Robottheory Fitness: GoBot's Engagement Edge for Spurring Physical Activity in Young Children

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***Abstract*— Children around the world are growing more sedentary over time, which leads to considerable accompanying wellness challenges. Pilot results from our research group have shown that robots may offer something different or better than other developmentally appropriate toys when it comes to motivating physical activity. However, the foundations of this work involved larger-group interactions in which it was difficult to tease apart potential causes of motion, or one-time sessions during which the impact of the robot may have been due to novelty. Accordingly, the work in this paper covers more controlled interactions focused on one robot and one child participant, in addition to considering interactions over longitudinal observation. We discuss the results of a deployment during which $N = 8$ participants interacted with our custom GoBot robot over two months of weekly sessions. Within each session, the child users experienced a teleoperated robot mode, a semi-autonomous robot mode, and a control condition during which the robot was present but inactive. Results showed that children tended to be more active when the robot was active and the teleoperated mode did not yield significantly different results than the semi-autonomous mode. These insights can guide future application of assistive robots in child motor interventions, in addition to informing how these robots can be equipped to assist busy human clinicians.**

I. INTRODUCTION

Physical activity is important for young children's overall health, including positive cognitive, social, and motor development [1]–[3]. At the same time, young children are not meeting the recommended guidelines of physical activity [4], a fact which is contributing to childhood obesity and other negative health outcomes. Many toys exist to assist children's walking, but few are self-propelled and designed to motivate young children to be active and explore the environment. Assistive robotics, the study of how social robots can support people in situations from health interventions to education [5], offers one potentially groundbreaking solution for addressing the sedentary behavior epidemic by motivating child movement and exploration. Specifically, research shows that robots can be more motivational and peer-like than other types of technology [6], [7], leading to positive outcomes such as our intended promotion of child physical activity. Toward the goal of encouraging young children to engage in physical activity and explore, we previously designed and built an assistive mobile robot with self-propulsion abilities and built-in toy-inspired features (i.e., lights, sounds, and bubbles) [8]. This new paper covers an evaluation of this robot with a larger number of users and over a longer timescale.

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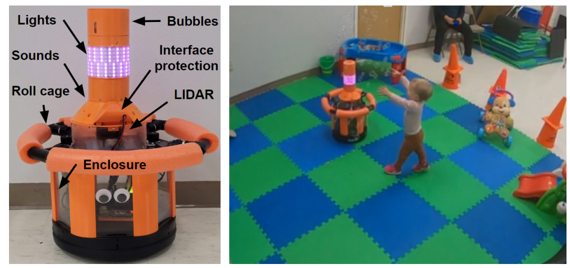

Fig. 1: *Left:* GoBot, our custom assistive robot. *Right:* GoBot deploying bubbles while interacting with a participant in the play space during a study session.

The key research goals behind this work were to assess *whether a mobile assistive robotic system can encourage movement by children with typical development and how this intervention's success changes over time.* As further covered in the related work in Section II, the physical embodiment and peer-like qualities of robots often set them apart in terms of how well they can support human health goals and outcomes. Nevertheless, few mobile robots have been tested in child motor interventions, and those that have typically been studied with few users and/or over short periods. Thus, this paper centers on sessions with GoBot, our custom assistive robot further detailed in Section III and shown in Fig. 1, which interacted with eight child participants over two months of child-robot interaction sessions. The methods of this longitudinal study are described in Section IV. The results in Section V demonstrate differences and similarities observed across the three studied conditions (i.e., control, teleoperated robot, and semi-autonomous robot), including a trend of greater incidence of the desired physical activity behaviors in cases with an active robot, as well as insights on whether direct teleoperation of a robot may be necessary in the envisioned robot-mediated motor interventions. We conclude in Section VI with recap of key results, discussion of main insights and important context for the work, and general conclusions. Key contributions of the work include empirical findings related to a relatively new domain for mobile assistive robotics, as well as presentation of a semi-autonomous control strategy that can match the performance of direct human teleoperation.

II. RELATED WORK

Related work in the promotion of physical activity, assistive robotics, and novelty in human-robot interaction informed our longitudinal study design.

Promoting Physical Activity: Multiple approaches have been developed with the goal of increasing physical activity levels for children. The "Let's Move!" program was developed with former First Lady Michelle Obama and focused on promoting physical activity for children, providing parents with tools for better food choices, and increasing awareness of the child obesity epidemic in the United States [9]. While the program showed some impact in terms of obesity rates for very young children, the overall prevalence of childhood obesity has not significantly diminished [10]. Technological solutions for encouraging physical activity include video games (e.g., Ring Fit Adventure [11]) and smartphone applications (e.g., the applications mentioned in [12]). These types of technologies have shown some efficacy in promoting physical activity, but require further longitudinal study to understand their influence beyond the point of novelty [12]. Assistive robots like GoBot may offer an engagement advantage compared to other tools for physical activity promotion due to people's tendency to view robots as more peer-like and influential than non-embodied technologies such as phones or computers [6]. We designed our robot to facilitate developmentally appropriate interactions, which we thought might effectively encourage child motion over repeated sessions.

Assistive Robots: Assistive robots for physical activity promotion have been mainly targeted toward older adults, with occasional instances of work focused on children. For example, Gorer et al. used a NAO robot as an exercise coach for older adults [13], and robots have supported rehabilitation activities for individuals after a stroke [14], [15]. In work for promoting child activity, assistive robots have shown initial promise for supporting the motor development of children with cerebral palsy [16] and autism spectrum disorder [17]. NAO and Dash robots were used in tandem in past work to encourage a child with Down syndrome to perform motor activities such as crawling up a ramp [18]. For more general child populations, the "Cratus" robot encouraged children to vigorously move the robot and themselves while playing a game in other related work [19]. Our own preliminary studies with GoBot showed that the robot could encourage standing and engagement while the robot was active [20]. The small sample sizes and short study durations of the past efforts warrant further longitudinal research; our present work aimed to address this gap.

Novelty in Human-Robot Interaction: Human interactions with a robot or other technologies for the first time often shows a novelty effect which changes after repeated interactions [21]. For example, users might become less interested in a technology as they habituate to it. Accordingly, it is imperative to perform longer-term empirical studies to understand the impact of robots, but most longitudinal studies to date have been with older adults [22] or in applications outside physical activity promotion, such as therapy [23] or education [24]. Sung et al. suggest that a minimum of two months is needed for a human-robot interaction study to move past the point of novelty and understand true robot efficacy [25]. Thus, we conducted our study over a two-month timeline to evaluate the long-term effects of GoBot in promoting physical activity for young children.

III. System Design

This section describes the GoBot robotic system and key operating mode information that is needed for understanding our study design and results.

A. Robotic System

The GoBot assistive robot used in this work was a custom robotic system designed in collaboration with the Oregon State Disability and Mobility Do-it-Yourself Co-Op. as shown in Fig. 1. The robot hardware centered on the TurtleBot2 platform, and the main software of the robot runs on a Raspberry Pi 4 using ROS Noetic on Ubuntu 20.04. We connected the Raspberry Pi to the robot's custom reward hardware stack, which had the ability to activate light, sound, and bubble rewards, using serial communication with a Pi Pico. The rewards, which are further discussed in our past work [8], [26], were activated manually by the operator on a PlayStation 4 controller that was connected to the robot via Bluetooth. The operator pressed the circle, square, or triangle buttons to activate individual rewards, or the 'X' button to activate all rewards simultaneously. The robot also had an onboard OLED-based user interface as an additional user input method and a foam-padded roll cage that softened any collisions between the robot and its environment.

Newly in this work, the Raspberry Pi was connected to an RPLIDAR-A1 LIDAR sensor for the environmental sensing and semi-autonomous adaptation discussed in the following subsection. A second modification from the previous iteration of GoBot hardware was the addition of a cover for the robot's onboard user interface and an enclosure around the TurtleBot base; these updates prevented children from deactivating the robot or reaching any system wires.

B. Robot Operating Modes

The GoBot operating modes were intended for use by individuals with some technical experience, but possibly little or no robotics experience, such as kinesiologists and clinicians. In the presented work GoBot operated in two different modes: *teleoperated* and *semi-autonomous*. The connection between these modes and the child-robot interaction study conditions is further explained in Section IV.

In the *teleoperated mode*, a human operator had full control of the robot's base motion and reward deployment via PlayStation 4 controller. The operator drove the robot in four different patterns (i.e., circle, square, X, and triangle) across the play area, with the goal of enticing the child to follow GoBot. Each reward was activated at least once per session, but otherwise, the operator freely combined rewards as deemed appropriate when the child was within one foot (30.5 cm) of the robot or more than two feet (61.0 cm) away from the robot.

In the *semi-autonomous mode*, GoBot followed a keep-away algorithm centered on the robotic system's onboard LIDAR sensing. As further detailed in Figure 2, the robot

```
KEEPAWAY()
while KEEPAWAYISACTIVE():
    lidarData = LIDARSCAN()
    objects = FINDNEARBYOBJECTS(lidarData)
    closestObj = FINDCLOSESTOBJECT(objects)
    if closestObj_position > 15.24cm
        MOVEROBOTFORWARD()
    elseif closestObj_angle < 150°
        SPINROBOTLEFT(180°)
    elseif closestObj_angle > 210°
        SPINROBOTRIGHT(180°)
    else
        MOVEROBOTFORWARD()
```

Fig. 2: Algorithm for the keep-away semi-autonomous mode, which attempts to detect and evade children in the play space, enticing them to move in pursuit of the robot.

used the LIDAR sensor and a tracking package [27] to identify and evade clusters of points likely to be objects. Specifically, the robot tracked the most nearby object, which presumably started out as the child based on beginning robot placement. Whenever this nearest object was within 0.5 feet (15.2 cm) of the robot, GoBot turned 180 degrees and moved away from this object, repeating the process for subsequent objects detected within 0.5 feet of GoBot. This mode was semi-autonomous, rather than fully autonomous, because a human operator still used the PlayStation controller to activate the robot's light, sound, and bubble rewards to entice the child to move toward the robot. The operator could also interrupt the autonomous base motion via the controller to reset the robot's position or to stop the robot's movement as needed.

IV. METHODS

To investigate GoBot's effect on child physical activity over time, we conducted a two-month-long child-robot interaction study. Our university ethics board approved this study under protocol #IRB-2020-0723.

A. Study Design

We conducted a within-subjects experiment to compare the effects of the following three conditions on promoting child movement during study sessions:

- *Control condition* (10 minutes per session): GoBot was present but not active in the play space.
- *Teleoperated condition* (Experimental condition 1; 5 minutes per session): GoBot was directly teleoperated by a research team member.
- *Semi-autonomous condition* (Experimental condition 2; 5 minutes per session): GoBot ran in the semi-autonomous mode, as fully described in Section III-B.

In all three conditions, the child was free to interact with an assortment of developmentally appropriate toys in the play space. A modified Latin squares method was used to balance the condition order.

To achieve a longitudinal view of participant experience, the study lasted over the course of two months. Participants attended eight weekly sessions, each of which involved a pre-specified order of the three conditions mentioned above. Overall, this design allowed for both assessment of the effects of investigated conditions and the study of how responses to the robot changed or persisted over time.

B. Participants

Eight participants (5 male, 3 female) completed the study. We recruited participants through local daycares and farmer's markets. Their ages ranged from 2.01 to 3.35 years old (M = 2.52 and SD = 0.50). All were typically developing, and one had previous experience with other robots.

C. Measures

We used a mixed-methods approach and collected two types of data during our study: *behavioral* and *self-reported*. Behavioral data included wearable sensor measurements and collected overhead video. Self-reported data consisted of parent responses to a survey during study sessions.

Behavioral measures: Accelerometer and gyroscope data was recorded at 100 Hz using three GT9X ActiGraph sensors, which the child wore on the wrist, ankle, and hip. A GoPro Hero Black 10 camera running at 30 Hz was used to record overhead footage. We also used a GoPro Hero Black 7 running at 30 Hz to record a side view of the play space.

Self-reported measures: The parents of study participants completed surveys about general and study-specific experiences with robots at the beginning of the study, after each session, and at the end of the study. In the *pre-study survey*, we used the Likert-type standard questions of the NARS (Negative Attitudes towards Robots Scale) [28] and the Trust Perception Scale-HRI [29] to gauge pre-existing participant perceptions of robots. Demographic questions captured information about participant age, gender, and development. Finally, free-response survey questions asked parents about experiences with robots and thoughts on robot usefulness. The *post-session survey* included questions about child engagement with the robot and perceptions of GoBot. Custom Likert-type questions in this survey asked the parent to rate child engagement with GoBot, general perception of GoBot, and belief in robot usefulness for child well-being on a 7-point scale from Strongly Disagree (1) to Strongly Agree (7). Parents also responded to free-response questions about perceptions of the robot and child interactions during the session. In the *post-study survey* the same NARS and trust perception questions were asked as in the pre-study survey. Free-response questions asked parents about perceptions of GoBot and child interactions with the robot, as well as ideas for system use and changes.

D. Procedure

Before beginning the study, parents provided informed consent. Next, before the first session began, parents completed the demographic survey and pre-study survey. For each play session, the child was outfitted with three ActiGraph sensors, which were placed on the right ankle, right wrist, and hip of the child. In each session, the three conditions (i.e.,

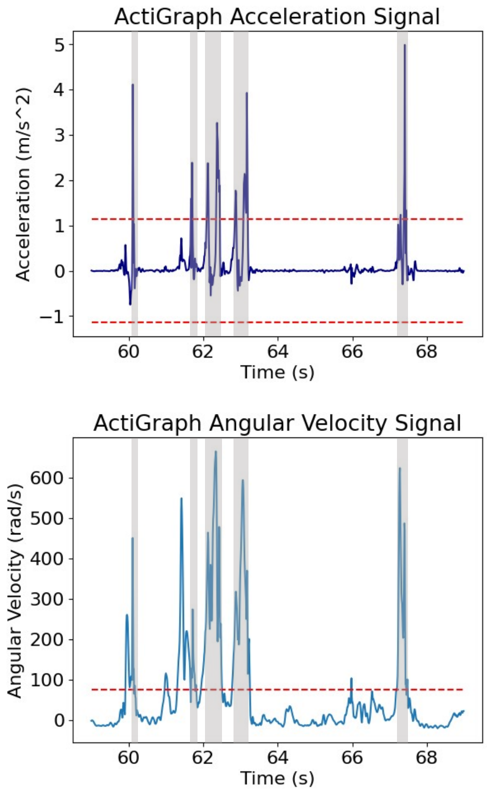

Fig. 3: Example ankle movement-identifying algorithm output over 10 seconds of one participant's ActiGraph data. Displayed values are the root mean square (RMS) minus the median. Red lines indicate participant-specific thresholds and gray boxes indicate ankle movement periods as determined by the algorithm (i.e., periods when both RMS readings exceeded the participant-specific thresholds). For the displayed data, the algorithm identified five movements.

control, teleoperated, and semi-autonomous) occurred in the pre-assigned order. At the close of a given session, the sensors were removed from the child and the parent completed the post-session survey. The full study lasted eight sessions. After completing the last session, parents completed the post-study survey.

E. Hypotheses

In this work, we tested three hypotheses:

- **H1:** The children will move more during the experimental conditions (i.e., teleoperated and semi-autonomous) when compared to the control condition. This idea is supported by past single-session work on robot-mediated physical activity promotion for children [19]; our efforts assess the same idea in a longer-term context.
- **H2:** Child physical activity levels will be similar between the two experimental conditions. This hypothesis is based on previous pilot sessions that implemented a simplified version of the teleoperated and semi-autonomous conditions, which both appeared to be promising for encouraging movement.
- **H3:** The effectiveness of the robot for motivating motion will decrease over time. This hypothesis is based on related work on the novelty effect (e.g., [21]), which typically shows a decline in interest in new technologies over the course of habituation.

F. Analysis

We analyzed the objective data from the ankle-mounted ActiGraph sensor and selected self-reported survey responses using the methods described below.

ActiGraph data: We first extracted the accelerometer and gyroscope data from the ActiGraph sensor using the *ActiLife* version 6.13.4 software. This data was evaluated for ankle movement counts using the algorithm presented in [30]. Based on this algorithm, we used each participant's raw ankle sensor recordings to calculate the root mean square (RMS) acceleration and angular velocity and identify instances when these values were outside the rejection range provided by the past related work. Figure 3 shows an example of ankle movements counted by the algorithm over 10 seconds of one participant's inertial data. We analyzed only the ankle sensor recordings since we were most interested in walking movement in the present study. To obtain a value comparable across conditions, we divided the ankle movement counts by the duration of the associated recording. A two-way repeated-measures analysis of variance (rANOVA) test was performed to test for significant differences between conditions and across sessions. The rANOVA used an $\alpha = 0.05$ significance level and were conducted using jamovi 2.3.18 [31], [32]. We used Tukey's HSD test for pairwise comparisons in the case of significant main effects. We report effect sizes using η^2, where $\eta^2 = 0.010$ is considered a small effect, $\eta^2 = 0.040$ is a medium effect, and $\eta^2 = 0.090$ is a large effect [33].

Survey responses: We used the survey data to understand engagement and well-being perceptions. These self-reports were collected only once per session and thus could not be used to compare across condition experiences; the mean and standard error of these ratings mainly helped to provide a rough understanding of perceived experiences.

V. Results

All participants successfully completed the full eight sessions of the study protocol. Data recording errors occurred for the ActiGraph data during two sessions (one session for each of two participants). The results for the ActiGraph and post-session survey data are presented below.

ActiGraph results: The distributions of ankle movements across conditions and over time are illustrated in Figs. 4 and 5. The results of the two-way rANOVA across conditions and sessions showed a significant main effect for conditions ($F(2,10) = 4.29$, $p = 0.045$, $\eta^2 = 0.028$). However, no pairwise differences were significant after post-hoc comparisons with Tukey's HSD. There was no significant main effect across sessions (p = 0.804). The average ankle motion rates were higher for both experimental conditions (compared to the control) for all sessions but one. Specifically, compared to the control, the ankle movement rates were higher for the

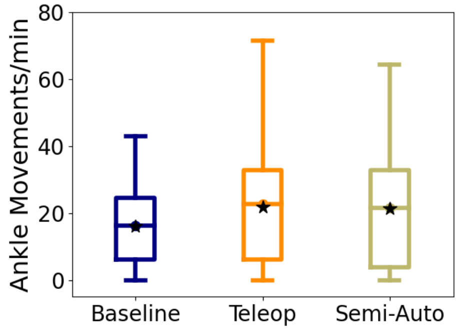

Fig. 4: Distributions of ankle movements per minute across conditions. Boxplots include boxes from the 25th to the 75th percentiles, center lines with a circle marker for medians, asterisks for means, whiskers up to 1.5 times the interquartile range.

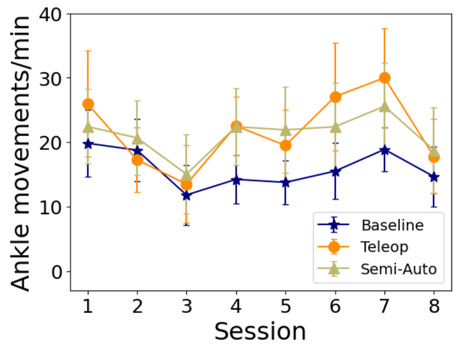

Fig. 5: Ankle movements per minute over study session. Markers show the mean and error bars show standard error.

teleoperated condition during seven sessions and were higher for the semi-autonomous condition during all eight sessions.

Survey results: Responses to the well-being and engagement questions from the post-session survey appear in Fig. 6. The data demonstrates the tendency for the mean well-being and engagement ratings to increase over time. The standard error values are small, which signifies a small spread in the ratings across the participant group.

VI. Discussion

The goal of this study was to explore children's responses to GoBot and GoBot's effectiveness for promoting physical activity in a longitudinal context.

The results of our study show some support of **H1**; GoBot tended to promote more physical movement in both teleoperation and semi-autonomous conditions compared to the control condition, although the associated pairwise differences were not significant after correction with Tukey's HSD test. The same robot influence trend appears across all study sessions; a longitudinal view of the data shows that only the result for one session's robot-mediated condition (teleoperated, for session 2) falls below the baseline motion levels. Parent free-response input supported the idea of the robot benefits. As one parent stated, "robots encourage [...] interaction [and] make children excited to play."

The results support **H2**. There was no significant difference between child responses to the teleoperated and semi-autonomous conditions. This result is promising because it implies that semi-autonomous robot behaviors, which are more feasible than direct teleoperation in intervention settings, can be equally effective as effort-intensive teleoperated behaviors. As one parent mentioned, this insight is useful since it could help to "keep children active even when [a parent] might not be able to entertain [their child]."

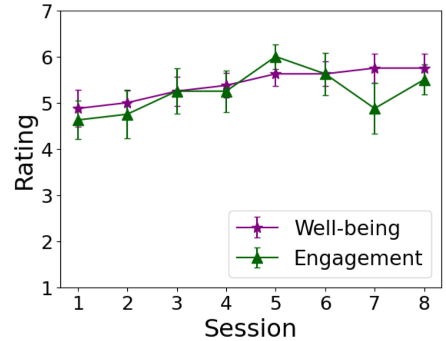

Fig. 6: Post-session parent ratings of GoBot usefulness for child well-being and child-GoBot engagement levels per session. The markers show the mean, and the error bars illustrate the standard error.

We were surprised to find that our study results did not support **H3**. Counter to our expectations, the child movement produced during experimental conditions remained almost uniformly higher than baseline motion levels during the full study, and parent ratings of robot promise tended to rise over time. This result is positive for future assistive robotics work for motivating child motion, since it supports the idea that platforms like GoBot may effectively promote healthy behaviors beyond the point of novelty.

Key strengths of this work include the relatively long-term nature of the work and the within-subjects design. These study design aspects help us to understand the influence of robot beyond the point of novelty and partially guard results from fluctuations that might arise from changing child affect. The testing of the system with young children is also unique in the assistive robotics space; even in work with children, it is unusual to find users below three years in age.

Limitations of this work include the small sample size, which is likely underpowered for revealing statistically significant results between conditions. We also faced challenges typical of work with young children, such as variations in mood during study sessions and stark differences in base interests across children. Further, the interaction times during the study (i.e., five- and ten-minute conditions) are relatively short. Future steps with a larger sample size, more sessions, and longer interactions could help to address all of these shortcomings.

In *conclusion*, in the presented work, we performed a two-month-long study evaluating two experimental conditions' and one baseline condition's effects on child motion. The results showed that robot intervention in the play sessions tended to yield more physical activity, although the study sample was too small to see a conclusive effect between conditions. The trend in responses persists for the relatively long two-month period of the study. Overall, this work shows the potential of assistive robots to influence child physical activity more effectively than other developmentally appropriate children's toys. Further, the similarity between results for the teleoperated and semi-autonomous conditions hints that users of this type of robotic system can save direct human effort and invest these resources in more enriching interaction efforts instead without a detriment to motor intervention success. Researchers of robotics and child motor interventions can benefit from this work.

Acknowledgments

We thank Tze-Hsuan Wang, April X. Murray, Eliora Olivares, and Lucas Yao for help with data collection and Lara Rupnawar for contributions to data analysis. This work is supported by funding from NSF award CMMI-2024950 and from the Caplan Foundation for Early Childhood.

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