Let Them Have Bubbles!
Filling Gaps in Toy-Like Behaviors for Child-Robot Interaction

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Abstract— **Robot-mediated interventions are one promising and novel approach for encouraging motor exploration in young children, but knowledge about the effectiveness of toy-like features for child-robot interaction is limited. We were interested in understanding the characteristics of current toys to inform the design of interactive abilities for assistive robots. This work first provides a systematic review of toy characteristics in *n* = 154 Fisher-Price products and then analyzes the effectiveness of common and uncommon toy-like behaviors from our custom assistive robot. Toy review results showed that light and sound features were significantly more common than bubbles, wheels, and self-propulsion. Exploratory play sessions with our assistive robot showed that bubbles were significantly more successful at encouraging child motion than other robot behaviors. Further, all studied robot behaviors demonstrated the capability to encourage child motion. The products of this work can inform the efforts of human-robot interaction and child development experts who study child mobility interventions.**

I. INTRODUCTION

Characteristics of children's playthings, from interactive lights and sounds to wheeled bases, can help to support early motor development [1], [2], [3], [4]. Relatedly, one new but growing area within assistive robotics promotes motor development of children via interactive systems [5], [6], [7]. As research on assistive robotics advances, it is worth formally investigating existing characteristics of toys intended for motor development and incorporating these features (as well as other experimental abilities) into intelligent robotic systems. Our central research goals in this work are thus to (1) systematically review features of current toys intended to support motor development and (2) examine the effects of common and uncommon robot-mediated toy features on child motion. Two core research topics–toy design and assistive robotics–inform our efforts.

Toy Design: Limited work has studied toy characteristics and their impacts on child motor development. One project studied how preschool children used modern toys to inform a framework for toy design which focused on matching the capabilities of the toy with intended play activity [8]. The authors of [9] propose three essential concepts in toy design: aimlessness, empathy, and play value. This work indicates that designing products with the goal of open-ended activity is difficult but greatly impacts a child's use of the toy. Abbott & Bartlett showed that having a variety of toys contributes to improved outcomes for child motor development [10]. Kudrowitz & Wallace developed the play pyramid as a method for corporations to classify toy concepts when designing new toys [11]. Our research goals align with the sensory axis of the play pyramid, which focuses on sensory features for engagement. To better understand what toy features leading toy design experts are already using in systems for motor play, we conducted a review of $n = 154$ toys from Fisher-Price, one of the largest toy vendors in the United States.

Assistive Robotics: Initial works applying assistive mobile robots in early motor interventions (i.e., for children preschool-aged and younger) show that NAO humanoid and Dash mobile robots can promote motion exploration in young children [12] and NAO robots can teach and reinforce kicking motions [13]. Both works used light, sound, and motion abilities to draw the attention of the child. Roball, a rolling robot, was designed to be a small mobile robotic toy that would encourage children to chase it [14]. In our own prior work [15], we designed a robot to promote early motor exploration in collaboration with child motion experts and conducted exploratory studies to evaluate child responses to the robot. Our custom assistive robot was designed to be more maneuverable and visible than past robotic playmates in the child-robot motor intervention space. The robot includes light, electronic sound, and bubble features, as well as a self-propelled mobile base, as shown in Fig. 1.

Present Work: In this paper, we review a representative set of existing toys for early childhood development and code videos from child-robot play sessions to understand how children respond to individual robot behaviors (interchangeably called "robot actions" for wording variety). In Section II, we discuss the toy review methods and results. Section III reports the play session methods, video coding strategies, and child responses. In Section IV, we discuss key conclusions and design implications for future robotic systems.

This paper offers two main contributions: 1) a novel and comprehensive insight into characteristics of commercial toys for young children and 2) preliminary findings of how young children respond to both toy-like and unique robot behaviors during exploratory play sessions.

II. TOY REVIEW

To design robots that have distinct abilities and potential benefits compared to current commercial toys, we need to understand features of existing toys and how well these

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Fig. 1: Robot interactions with children. *Left:* Robot using lights. *Center:* Robot using bubbles. *Right:* Robot using motion.

TABLE I: Percentages of Fisher-Price toy characteristics by age range. Bolding denotes feature inclusion in a majority of toys ($> 50\%$) while grayed entries have 0% presence. Note that percentages do not add to 100 because toys can possess multiple coded features.

	Count	Lights	Electronic Sounds	Mechanical Sounds	Bubbles	Wheels	Moves Itself
6-12 month	107	**60%**	**73%**	43%	0%	10%	3%
12-18 month	31	**68%**	**81%**	19%	0%	45%	0%
18-24 month	9	33%	44%	22%	0%	33%	0%
2+ year	3	33%	33%	0%	0%	33%	0%
3+ year	4	25%	25%	0%	0%	25%	25%

characteristics are represented across the commercial toy space. To accomplish this review, we analyzed toys in the Fisher-Price catalog [16] and categorized toy characteristics by age range and development tags.

A. Methods

Fisher-Price was chosen as the data source for this analysis because it is one of the most recognizable toy brands in the United States. Toys in the catalog are arranged by age range (e.g., 6-12 month).

Procedure: Using the Fisher Price website for data collection, we noted 494 total toys across the catalog-designated 6-12 month ($n = 162$), 12-18 month ($n = 94$), 18-24 month ($n = 31$), 2+ year ($n = 54$), and 3+ year ($n = 153$) age ranges. Duplicate toys ($n = 143$), and non-toys (e.g., booster seats; $n = 59$) were removed. Additionally, because we were primarily focused on toys that encourage developmental benefits similar to our assistive robot, we removed any remaining toys that did not include the Where Development Comes into Play™ designation ($n = 138$).

Measurement: The resulting set of 154 toys was systematically reviewed. For each of these toys, trained coders noted:

- the presence of lights, electronic sounds (i.e., sounds produced by speakers), mechanical sounds (i.e., sounds produced by physical toy components, such as crinkling, popping, and rattling), bubbles, wheels, and ability for the toy to move itself (i.e., using a motorized base).
- whether the toy was marked with the "Gross Motor" Where Development Comes into Play™ subtag, which helps to identify specific toys with intended motor development benefits similar to those of our proposed robotic system.

Analysis: Percentages were calculated to describe the proportion of toys with each coded feature. For both the full toy set and the set with the Gross Motor subtag, χ^2 tests of independence were conducted to assess significant differences in toy feature presence both across age groups and between two broader age range groupings (i.e., 6-18 months and 18+ months) which more closely parallel the two main child age ranges involved in our child-robot interaction work. A post hoc Bonferroni correction was performed for significant results.

B. Results

Counts and percentages of toy characteristics by age range are shown in Table I. Each increasing age range tended to include a decreasing number of toys marked with the Where Development Comes into Play™ tag. Light, electronic sound, and wheel features were represented in at least a subset of toys for all age ranges. These same features tended to be most present in the 12-18 month range and decrease in subsequent age ranges.

Results showed that light, electronic sound, and mechanical sound features were significantly more common than bubbles, wheels, and ability for the toy to move itself ($\chi^2(1, N = 894) = 244, p < .001$). Electronic sounds were also significantly more present in toys than mechanical sounds ($\chi^2(1, N = 308) = 39.4, p < .001$). No toys with the Where Development Comes into Play™ tag offered bubbles. Toys for 6- to 18-month-olds were significantly more likely to have light, electronic sound, and mechanical sound features than toys for the upper three age ranges ($\chi^2(1, N = 459) = 9.98, p = .002$). The presence of wheels did not differ significantly by age range.

We also reviewed characteristics for catalog items with the Gross Motor subtag ($n = 62$). Out of all 154 toys reviewed, 46% ($n = 49$) of the 107 toys in the 6-12 month, 39% ($n = 12$) of the 31 toys in the 12-18 month, 11% ($n = 1$) of the 9 toys in the 18-24 month, and 0% ($n = 0$) of the 3 and 4 toys in the 2+ and 3+ year age ranges, respectively, were marked with the Gross Motor subtag. Counts and percentages of toy characteristics by age range for the Gross Motor tag appear in Table II. Each increasing age range tended to include a decreasing number of toys marked with this subtag.

TABLE II: Percentages of toy characteristics under the Gross Motor subtag.

	Count	Lights	Electronic Sounds	Mechanical Sounds	Bubbles	Wheels	Moves Itself
6-12 month	49	**74%**	**76%**	**61%**	0%	23%	6%
12-18 month	12	**58%**	**75%**	33%	0%	**58%**	17%
18-24 month	1	0%	0%	0%	0%	**100%**	0%
2+ year	0	0%	0%	0%	0%	0%	0%
3+ year	0	0%	0%	0%	0%	0%	0%

Fig. 2: Views of the assistive robot and play environment. *Left:* Custom assistive robot base and interactive module. *Right:* Overhead view of a playgroup session.

Light, electronic sound, and mechanical sound features were significantly more common for toys with the Gross Motor subtag in the 6-12 month age range than all other age ranges ($\chi^2(1, N = 189) = 7.24, p = .007$).

C. Summary of Key Results

Across all age ranges, Fisher-Price toys were significantly more likely to have light, electronic sound, and mechanical sound features than any other investigated characteristic. Toys for 6- to 18-month-olds were more likely to have light, electronic sound, and mechanical sound features when compared to all other age ranges. None of the toys marked with the Where Development Comes into Play™ tag incorporated bubbles as a feature, and only four toys overall were capable of moving themselves. All but one toy marked with the Gross Motor subtag belonged to the 6- to 18-month-old age range. These Gross Motor toys included light, electronic sound, and mechanical sound features more than any other feature. We included both common toy features (e.g., lights and electronic sounds) as well as uncommon toy features (e.g., bubbles and self-propulsion) in our custom assistive robot. As discussed further in the next section, child responses to robot behaviors helped us to begin to assess whether uncommon features could encourage child motion more successfully than common features.

III. Child-Robot Play Sessions

We designed a custom mobile assistive robot with light, electronic sound, and bubble actions and conducted exploratory play sessions with children. These efforts helped us to better understand how common toy features (e.g., lights, sounds) compared to uncommon toy features (e.g., bubbles, base motion) for encouraging developmentally beneficial child motion. An earlier, non-archival version of this section was previously presented as a workshop paper [17].

A. Methods

We conducted three exploratory child-robot play sessions with the Oregon State University Social Mobility Lab under protocol #IRB-2019-0253. These particular sessions were selected as a starting place to investigate the robot because intended child users of the robot are developmentally beginning to play with peers; the study was grounded in this real-world context.

System Design: The custom assistive robot used in these sessions comprises a TurtleBot2 base running Ubuntu 18.04 on a Raspberry Pi 4 and an interactive module capable of supplying light, electronic sound, and bubble behaviors, as shown in Fig. 2. The module behaviors were designed in coordination with the Social Mobility Lab to provide a variety of developmentally appropriate interactive abilities. In particular, our robot includes behaviors that mix common and uncommon features of typical children's toys. A goal of the current robot design is to keep children's interest in the robot throughout repeated play sessions.

Participants: The playgroup included six children (1 male, 5 female) with typical development. Children were 1.6 to 6.7 years old (M = 3.6 and SD = 1.9).

Procedure: The play space included our robot and additional developmentally appropriate toys during each session, as shown in Fig. 2. During the three 30-minute play sessions, the robot was teleoperated by a researcher. This operator engaged with each child in the playgroup using each robot behavior (i.e., lights, electronic sounds, bubbles, and motion) at least once per child per session. We randomized the order in which children were approached. Spinning and combinations of actions also occurred occasionally at the operator's discretion.

Measurement: We recorded overhead video of play sessions for later coding.

Analysis: We used the ELAN annotation tool [18] to code video of each play session. Our codebook included: (1) robot behaviors (i.e., lights, electronic sounds, bubbles, motion, and spinning in place) and (2) robot behavior success, as defined by any child moving toward the robot up to two seconds following the robot action; it is reasonable to expect that if children move towards the robot immediately following a robot action, then the robot action is likely the reason for the approach behavior, but limitations of this assumption are discussed in Section IV. As these events were straightforward to identify, a single coder completed this video annotation. Examples of both successful and unsuccessful coded robot

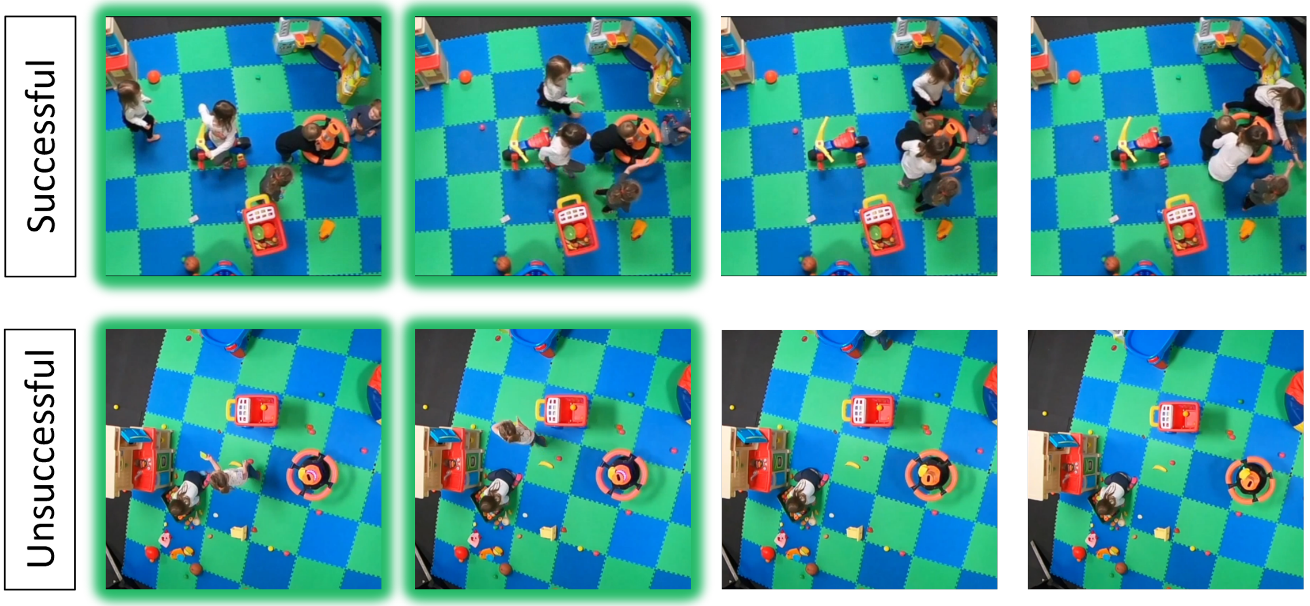

Fig. 3: Cropped keyframes from successful and unsuccessful robot behaviors. Success is defined as any child moving toward the robot up to two seconds following the robot action. Images with a green border depict the robot performing an action. *Top:* Robot performing a successful action (bubbles). *Bottom:* Robot performing an unsuccessful action (lights).

TABLE III: Counts of robot actions for each play session.

	Lights	Elec. Sounds	Bubbles	Motion	Spin
Session 1	14	18	9	88	15
Session 2	13	17	4	91	36
Session 3	29	4	N/A	62	11

actions are shown in Fig. 3. χ^2 tests of independence were conducted to assess the success of individual behaviors with a post hoc Bonferroni correction for significant results.

B. *Results*

All studied robot behaviors functioned correctly during all three play sessions, with the exception of the bubbles, which were out of operation during Session 3. The video coding results show the following overall success rates for singular robot behaviors across all sessions: 36% for lights, 21% for electronic sounds, 85% for bubbles, 29% for motion, and 15% for spinning. The results showed the bubble behavior to be significantly more successful than lights ($\chi^2(1, N = 69) = 10.2, p = .001$), electronic sounds ($\chi^2(1, N = 65) = 9.67, p = .002$), motion ($\chi^2(1, N = 316) = 20.6, p < .001$), and spinning ($\chi^2(1, N = 75) = 27.0, p < .001$). There was no significant difference between the success of any other individual robot behaviors.

We also examined the success of robot behaviors by session. Table III shows counts of each individual action's use during every play session. Motion occurred most frequently since the operator moved the robot around the playgroup to interact with each child. Other robot behaviors occurred individually at least once per session per child (sometimes happening as part of a combination, as further discussed in the Appendix). As evidenced in Fig. 4, each individual action was successful at promoting child movement toward the robot at least once per session when functional. The electronic sound success increased from 22% to 25% between Sessions 1 and 3, but singular electronic sounds also occurred much less frequently during Session 3. The bubble success decreased from 88% to 75% and was non-functional during Session 3. All other actions were less successful during Session 3 than in Session 1; light success dropped from 43% to 28%, motion dropped from 57% to 19%, and spin dropped from 40% to 9%.

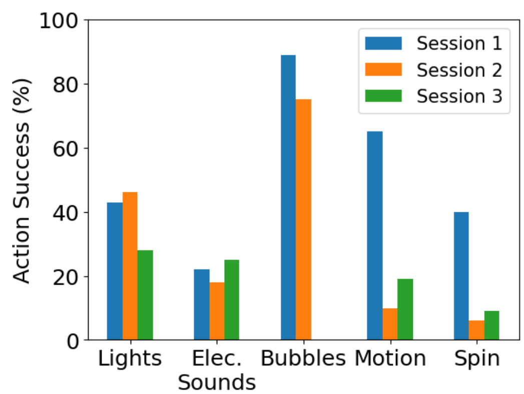

Fig. 4: Robot action success rates by session.

To understand how each child responded to individual robot behaviors, we further broke down the success of each action by child age range. We grouped the children into the three ranges shown in Table IV for relative alignment with toy review age brackets. Light, electronic sound, and bubble behaviors tended to be more successful among the

TABLE IV: Percentages of success of individual behaviors by participant age range. Counts indicate number of participants in each age range.

	Count	Lights	Elec. Sounds	Bubbles	Motion	Spin
6-24 month	2	21%	25%	23%	42%	40%
2-4 years	2	48%	50%	47%	42%	40%
4-7 years	2	30%	25%	30%	16%	20%

children in the 2-4 year range, while motion and spinning behaviors were equally successful among the children in the 6-24 month and 2-4 year ranges.

C. Summary of Key Results

The bubble action, a feature not represented in the Fisher-Price review, showed significantly more success at encouraging motion than other robot behaviors. All behaviors, with the exception of electronic sounds, showed lower success rates in repeated play sessions, but all functioning behaviors were successful at least once per session. All behaviors tended to be equally or more successful at encouraging motion in the 2-4 year age range when compared with other age ranges.

IV. DISCUSSION

The results of our systematic review of Fisher-Price toys showed that for combined younger child age ranges (i.e., 6-18 months), the presence of lights and electronic or mechanical sounds was more common than wheels, bubbles, or the ability for the toy to move itself. As infants begin to walk (i.e., for the 12-18 month range and on), the presence of self-propelled toys tended to increase but remained limited. Toy base movement offers new opportunities for child exploration during the transitions from crawling to cruising and cruising to walking [19], so it follows that mobile toys would be more represented in older age ranges. In our play sessions, we anecdotally observed instances of children from the 6-24 month group grabbing the robot to walk around the play space, similarly to how a child would use a walker toy.

Although the toy review uncovered no Fisher-Price toys with bubbles as a feature, our child-robot play session results showed that the bubble behavior was the most successful tactic for encouraging child motion toward the robot. As illustrated in Fig. 1, we informally observed that the bubble behavior also held promise for drawing groups of children toward the robot. While the toy review showed that significantly more toys were present with light and electronic sound and mechanical sound features at younger age ranges (i.e., 6-18 months), our robot behaviors tended to yield more success in the older 2-4 year age range. Beyond the Fisher-Price catalog, products do exist that allow for caregivers to manually blow bubbles, use a trigger to activate bubble blowing, or position a stationary base that automatically blows bubbles; however, our assistive robot may be uniquely equipped to inspire child motion and social interaction due to its uncommon combination of a automatic bubble-blowing module atop a self-propelled base.

When designing robots to work with children, it is important to consider the targeted age range and what developmental goals the robot will support. For encouragement of gross motor movement, our analyses to date show that common toy features such as lights and sounds can be effective, but uncommon toy features such as automatic bubble-blowing are likely to be more effective. Our results also suggest that novelty is a factor in the success of assistive robot behaviors. Incorporating a variety of interactive abilities (including both common and uncommon toy-like features) into child-robot interactions will be important to the success of and sustained interest in robots for longitudinal early interventions. Combinations of actions may also keep child interest and engagement high, but as described further in the Appendix, more observations are needed to better understand these interactions.

Key *strengths* of this work include that this is, to our knowledge, the first systematic review of toys and their characteristics for supporting motor development. Through the described play sessions, we demonstrated that uncommon features (i.e., bubbles) are the most effective choice for encouraging child motion, but common toy-like features (e.g., lights and sounds) tended to still encourage motion. Further, this work is one of the first efforts in the growing body of research on using assistive robots to support the motor development of very young (preschool-aged and younger) children.

Limitations of this work include that only the toys from one United States vendor were analyzed. Other toy vendors within and outside of the United States may use different features in their toy design. We also focused on one particular developmental subtag based on our own research interests; further insights may come from examining a wider variety of developmental promotion designations. Our exploratory playgroup had a low number of play sessions (we cancelled a fourth session due to the COVID-19 pandemic) and small group size. The gender and age distribution of the playgroup was also not wholly representative of future target robot users. Lastly, even when we see motion toward the robot in the present work, we do not know if the relationship is correlational or causal. Although we view the current work as an essential first step, further efforts would be needed to conclude whether changes in child motion are truly caused by the robot.

In *future work*, we will consider other developmental subtags and characteristics of toys from additional toy vendors. Our next child-robot interaction studies will incorporate more sessions, larger sample sizes, and more diverse participants. We will conduct this research in lab, home, and clinical settings to further understand the influence of assistive robot abilities on motor development in increasingly naturalistic settings that challenge the robot to maintain engagement past the point of novelty. Our ongoing efforts can inform robotics and child development researchers with interest in early childhood mobility interventions.

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TABLE V: Counts of robot action combinations for each play session. The success rate of each behavior is shown as a percentage in parentheses.

	Motion+Module Action	Motion+Spin	Module Combination
Session 1	14 (79%)	8 (63%)	3 (67%)
Session 2	8 (0%)	3 (0%)	1 (0%)
Session 3	29 (17%)	2 (0%)	5 (40%)

Appendix

Analysis of Behavior Combinations: As mentioned in Section III-B, robot behaviors sometimes happened individually and sometimes in parallel. The interpretation of combinations of actions is complex; if a child responds in these cases, it is not clear what individual behavior(s) have motivated this child movement. Accordingly, we share the results for combinations of robot actions here and note the need for further investigation to better understand the influence of distinct behavior combinations.

The overall success of combinations of robot behaviors during the play sessions was as follows: 31% for motion + singular module action; 38% for motion + spinning; and 44% for any combination of light, electronic sound, and/or bubble actions. Here, module action is defined as using the light, sound, or bubble behaviors. Electronic sounds were most commonly paired with another action (24 occurrences), followed by lights and another action (20 occurrences). The bubble action was only paired with electronic sounds (1 occurrence). The success of each combination was as follows: 38% for sound + another module action, 55% for lights + another module action, and 100% for bubbles + another module action. We also examined the changes in child responses to combinations of robot behaviors over play sessions. Table V shows the occurrences and success rates of all noted combinations. All combinations were less successful in Session 3 than Session 1. Combinations of robot behaviors showed no success during Session 2. Although motion + module action was used more frequently in Session 3, combinations of actions were relatively rare; more observations are needed to gain a better understanding of these complicated interactions.