state. Additionally, higher DQ scores for receptive language, verbal and mental age and higher AEN scores for visual reception, fine motor, receptive language, verbal, nonverbal and mental age scores were negatively associated with holding the robot when it was sad. These correspondences were anecdotally supported by children during the robot's angry and sad states when they made comments such as, "This isn't fun", "Ugh! Again?!" and "Can I go now?"

In general, higher MSEL scores tended to lead to less physical interaction or even complete disengagement from the robot when it simulated anger or sadness but elicited more contact when it simulated pain or fear. In the present study, 3 out of 4 emotions presented were considered to be negatively valenced. Consequently, we believe this may contribute to the negative correlation of enjoyment to higher MSEL scores.

VI. CONCLUSIONS

This research contributes to a broader understanding of affective response and the connection between play and developmental ability in young children by employing a novel interaction design with a non-humanoid robot. We examined the efficacy of a novel interaction design to autonomously collect data pertaining to characteristic patterns of play. Further, we presented a multi-modal interface in which four emotions are simulated through sound, color and movement to explore relationships between observed affective response and recorded patterns of interactive play. Finally, we conducted analyses of associations between distinguishable patterns of interactive play, affective response and developmental ability.

Analysis of captured accelerometer and gyroscopic signal data and corresponding videos confirms that characteristic patterns of play during unstructured interaction with a robot are identifiable through autonomous data collection. Results from our investigation also indicate some relationship between play activities, affective response and developmental ability.

Future investigations should leverage the insights gained through this study to address many additional, compelling research questions. In particular, applying the interaction design described here to a future study with other very young populations of children at risk for or diagnosed with developmental delays may inform new approaches for augmenting early detection techniques.

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