Feasibility of Using the Robot Sphero to Promote Perceptual-Motor Exploration in Infants

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***Abstract*—Infant-robot interaction has been increasingly gaining attention, yet, there are limited studies on the development of robot-assisted environments that promote perceptual-motor development in infants. This paper assesses the feasibility of operating a spherical mobile robot, Sphero, to engage infants in perceptual-motor exploration of an open area. Two case scenarios were considered. In the first case, Sphero was the only robot providing stimuli in the environment. In the second case, two additional robots provided stimuli along with Sphero. Pilot data from two infants were analyzed to extract information on their visual attention to and physical interaction with Sphero, as well as their motor actions. Overall, infants (i) expressed a preference to Sphero regardless of stimulation levels, and (ii) moved out of stationary postures in an effort to chase and approach Sphero. These preliminary findings provide support for the future implementation of Sphero in robot-assisted learning environments to promote perceptual-motor development in infants.**

***Index Terms*—socially assistive robots, rehabilitation, human-robot interaction, visual attention, motor development**

I. Introduction

Over the recent years, there has been an increasing interest in social and physical infant-robot interaction, for the learning opportunities robots may offer if introduced in the early stages of human development [1]–[14]. Robots assessed for use in infant motor interventions, in particular, include humanoid robots to encourage kicking movements in infants while sitting [5], robotic overhead mobile systems to promote spontaneous movements in infants in supine position [9], ride-on robots utilized as body transport devices by infants to increase their open-area mobility [6], [11], [12], and small mobile and humanoid robots used in combination with other technology, such as body transport devices and harness systems, to concurrently ease biomechanical constraints and engage infants in chasing games [10], [15]. The robot operation protocols across these studies vary, posing interesting questions regarding the most efficient utilization of robots in their interaction with infants and emphasizing the need for further examination.

The protocols in the studies where infant-robot social interaction is used as a means to promote motor ability varies in many levels; from the type of manual tasks performed by humanoid robots, to the motion patterns assigned to ground mobile robots. Additionally, the number of robots in the environment varies; in most studies, robots participated in activities with infants solo [1], [3], [5], [9], whereas only a few cases have concurrently utilized more than one robot in group activities with infants [10]. Our future work on robot-assisted environments for infant motor training gears toward the examination of different operation protocols and their effects on producing a variety of motor responses by infants.

In the pilot work discussed in this paper, we assess the feasibility of operating a different small mobile robot, Sphero (Sphero, Inc.), which will be later used as the primary agent participating in solo and group activities in our next study. Although a few studies examined the use of Sphero and other spherical mobile robots with very young children, the minimum age of participants reported was 12 months [16]–[19]. The work outlined in this paper provides insights on: (i) the potential for employing Sphero to elicit motor actions of infants that are in the process of motor milestone development (younger than 12 months of age), and (ii) the conditions under which the nature of interaction may differ (Sphero solo vs. in combination with other robots). Information from this study may lead to the potential application of this infant-robot interaction paradigm in motor interventions for infant populations with or at risk for motor delays.

II. Methods

A. Participants and Experimental Design

Two neurotypical female infants (11 and 8 months of age) participated in pilot activities with Sphero. Both infants had reached the typical developmental milestones for their age;

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they were able to sit and crawl but not walk independently. Sphero was operated in a single session for each infant to specifically assess the feasibility of this particular robot for our next study. Both infants participated in additional sessions in which other robots were operated (Sphero was not one of them), as part of a larger study. The Institutional Review Board of both institutions approved the experimental protocols, and caregivers provided written informed consent for their infant's participation and use of images for publication.

As previously mentioned, the main robot of interest here is Sphero. Sphero is a spherical toy robot with minimal sensing and communication capabilities, which is able to move with a maximum speed of approximately 7 ft/sec, depending on terrain. Sphero contains an IMU sensor consisting of a 3-axis accelerometer, a 3-axis gyroscope and a 3-axis magnetometer. Two additional robots with different motion capabilities had presence in the scene (to examine solo vs. group stimulation activities): a wheeled mobile toy robot (Dash™ Wonder Workshop) and a small humanoid robot (NAO™ Aldebaran Robotics). The wheeled robot is able to move with a maximum speed of approximately 3.3 ft/sec on level ground, and the humanoid can perform motor actions (e.g., sit, walk, move arms, etc.). All robots are capable of providing simultaneous motion, sound, and light stimuli, which can be perceived by infants at this age [20]. The robots were remotely controlled by a researcher using the dedicated APIs and SDKs for the robots, for the purpose of engaging the infants in motor actions (e.g., chasing, imitation, etc.). The wireless bidirectional communication between the robots and the remotes was established through Wifi and Bluetooth channels.

The robots' play actions were designed to trigger infant-robot interactions meant to elicit and assess infants' motor response in natural, play-type scenarios for approximately 3 minutes. The interaction space was a $10\times10\text{ft}^2$ area equipped with foam-padded equipment to ensure the infant's safety and comfort. Stimuli provided by the robots included random motion patterns, self-rotations, flashing lights and sounds. One researcher remained present in the area with the infant and the robot(s) throughout the activity. The researcher refrained from touching the robot(s) unless intervention was required in order to continue the activity (e.g., if robot was stuck, infant held the robot for prolonged periods of time, etc.) Infants' interaction was assessed in two case scenarios, in which the robot activation protocol was different (Fig. 1).

Case A. Sphero was the only robot providing stimulus during the activity. The other two robots remained in the interaction space inactivated. The participant in this case had experience with the other robots from previous sessions but not with Sphero.

Case B. All three robots provided stimuli at various time points during the activity, including periods of simultaneous stimulation by more than one robot. The participant in this case had no experience with any of the robots.

The selected scenarios allowed for the examination of infants' interaction with Sphero in the presence or absence of stimuli coming from other robots. This approach may provide some insights on the emergence of infants' actions toward Sphero in a multi-factorial environment, resembling a natural learning environment in which infants interact with various objects at the same time, and thus, by maintaining ecological validity [21], [22].

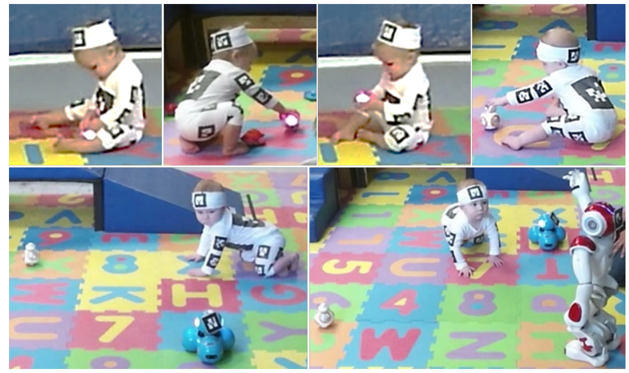

Fig. 1. Snapshots of infant physically interacting with Sphero while in sitting positions (top) and shifting visual attention between robots providing stimuli while being in an all fours position (bottom).

B. Data Collection and Analysis

The session was recorded (@15 frames/sec) via a network of five cameras placed around the environment (KINECT™ Microsoft). The data were acquired and integrated using the Robot Operating System (ROS). Video recordings were used for offline annotation and digitization analyses to extract information about the infant's attention to and physical interaction with the robots, as well as the infant's mobility throughout the activity. For the first type of analysis, variables of interest were annotated from the video recordings to quantify the infant's interest and interaction with the robots (Table I). The interrater reliability (overall agreement) between the two coders was

TABLE I
ANNOTATED VARIABLES AND DESCRIPTIONS

Interest in Robot
Visual Attention (Duration): Infant aligns head and eyes with each robot target or looks at the environment overall.
Robot Stimulus (Duration): Any robot in the environment provides at least one type of stimulus.
Physical Interaction with Robot
Touching (Frequency): Infant reaches for and touches robot with either hand.
Touching Attempt (Frequency): Infant reaches for robot with either hand but does not succeed. Either robot leaves before hand reaches target, or target is missed.
Holding (Frequency): Infant picks up and holds robot with one or both hands and explores its features.
Infant Mobility
Chasing (Frequency): Infant moves in direction of robot.
Chasing Attempt (Frequency): Infant initiates movement toward robot but eventually holds back.
Transitions (Frequency): Infant gets out of stationary positions (sitting, all fours) and starts moving.

91.1%. For the second analysis, the video recordings from the ceiling-mounted camera were used to track the location (Kinovea 0.9.5) of all play companions in the environment (infant and each robot) at every frame and obtain the x, y coordinates. The total distance the infant travelled in the 2D space as well as the distance between the infant and each robot were computed to describe how far the infant moved each time and in relation to the robots' motion.

III. Results

Overall, both infants looked at the robots for the majority of the time during the activity (Case A: 58.7%; Case B: 90.4%). In Case A, Sphero provided stimuli throughout the activity (lights were on/flashing and were combined with motion and sound in various instances). The infant expressed interest in the activated Sphero and did not look at the inactivated robots at all. Nevertheless, the infant was distracted several times by humans and/or the surroundings (especially toward the end of the activity). In case B, all robots alternated between states of providing stimuli and no stimuli. Dash provided the most stimulus for the infant, NAO the least, and Sphero intermediate. Simultaneous stimuli were provided by at least two robots for 69.0% of the time. The infant's visual attention was divided among the three robots, with minimal interest in the surroundings. Despite the extended and continuous stimuli provided by Dash, the infant in this case also seemed to exhibit preference to Sphero (Table II). Lastly, both infants interacted physically with the robots; in Case A the infant held Sphero multiple times, and in Case B the infant touched Dash but not Sphero (Table III).

Regarding mobility, the infant in Case A was the most active, covering a greater 2D area and completing twice the distance (Case A: 29.13m; Case B: 13.02m) of the other infant (Fig. 2). Yet, both infants performed motor actions during their interaction with Sphero, such as getting out of stationary positions in order to move toward the robot, and remaining in short distance from the robots for prolonged periods of time (Fig. 3). In Case A, the infant performed seven out of the eight sitting-to-crawling transitions and one all fours-to-crawling transition in order to approach Sphero. In Case B, the infant performed five out of the seven sitting-to-crawling transitions and one all fours-to-crawling transition to approach Sphero. Lastly, both infants readily chased the Sphero multiple times during the session (Table IV).

TABLE II
Visual Attention to Robots (% time)

	Case A			Case B		
Robot	Total Attent	Stim Given	Subtotal Attent	Total Attent	Stim Given	Subtotal Attent
Sphero	58.67	100.00	58.67	52.84	53.06	60.40
Dash	0.00	0.00	0.00	24.65	89.04	27.68
NAO	0.00	0.00	0.00	12.91	54.15	24.22
None	41.33	0.00	41.33	9.60	1.76	-

TABLE III
Physical Interaction With Robots (counts)

	Touch Attempts	Touches	Holds
Case A	0	0	6
Case B	1	1	0

TABLE IV
Infant Mobility (counts)

	Chase Attempts	Chases	Transitions out of	
			Sitting	All Fours
Case A	2	7	8	1
Case B	0	4	7	1

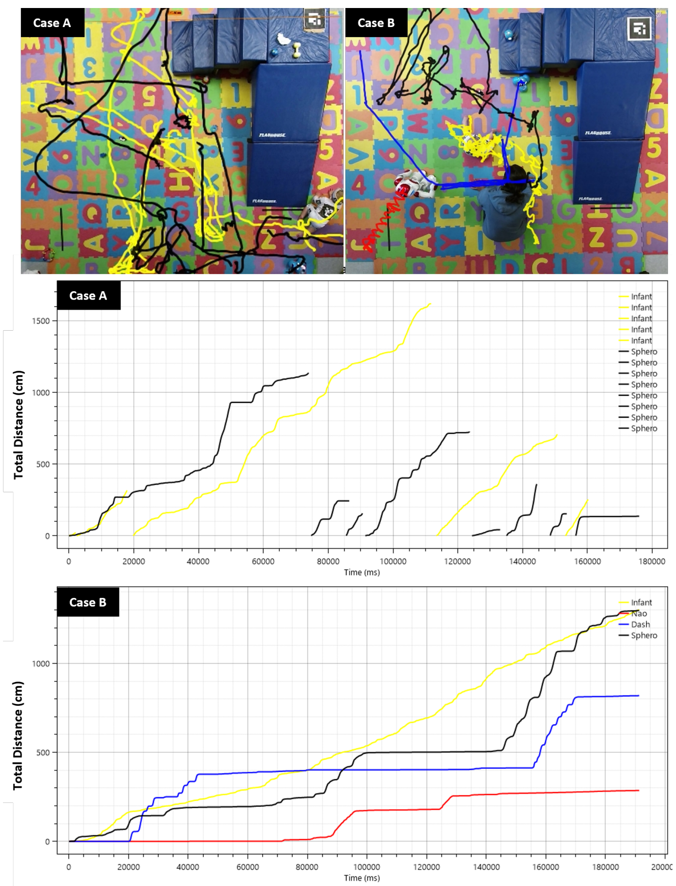

Fig. 2. Movement paths (top) and distance covered over time (middle, bottom) for the infant and robots in both case scenarios. Multiple trajectories (Case A, middle) indicate interruptions in the path analysis due to occlusions.

IV. Discussion

This paper provides feasibility data on operating the Sphero robot with infants and provides some insights on their interaction during participation in a complex, but ecologically-valid, perceptual-motor activity. More specifically, this work supports that neurotypical infants that are younger than 12 months old with no upright locomotor experience (i) are interested in and interact with Sphero, and (ii) move out of stationary postures in an effort to chase and approach Sphero.

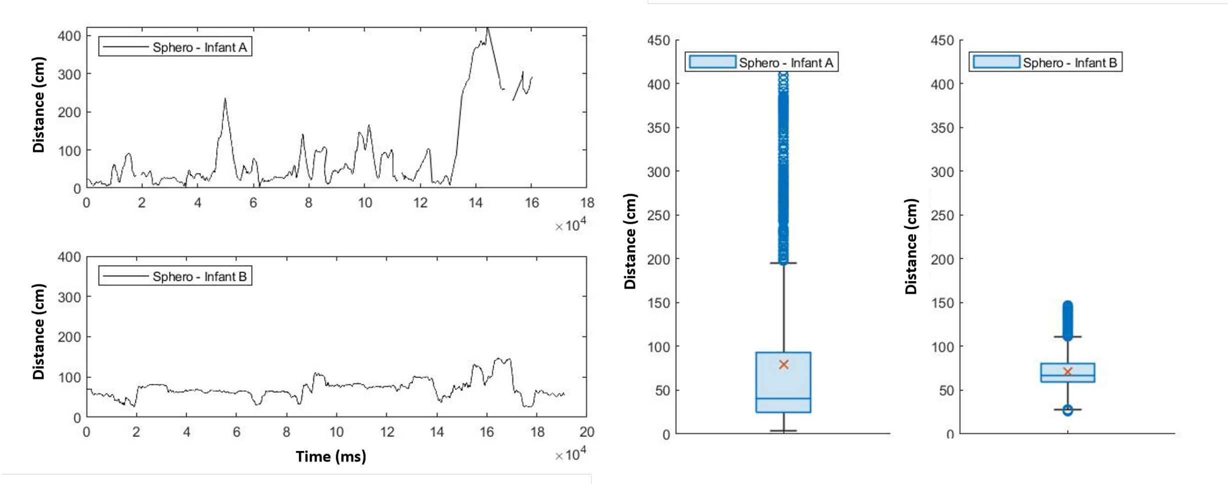

Fig. 3. Changes in proximity between each infant and Sphero over time (left) and box plots displaying the distribution of distance data in each case (right). Toward the end of the activity, the infant in Case A was distracted by the surroundings and was eager to move outside of the interaction area.

These findings are important as they lay the foundation for building infant-robot interaction environments and models that involve a single Sphero or combinations of robots including Sphero, which can be utilized in various pediatric applications. Although these preliminary results cannot answer central questions regarding infant-Sphero interaction this time, they provide some early evidence that motivates the establishment of new hypotheses regarding how mobility-centered infant-robot interaction can be established, maintained, and utilized for motor interventions in the future.

In the pilot sessions described in this paper, it was anticipated that pre-walking infants would be somewhat interested in, and interact with, a mobile robot (including Sphero). What was not anticipated was the preference in interest and level of interaction with Sphero when the latter was not the sole provider of playful stimuli to the infant, such as in our case where stimuli were provided from multiple heterogeneous sources (robots). It is also worth noting that both infants kept short distances from Sphero for the majority of the recorded activity. Close proximity levels have been suggested to be an important factor to efficient human-robot interactions [19], [23]; especially for crawling infants (i.e., like the participants in this paper) who generally display a tendency to interact with objects that are nearby [24], [25]. Whether the morphology/size of a particular robot, or the number of active robots in the environment can have an influence on the level of infant-robot social interaction is still an open question.

A number of limitations may warrant future consideration. Although the ecological nature of the experimental design is a strength, it did lead to infants having different opportunities for interaction (i.e., levels of stimulus given). Furthermore, no baseline condition was considered in which robots would be inactivated and/or regular toys would be given for comparison. Lastly, the amount of observations was small. Such limitations can impact the development of human-robot interaction models; thus, further large group studies are needed.

V. FUTURE WORK

In this pilot work, we observed infants socially and physically interacting with Sphero through chasing, touching, picking up, manipulating, and tossing it around. At the same time, multiple heterogeneous and decoupled stimulus sources offered signals or indications of increased total interaction with robots compared to a single source. Still, we do not know how long and in which way we can sustain the robot-infant interaction and re-engage infants after a period of inactivity. When we design infant-robot interaction paradigms, we need robots that keep different elements of the social interaction novel, interesting, dynamic, and challenging; highly agile robotic swarms have potential for such actions.

This is why our future work centers around an idea of enlisting Sphero robots in *coordinated* groups, and judiciously controlling their motion along agile maneuvers as a means of interacting with infants and in an effort to engage them in perceptual-motor activities. Such cooperative dynamic multi-robot control laws that generate swarm maneuvers which can trigger infant motor response are collective motion where the swarm slowly and "reluctantly" approaches the infant could be interpreted as a social gesture to "meet & greet"; one where the swarm follows or mirrors the movements of the infant could be perceived as a sign of interest or friendliness; a fast and coordinated direct approach along the line of sight is likely to be seen as aggressive. The significance of probing a human's personal space in a more systematic way has been previously reported in social robot interaction studies involving adults [23]; but not infants. The next step in our future work is to assess the feasibility of operating multiple Spheros with infants and examine various patterns of robot coordinated activity in an effort to maximize infants' perceptual-motor exploration.

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