

The Impact of a Socially Assistive Robot on Peer and Toy-Use Interactions During Children's  
Free Play

By  
Elora Olivares

A THESIS

submitted to

Oregon State University

Honors College

is partial fulfillment of  
the requirements for the  
degree of

Honors Baccalaureate of Science in Biochemistry & Molecular Biology  
(Honors Scholar)

Presented March 2, 2023  
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## AN ABSTRACT OF THE THESIS OF

Elora Olivares for the degree of Honors Baccalaureate of Science in Biochemistry & Molecular Biology presented on March 2, 2023. Title: The Impact of a Socially Assistive Robot on Peer and Toy-Use Interactions During Children's Free Play

Abstract approved: \_\_\_\_\_  
Sam Logan

The purpose of this study was to determine the viability of a mobile socially assistive robot (SAR) in a children's free play environment. The researchers hypothesized that the SAR would prompt more movement among the participants. In order to test this, the researchers utilized a matched pair study in which six children attended seven weekly play sessions with four baseline sessions (weeks one to four) and three intervention sessions (weeks five to seven). Each play session was recorded for 30 minutes, during which all the participants engaged in several types of play behavior and with a variety of different toys. Researchers coded these physical activity, play, and toy-use behaviors. The SAR helped create novel experiences, facilitate movement, and encourage imaginative play. Examples of this were children playing catch with the robot or making and delivering food to the robot, two play opportunities that were previously not available during the baseline stage. Despite the fact that there was an observed decrease in peer interaction, the increase in adult interaction demonstrates that children became more comfortable within the play space as shown by significant increases in child-initiated play with the researchers. Ultimately, the results show that the SAR has viability as a support for helping children feel more comfortable within a classroom environment.

Keywords: children, play, physical activity, robots

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Honors Baccalaureate of Science in Biochemistry & Molecular Biology project of Eliora Olivares presented on March 2, 2023.

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I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

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Eliora Olivares, Author

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### **3 - Abstract**

The purpose of this study was to determine the viability of a mobile socially assistive robot (SAR) in a children's free play environment. The researchers hypothesized that the SAR would prompt more movement among the participants. In order to test this, the researchers utilized a matched pair study in which six children attended seven weekly play sessions with four baseline sessions (weeks one to four) and three intervention sessions (weeks five to seven). Each play session was recorded for 30 minutes, during which all the participants engaged in several types of play behavior and with a variety of different toys. Researchers coded these physical activity, play, and toy-use behaviors. The SAR helped create novel experiences, facilitate movement, and encourage imaginative play. Examples of this were children playing catch with the robot or making and delivering food to the robot, two play opportunities that were previously not available during the baseline stage. Despite the fact that there was an observed decrease in peer interaction, the increase in adult interaction demonstrates that children became more comfortable within the play space as shown by significant increases in child-initiated play with the researchers. Ultimately, the results show that the SAR has viability as a support for helping children feel more comfortable within a classroom environment.



## 4 - Introduction

### 4.1 - The Issue

Interaction and play contribute to children's relationship with learning and engaging with the world. While rote memorization can yield results in the classroom, classrooms without a focus on play and developmentally-appropriate teaching methods lead children to be academically behind, have less empathy, and be more likely to experience “stress-induced” hyperactivity than their peers who have access to play within a classroom (Singer et al., 2006). Additionally, the ability to engage with peers is a crucial part of child development through play, and there can be some notable learning losses in this area due to the pandemic. According to the World Bank’s multi-country report on remote learning during lockdown, they note a worldwide need to reorganize education systems to aid students’ learning recovery (Barron Rodriguez et al., 2021). While the report specifically recognizes students who may have lost a caregiver due to the pandemic or had to drop out of school to prioritize working instead (Barron Rodriguez et al., 2021), there is an achievement gap that could have been created during the pandemic regarding all children’s abilities to interact with each other and educators. Severity of lockdowns and closing of childcare centers prevented children from participating in a variety of activities (Bergmann et al., 2022), possibly holding back children from accessing a benchmark of mature development: mutual interpersonal play with a peer in a shared space and activity (Howes, 1980).

### 4.2 - A Solution

In order to address diminished play, there needs to be a way to promote and encourage opportunities to move and play with others. A mobile socially assistive robot (SAR) is used in this study for the purpose of encouraging movement and play for children. For the purposes of this thesis, a SAR is a useful tool to aid children in skill development such as sociability, language acquisition, and focusing attention (Kabacińska et al., 2021). Previous work done with the SAR used in this study has also demonstrated some success in encouraging movement and play within infants (Vinoos et al., 2021). Because of mobile SARs’ usage in skill development and its similarities to interactive toys, observing a SAR’s effects on movement and play will provide a stronger baseline as to how assistive technology encourages skill acquisition and interaction with one’s environment.

### 4.3 - Relevance to Child Development

Lifelong health and well-being is fostered during childhood and adolescence through developing movement skills and healthy habits (Rodgers, 2018). Play also contributes to children’s physical and mental fitness as physically active children are noted to have higher cardiorespiratory fitness, stronger muscles and bones, improved cognition and executive function, and reduced symptoms of depression (Rodgers, 2018). The findings of this study lend themselves to possible classroom restructuring and continuing the accessibility of learning tools that was emphasized during lockdown. Marked increases in movement and adult interaction play show the viability of a

classroom mobile SAR to engage students, increase physical activity, and support in gaining familiarity with a new classroom environment and educator.

#### **4.4 - Structure and Content Overview**

This honors thesis will first discuss the previous work done in this subject area to establish background information and note current gaps in the research. Following this, the methodology of this study will be laid out in detail to show how the researchers examined how the presence of a SAR in a children's free play space impacts children's physical, play, and toy-use behaviors. The methodology then leads into the results and discussion, ending with transparency regarding the limitations of this study and future work to be done following this study.

## 5 - Related Work

This section includes overviews of the work related to this study. The purpose of this section is to establish what is already known about physical activity for young typically developing children and the pandemic's effects on it, play's impact on child development, the use of toys and learning tools, and what affordances to children the mobile SAR provides.

### 5.1 - Physical Activity

Physical activity can be defined as the movements a child makes within their environment. This is a key variable in the development of children as generating learned movements and practicing consistent physical activity positively contributes to brain structure and development and academic success (Chaddock-Heyman et al., 2014). Consistent active play throughout the day is recommended for preschool children (aged 3-5), and school-aged children can reach their recommended daily physical activity by engaging in moderate to vigorous physical activity for 60 minutes or more a day (Rodgers, 2018). Physical activity habits are established in early childhood, and the preschool a child attends is significantly associated with their physical activity (Gubbels et al., 2011).

An observational study was conducted in 2006 to assess the amount of activity preschool-aged children engage in during their days, and it was found that they spent more than 80% of observation intervals in sedentary activity, and three classroom contexts – transition, snacks, and naptime – made up the greatest percentage of coded activity for the preschoolers (Brown et al., 2006). While preschool curriculum may have changed since 2006, the amount of physical activity children engage in during school should be a point of focus, especially with the return back to school from remote learning and the contribution of technology to more sedentary lifestyles during the pandemic. In a study released in 2022, caregivers in 12 different countries reported increased screen time for their children aged 8-36 months during lockdown than before lockdown (Bergmann et al., 2022). Increased screen time does have to do with a need to engage young children's minds, especially since close to 16,000 childcare centers across the United States were closed due to fluctuating attendance and decreased demand during COVID along with increasing costs (Leonhardt, 2022, p. 00). However, increased screen time has been associated with decreased physical activity (Rosen et al., 2014). While a study done in 2014 shows that factoring out screen time in children aged 4-8 lessened the severity of lack of physical activity (Rosen et al., 2014), the removal of key activity points built into a child's daily school schedule and opportunities for children to learn outside of the home due to the pandemic (Bergmann et al., 2022) can be a point of concern and baseline for changing classrooms to address activity. As children return back to in-person school attendance, it is important to consider environmental factors that affect physical activity. Physical environmental factors included availability of play equipment and activity opportunities, shorter recess duration, and smaller school size. Social environmental factors included smaller group size and child-initiated activities vs. staff-initiated activities. A study investigating the association between child-care

environment and physical activity of 2-3 year olds found that increased physical activity is attributed to both physical and social environmental factors; ineffective physical activity interventions occurred when looking at just the physical environment alone (Gubbels et al., 2011).

## **5.2 - Play Behavior**

Play behavior can be defined as the interpersonal interactions a child has within a play space. While play can be solitary (child playing alone) or parallel (children engaging in separate play within three feet of each other), progression towards higher level play including children's reciprocal acknowledgement and engagement in the same activity demonstrates a path to mature development (Howes, 1980).

Preschool play behavior was categorized in six stages by Mildred Parten in the 1930s when she researched the different modes of play that children can engage in. The following descriptions of play will be from an overview of Parten's work written by Elaine Bernstorf, a special music education teacher and speech pathologist (Bernstorf, 2012). Additionally, descriptions of Carollee Howes's peer play scale, released in 1980, will be used to supplement Parten's stages with peer interaction behavior in order to gain a holistic understanding of types of play behavior children engage in. The stages of play will end with Bernstorf's suggestions for aiding children in moving through the stages.

### **1. Unoccupied behavior**

Unoccupied behavior is associated with more solitary activities. Although a child is not playing or engaging with the assigned activity that others are doing, a child at this stage of play will fidget, make noises, or look around to engage themselves. This behavior can typically be seen in children who might not have practice in group play or who have disabilities. It is important to recognize this as a mode of play rather than a defiant behavior. Reaching out to the child and assigning meaning to activities is a useful method of helping children progress past unoccupied behavior.

### **2. Onlooker behavior**

Onlooker behavior is associated with children observing activities. Rather than actively participating in an activity, the child will watch other children play, offer commentary or suggestions, or ask questions. In this case, a child will be within range of the activity to see and hear what is taking place. For this type of behavior, it is important to not force a child to move through this stage too quickly as this stage allows them to gauge comfort level with trying an activity. Gentle guiding and modeling for children with cognitive or learning disabilities allows for movement through this stage at the child's own pace.

### 3. Solitary-independent play

Solitary-independent play is associated with children that engage in their own distinct activity within the vicinity of a group activity. This can also be associated with Howes's Level 1 play where children are participating in similar activities, but there is no eye contact or socialization among them (Howes, 1980). This stage is different from unoccupied behavior and onlooker behavior because it has both awareness of others and active participation in a set activity of their own. This stage of play can be seen in all ages and demographics, so it is an important stage of play. In cases where it is time to end solitary-independent play, it is useful to give a prompt to come back to the activity later and rejoin the group.

### 4. Parallel activity

Parallel activity is associated with playing beside others but not directly interacting with them. This can also be associated with Howes's Level 2 play where children are participating in similar activities and share eye contact (Howes, 1980). While Parten's description might not elicit eye contact, there is not enough social interaction for this stage to be considered Level 3 play according to Howes. Typically, a child engaging in this stage of play will play with the same toy set as other children – they may even mimic movements – but there is not an attempt to engage with other children to mutually play together. Parallel activity is an important first step towards play with others, and prompting from playmates can help others move from this stage to the next one.

### 5. Associative play

Associative play is associated with a clear regard for and interaction with playmates in a shared activity. This can also be associated with Howes's Level 3 play where children actively socialize with each other; this can be through talking to each other, giving and taking toys, and more (Howes, 1980). When the attempts to socialize are reciprocated, the play can be characterized as Level 4 play (Howes, 1980). This stage of play is where borrowing and interacting on the same level is introduced. There is no hierarchy or assigned roles within the play, and the child's focus is on the interactions they have with other children rather than the interests of themselves. It is important to note that with no assigned roles, there are no distinct attempts to include or exclude.

## 6. Cooperative or organized supplementary play

Cooperative or organized supplementary play is associated with distinct roles the children take on during a shared play activity. This can also be associated with Howes's Level 5 play where children engage in play with conditions and designated actions in response to certain conditions (Howes, 1980). This stage of play is where one can see formal games or dramatizations of situations (ex: playing house) being played. With the implementation of distinct roles, there is a clear mark of who is included and not included in the activity and who is in charge of how the activity plays out. Bernstorff critiques Parten's characterization of this stage, saying that it is similar to a description of bullying. While this stage's organization demonstrates a child's maturity to play through a variety of situations and formal games, it is important for educators and caregivers to foster an environment where all levels of play are welcomed and children are prompted to move back and forth between roles, allowing children to have autonomy in their play.

### 5.3 - Toy-Use Behavior

Toy-use behavior can be defined as the ways in which a child interacts with toys in their play space. For the purposes of this study, a toy will be defined as a tool children use for developmentally-appropriate play. The purpose of play changes as a child grows; children practice exploratory play using the five senses and practicing fine motor skills as babies, understanding the function of objects and differentiating colors and shapes as toddlers, fostering imagination and more intricate movements like running and jumping as preschoolers, and developing talents and interests when they become big kids (*Smart Toys for Every Age (for Parents)* - Nemours KidsHealth, 2018). Caregivers and educators must realize the importance of play in learning and be willing to critique the wide variety of toys that can be used as learning tools, especially with new technology being introduced to play. Because of this thesis's focus on a mobile SAR in a free-play environment, toy-use behavior will be examined through observations with new media for play such as video and computers and how they contribute to play environments for developing these skills.

New media for play demonstrate the importance of adult interaction and engagement in play. Videos can be a vessel through which educators and caregivers can teach children skills in an auditory and visual package. A study measuring the impact of children's TV programs on language acquisition was released in 2005 (Linebarger & Walker, 2005). The sample was composed of 51 midwestern middle- to upper-middle-class families, resulting in 23 boys and 28 girls total. The data was collected through parents, direct observations of caregiver-child interactions, and sharing information about the children's experiences at home and in childcare settings. It was found that programs like *Blue's Clues* and *Dora the Explorer* resulted in the acquisition of 13.30 more vocabulary words at 30 months with a 1.35 words per month increase in the rate of growth in vocabulary words as compared to children who did not view these

programs. Meanwhile, programs like *Barney & Friends*, while negatively associated with vocabulary acquisition, were positively correlated with expressive language production, or the production of words, sentences, gestures, and writing that conveys meaning to others (“Expressive Language (Using Words and Language),” n.d.). These results reflect the variety of skill targets video allows children to practice. Additionally, the results also emphasize parental involvement in educational play as when children viewed *Barney & Friends* without a parent co-viewer, they learned just one word rather than 3.5 words that came from children with parent co-viewers (Linebarger & Walker, 2005).

It is important to note that not all videos are equally educational, and adjustments must be made in order to make the content useful for fostering target skill sets in children. Notably, *Teletubbies* is criticized for promoting poor language development due to the program’s usage and babies’ repetition of vocalizations and baby talk (Singer et al., 2006). Additionally, studies done by Deborah Linebarger found that the 2001 redesign of *Sesame Street* addressed the concerns regarding the program’s usefulness as a learning tool and appropriately holds children’s attention to properly teach lessons (Singer et al., 2006). *Sesame Street*’s changes to production show that video is a viable method of delivering lessons through play as long as the creators are willing to adjust “curriculums” to suit the needs of its “students.”

New media for play also emphasize the importance of open-ended play and the expansion of play opportunities in order for children to develop and practice skills. Computers are useful tools for fostering children’s imagination by encouraging them to explore different routes of achieving an end goal that aligns with their interests. Two different students utilized programmable mini computers (Cricket) that can “control motors and lights, receive information from sensors, and communicate with one another via infrared light” to create machines based off of their interests (Singer et al., 2006). With the open-ended play the Crickets provide, two girls were able to make a marble machine and bird feeder respectively while practicing the scientific method of hypothesis generating while coming up with machine modifications and conducting testing and analysis (Singer et al., 2006). The children were able to learn through hands-on play, demonstrating the importance of educational toys that allow for open-ended play and the development of skills and interests.

Previous studies show that SARs are viable tools for facilitating open-ended play and the expansion of play opportunities. While observing children’s interactions with a SAR during a problem solving task, it was found that children who engaged with a SAR voluntarily during their process outperformed children who were required to take turns with a SAR while completing the same task, showing that a SAR can help provide exploratory movements and opportunities to students (Charisi et al., 2020).

#### 5.4 - Mobile SAR

Mobile SARs are assistive devices to help with skill acquisition and practice (Kabacińska et al., 2021). Children are receptive to SARs as they were used in healthcare settings for helping pediatric patients find comfort and entertainment during hospital stays (Kabacińska et al., 2021). For example, a Nao, a form of mobile SAR currently available on the market, was sent with an entertainment program to leukemia patients, who had to stay in isolation and could not receive a visit from Child Life Specialists or pets due to the patient being immunocompromised (Kabacińska et al., 2021). Due to children's receptiveness to SARs and previous work done with them, the use of a SAR in free play environments may have similar benefits to what has previously been established.

The SAR used in this current study was previously used to assess the usefulness of a mobile SAR in providing motivation during mobility interventions using a modified ride-on car. The mobile SAR used in this current study was developed from a previous study done at Oregon State University by the Social Mobility Lab, and the following information will be from the previous study (Vinoos et al., 2021). An infant-sized mobile SAR was used to promote modified ride-on car driving down a 90-ft long track lined with green and blue foam squares. The goal for the sample of five male typically developing infants ranging from 12-35 months was to activate the car at the start of the track and drive towards their parents. The infants were not instructed on how to activate the car and had to learn from being in the car. The parent stood at the 30-ft cone and was instructed to provide minimal encouragement. Minimal encouragement in this case was simply noting the features and behaviors of the car and the robot. The parent moved further along the track whenever the child used the car to reach a certain distance away from them. The trial was concluded at whichever came first: when the child reached the 90-ft cone, when 90 seconds had passed, or when the child began to climb out of the car. Parent intervention occurred if the parent recognized that the child was feeling distressed, and the child was able to take a 5-minute rest period before the next trial. For the baseline and retention phases, the robot was set at the 6-ft marker and sat motionless while the parent provided the minimal encouragement. However, during the treatment phase, the robot was activated at the start of the trial and moved back-and-forth with a reward stimulus. There were two conditions the robot operated under: a motion condition where the robot would move to the next marker or a motion + reward condition where the robot would demonstrate a reward stimulus and then move to the next marker. The conditions occurring were contingent upon the child driving within 2 feet of the robot.

The results collected from video recordings, car hardware, questionnaires, and interviews gave mixed results regarding the effectiveness of the SAR, but overall the SAR's effectiveness got worse as the study progressed as shown by decreases in driving distances. Rewards helped mitigate the losses in distance a bit. The researchers found that the length of the track and lab setting may have contributed to the decrease in the robot's efficacy. Additionally, parents expressed concerns about AI and discomfort with SAR interventions. This study is a good



starting point for considerations in the experimental design of this thesis in order to maintain children's engagement with the robot as well as ease parents' worries regarding the use of SARs.

## 6 - Methods

This study utilized a matched pair design with weekly free play sessions to observe the effect of a SAR on children's physical, play, and toy-use behaviors.

### 6.1 - Participants

Ten children between the ages of one and seven (Range = 1.6 to 6.7 years;  $M = 3.6$ ;  $SD = 1.9$ ) were included as participants in this study. However, due to the matched pair method of collecting data, only the behaviors of the children who attended two or more play sessions during both the baseline and intervention phases were recorded and analyzed for this study. Out of the ten, six children (five females, one male; all White) attended two or more play sessions during both phases.

### 6.2 - Procedure

This section goes over the procedure involved in executing this study. This section involves the procedures for IRB and informed consent as the study involves working directly with children, the play area setup, the intervention phase, and data collection and video coding for analysis of the play sessions.

#### 6.2.1 - IRB and Informed Consent

All study procedures were submitted to and approved by the Oregon State University Institutional Review Board. Parents of the participants gave written informed consent to the researchers prior to the study beginning.

#### 6.2.2 - Play Area

Alternately colored blue and green foam squares were used to line the play area. Each foam square was 2 × 2 feet, for a total of ~440 square feet. The participants were asked to remain in the play area for the duration of the session.

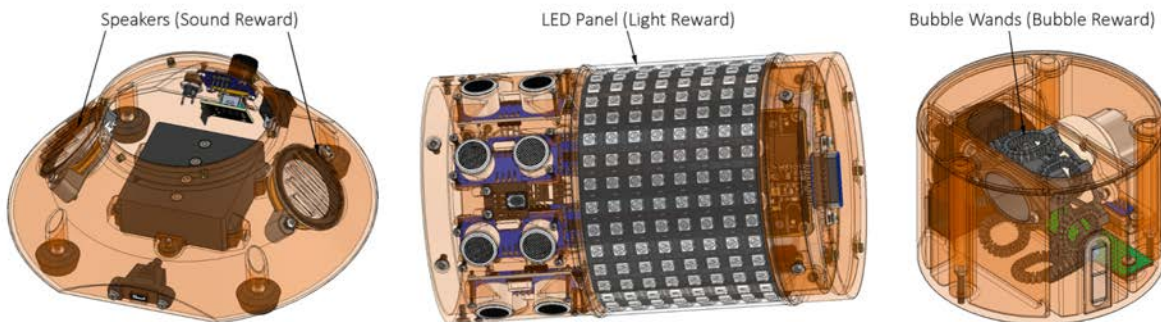
The same set of developmentally appropriate toys were used for each play session, and they were set up in the same location at the start of each session (Figure 1). The toy set included physical activity and recreation toys, sensory toys, learning toys, pretend play toys, and the SAR.





**Figure 2:** Overview of the mobile socially assistive robot. A removable 3D-printed cover was added following the first intervention session to protect the user interface from participants. (This figure has subsequently been published in a peer-reviewed article. Please see Vinoo et al., 2021)

In order to deliver rewards, the researchers constructed a 3D-printed reward column (Figure 3). Speakers in the bottom of the column played animal noises as a sound reward, the LED panel in the middle displayed a light design as a light reward, and the bubble wands at the top allowed researchers to deposit bubble solution for a bubble reward. The bubble compartment was filled with diluted solution at the beginning of each session and emptied and cleaned with a syringe and water at the end of each session.



**Figure 3:** Closer view of the reward column's structural components. The column provides sound, light, and bubble rewards. (This figure has subsequently been published in a peer-reviewed article. Please see Vinoo et al., 2021)

#### **6.2.4 - Intervention**

The study consisted of seven weekly sessions with four baseline sessions (weeks one to four) and three intervention sessions (weeks five to seven). A fourth intervention session was planned but canceled due to the COVID-19 pandemic. During each play session, the participants engaged in free play for approximately 30 minutes. For the purposes of this study, free play is defined as play behavior that involves minimal intervention of adults and is primarily controlled by the child (O'Brien & Smith, 2002). Parents and the researchers engaged in minimal intervention during play time and only intervened when a child began to engage in possibly dangerous activities such as standing on a precarious ledge or approaching heavy equipment that were present outside the perimeter of the play area.

As the purpose of the study was to determine how a SAR impacts children's play, mobile, and toy-use behaviors, an infant-sized mobile robot capable of providing configurable rewards of light, sounds, and bubbles was placed in the play area at the start of each weekly play session. During the baseline phase, the SAR was turned off. During the intervention phase, a researcher used a teleoperation interface to remotely control the robot and use it to approach each child in the play area. These approaches involved the activation of light, sound, or bubble rewards. Order in which children were approached each session was randomized using number assignments to each of the participants and a random number generator. Rewards following the initial approach were given whenever the child came within three feet of the robot. All three rewards were given to every child during each play session of the intervention phase.

#### **6.2.5 - Data Collection and Video Coding**

For all of the play sessions, the participants were asked to remain in the blue and green foam play area as it had two overhead GoPro cameras placed above to record the 30-minute play sessions in full. Each overhead camera recorded half of the play area to be able to record participants' movements as they went throughout the play area. The videos from these cameras were used for data analysis.

### **6.3 - Measurement**

This section details the measurement of a participant's physical activity, play behavior, and toy-use behavior along with their positioning and the SAR's positioning. A predefined codebook (Table 1) was created to facilitate interrater reliability among the research team's behavior coders.

#### **6.3.1 - Physical Activity**

A commonly used direct observation system called the Observational System for Recording Physical Activity in Children: Elementary School (OSRAC-E) was adapted for the purposes of this study to record the participants' physical activity behaviors (McIver et al., 2016). The

adapted OSRAC-E observation system includes play behaviors that were observed in the participants such as catching/throwing, riding, and walking on knees (Table 1).

### 6.3.2 - Play Behavior

Adaptations from the Parten's Stage of Play (Parten, 1932) and Peer Play Scale (Howes, 1980) were used to record the participants' play behaviors. These adaptations include the study's behaviors of interest. The categories of play behavior as defined earlier were unoccupied play, solitary play, parallel play, peer interaction play, and adult interaction play (Table 1).

### 6.3.3 - Toy-Use Behavior

The type of toy a participant was interacting with was used to coded toy-use behaviors. The toys within the play area included physical activity and recreation toys, sensory toys, learning toys, pretend play toys, and the SAR (Table 1).

### 6.3.4 - Child and SAR Positioning

OpenCV multi-object tracking programming function was used to extract positional data for the child and SAR. This was done by a user's selection of bounding boxes for the SAR and each child in the play area. The user would re-select a child or the SAR upon re-entering the frame after leaving the play area. Microsoft Excel was used to store the automatically generated position data from the centers of the bounding boxes. The duration of time spent by the child in parallel or more complex play behaviors within close proximity to the SAR was determined by first calculating the distance between the SAR and each child for every frame. This calculation was done with a total of 25 frames per second and then used to calculate the percentage of frames where the robot was within three feet of any participant.

**Table 1: Free Play Codebook**

<b>Behavior</b>	<b>Categories</b>
Physical Activity Type	Standing, Sitting/Squatting, Climbing, Sliding down, Walking, Crawling, Kneeling, Running, Lying, Bending, Lifting, Pulling/Pushing, Jumping, Riding, Throwing/Catching, Walking on Knees

Play Behavior	<ul style="list-style-type: none"><li>· Unoccupied play<ul style="list-style-type: none"><li>o child not engaging in any play behavior</li></ul></li><li>· Solitary play<ul style="list-style-type: none"><li>o child playing independently without interaction with anyone</li></ul></li><li>· Parallel play<ul style="list-style-type: none"><li>o child playing within three ft. of another child without deliberate interaction with the peer</li></ul></li><li>· Peer interaction play<ul style="list-style-type: none"><li>o child engaging in direct verbal or physical interaction with peer</li></ul></li><li>· Adult interaction play<ul style="list-style-type: none"><li>o child engaging in direct verbal or physical interaction with adult</li></ul></li></ul>
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Toy-Use Behavior	<ul style="list-style-type: none"> <li>· Physical activity and recreation toys <ul style="list-style-type: none"> <li>o Mini basketball unit, slides, walkers, balls, and trike</li> </ul> </li> <li>· Sensory toys <ul style="list-style-type: none"> <li>o Sensory table and bean bag chair</li> </ul> </li> <li>· Learning toys <ul style="list-style-type: none"> <li>o Play unit and activity tables</li> </ul> </li> <li>· Pretend play toys <ul style="list-style-type: none"> <li>o Play kitchen, play food, play mobile phone, hand puppets and shopping cart</li> </ul> </li> <li>· SAR (Wk 4-7 on)</li> </ul>
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**Table 1:** The types of behaviors and subcategories of those behaviors are outlined in this table. For ease of coding, associative and cooperative play fall under “Peer interaction play.” Coders conducted codings of the video recordings with an additional master coder in order to reach at least 85% interrater reliability. (This table has subsequently been published in a peer-reviewed article. Please see Raja Vora et al., 2021.)

#### 6.4 - Data Procedure

A momentary time sampling observation system (Brown et al., 2006; Logan et al., 2015) was used for video coding. The 30-minute play session was divided into 10-second consecutive intervals. During the 10-second interval, the first two seconds were used to observe a participant’s behavior and the last eight seconds were used to record the behavior in Microsoft Excel. This method of data analysis was adapted from previous research involving coding child behaviors in 15-second intervals (Logan et al., 2015) or 25-second intervals (Brown et al., 2006). With six observation intervals per minute, 180 observations were coded per child for every play session, resulting in a total of 5,400 observations studywide that were included for analyses.

Two coders coded behaviors for all the video recordings with one coding physical activity and the other coding play behavior and toy-use behavior. Coders conducted 10% of codings of the video recordings with an additional expert coder in order to achieve at least 85% interrater reliability as agreement of 85% or higher is considered acceptable in studies observing children (Logan et al., 2015). Equation 1 shows how percent agreement between each coder and the expert was calculated.



$$\text{Percent Agreement} = \left( \frac{\# \text{ of agreements between coders}}{\# \text{ of agreements} + \# \text{ of disagreements}} \right) \times 100$$

The coders determined the percentage of total intervals when the child was within view of at least one of the play area's overview GoPro cameras for physical activity, play behavior, and toy-use behavior. The percentage of total frames when a participant in the camera's field of view was within three feet of the robot was reported for child and SAR positioning to accurately determine how much time each child spent in each type of behavior. Equation 2 shows how the mean percentage of time in behavior was calculated for each child.

$$\text{Mean \% of Time in Behavior} = \left( \frac{\# \text{ of observed intervals for the behavior}}{\text{Total \# of intervals}} \right) \times 100$$

#### **6.4.1 - Statistical Analysis**

A within-subjects design was used to analyze the data recorded of the participants' play, mobile, and toy-use behaviors. A paired-Wilcoxon signed rank test through the SPSS statistical software (Version 25) was carried out due to the data's non-parametric nature.

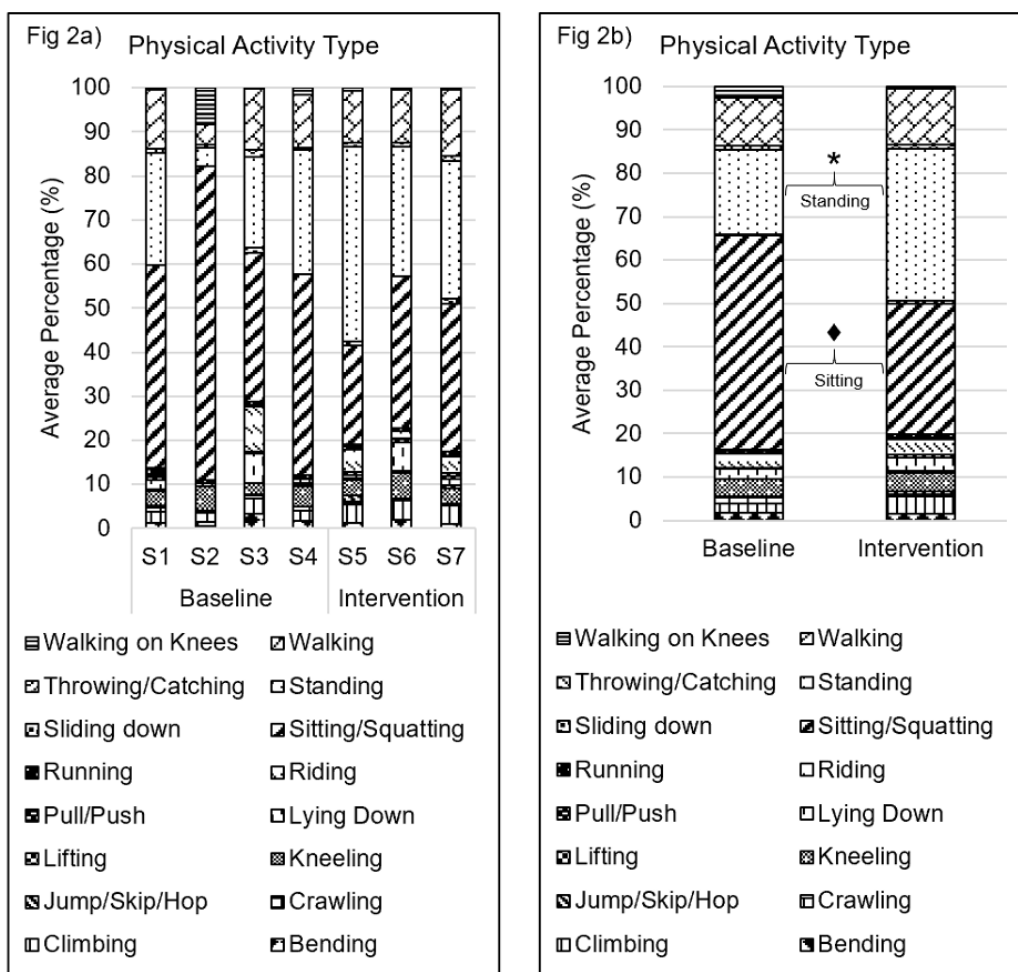
## 7 - Results

This section covers the coding results for the behavioral categories specified in Section 7.3. As noted in Equation 2, the data is presented as a percentage of the number of observed intervals for the behavior within the span of the total intervals the child was visible within the play area.

### 7.1 - Physical Activity Type

The majority of play time was spent in three types of physical activity: sitting/squatting (~40%), standing (~27%), and walking (~12%). The other physical activity types made up a total of ~21% of the time intervals (Figure 2a).

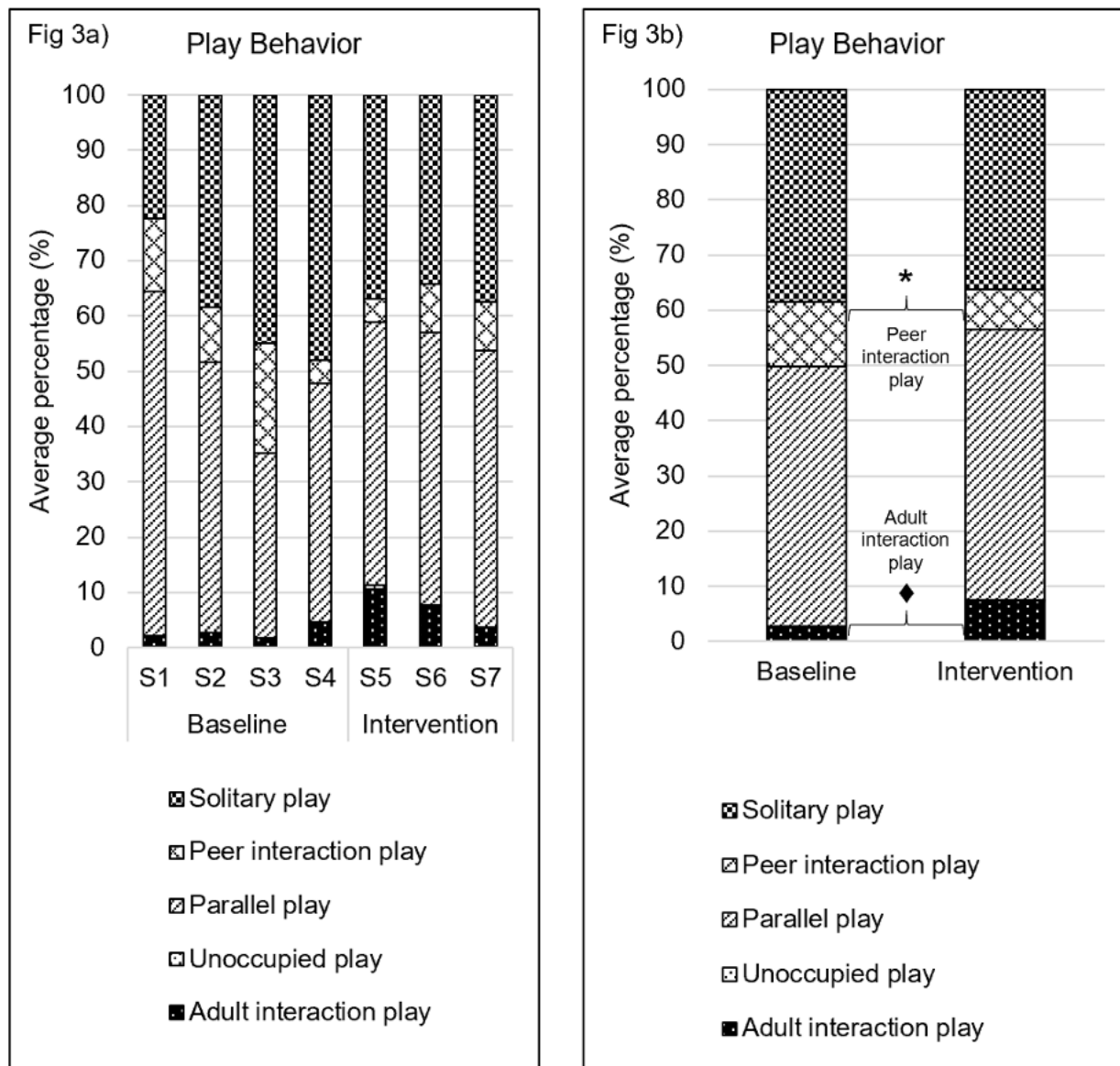
From the baseline to the intervention, participants' time spent standing increased by around 15% ( $Z = -2.09$ ;  $p = 0.037$ ) while time spent sitting decreased by around 19% ( $Z = -1.89$ ;  $p = 0.059$ ) (Figure 2b).



**Figure 2:** (a) Gives breakdown of the average percentage of time intervals participants spent in physical activity types by play session. (b) Gives breakdown of the average percentage of time intervals participants spent in physical activity types by phase. (This figure has subsequently been published in a peer-reviewed article. Please see Raja Vora et al., 2021.)

## 7.2 - Play Behavior

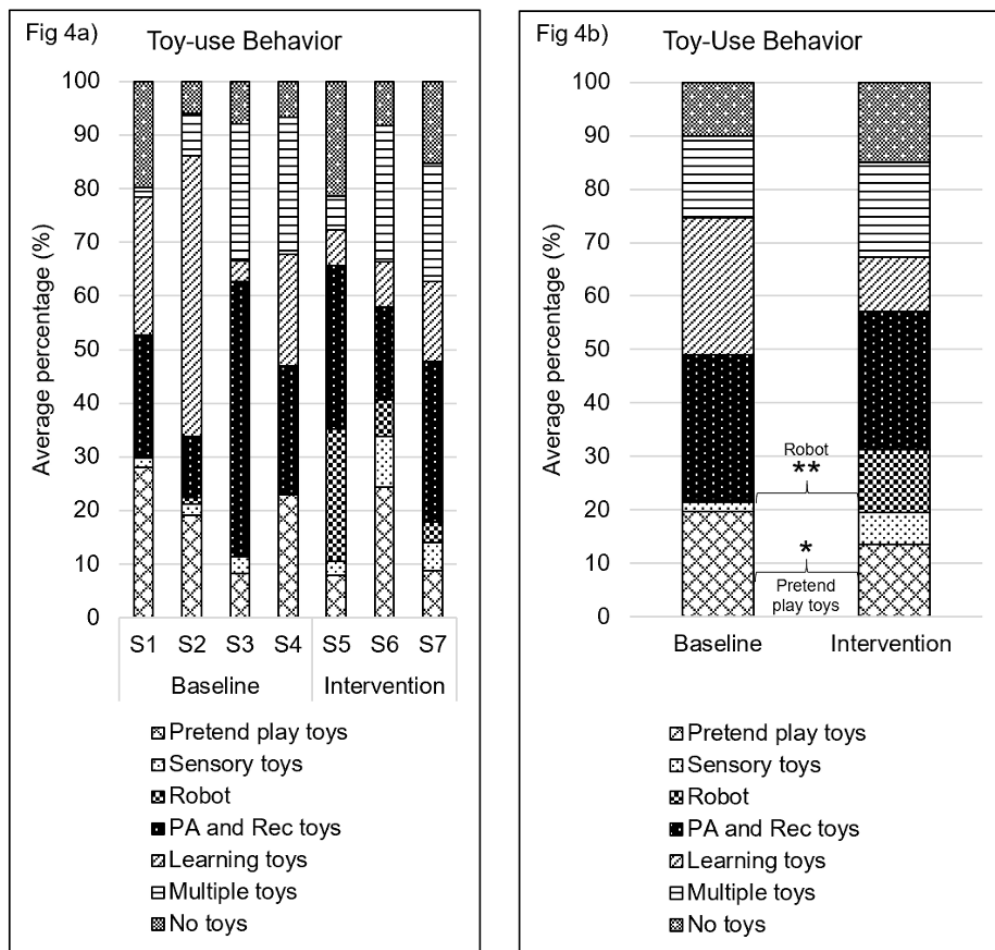
The majority of play time was spent in parallel play (~48%) with the next highest play behavior percentage being ~37% of play time spent in solitary play (Figure 3a). Peer interaction play decreased significantly from the baseline phase to the intervention phase ( $\sim 4.5\%$ ,  $Z = -2.70$ ;  $p = 0.007$ ) (Figure 3b). Additionally, the tendency towards adult interaction play increased from the baseline phase to the intervention phase ( $\sim 4.5\%$ ,  $Z = -1.89$ ;  $p = 0.059$ ) (Figure 3b).



**Figure 3:** (a) Gives breakdown of the average percentage of time intervals participants spent in play behavior types by play session. (b) Gives breakdown of the average percentage of time intervals participants spent in play behavior types by phase. (This figure has subsequently been published in a peer-reviewed article. Please see Raja Vora et al., 2021.)

### 7.3 - Toy-Use Behavior

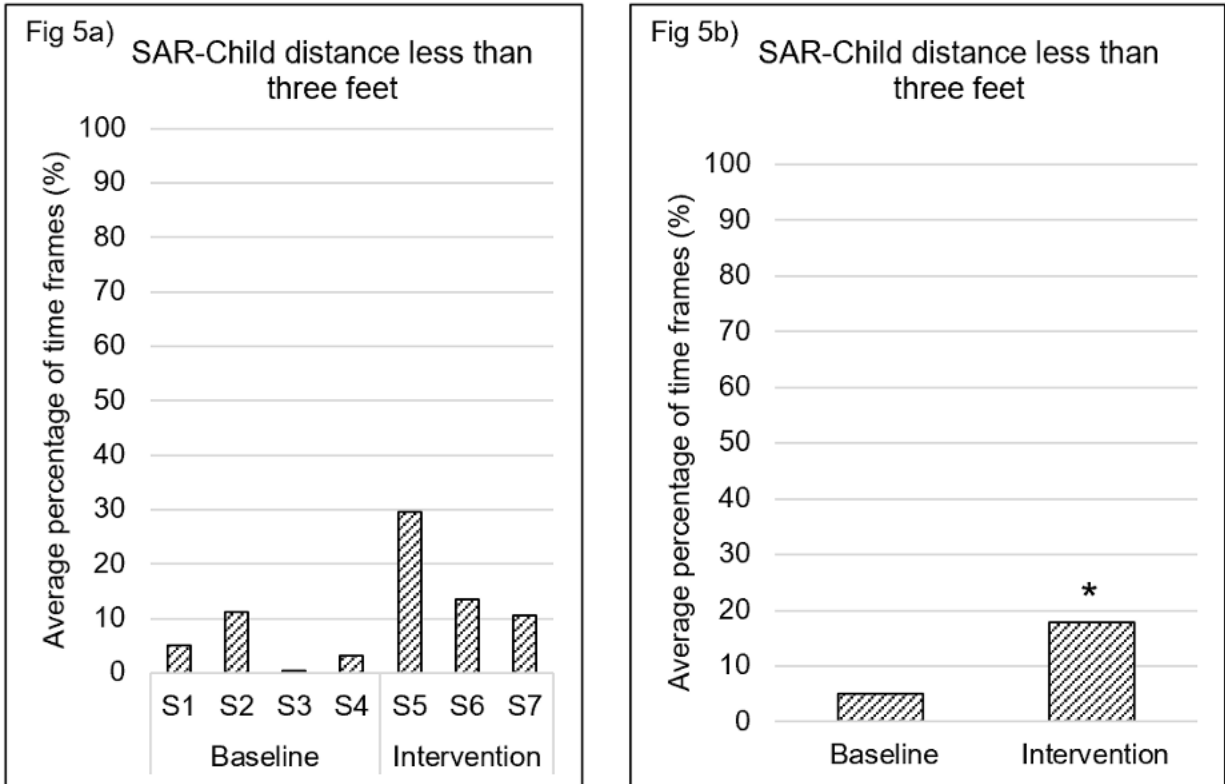
As mentioned in Section 7.3.3, the toy set included physical activity and recreation toys (~26.5% of time intervals), learning toys (~18% of time intervals), pretend play toys (~17% of time intervals), with the SAR (~5% of time intervals), and sensory toys (~4% of time intervals) (Figure 4a). The participants played with multiple toys at a time for around 16.5% of time intervals and played with no toys for around 12.5% of time intervals (Figure 4a). Interaction with the robot increased significantly (~11.5%,  $Z = -2.52$ ;  $p = 0.012$ ) from the baseline phase to the intervention phase (Figure 4b). Participants interacted with the robot through touching, following, looking at, pushing/pulling, or going towards the robot or its rewards. Pretend play toys had a significant decrease (~6 %,  $Z = -2.40$ ;  $p = 0.017$ ) in interaction from the baseline phase to the intervention phase (Figure 4b).



**Figure 4:** (a) Gives breakdown of the average percentage of time intervals participants spent in toy-use behavior types by play session. (b) Gives breakdown of the average percentage of time intervals participants spent in toy-use behavior types by phase. (This figure has subsequently been published in a peer-reviewed article. Please see Raja Vora et al., 2021.)

#### 7.4 - Child and SAR Positioning

Throughout the study, the participants spent approximately 10.5% of their time within three feet of the robot (Figure 5a). When the robot was interacting with the participants in the play space, the participants' time spent within three feet of the robot increased significantly from the baseline phase to the intervention phase ( $\sim 12.9\%$ ;  $p = 0.02$ ) (Figure 5b).



**Figure 5:** (a) Gives breakdown of the average percentage of time frames participants spent within three feet of the SAR by play session. (b) Gives breakdown of the average percentage of time frames participants spent within three feet of the SAR by phase. (This figure has subsequently been published in a peer-reviewed article. Please see Raja Vora et al., 2021.)

## 8 - Discussion

This section discusses the relevance of the data collected regarding the participants' physical activity, play behavior, and toy-use behavior. With this being the first study to utilize a mobile SAR in a children's free play environment, the changes in participants' behaviors lend themselves as support for the SAR's usage in other free play environments such as daycares and classrooms.

### 8.1 - Physical Activity

Although children spent the majority of time sitting, the significant increase in standing time and decrease in sitting time along with related play, toy-use, and child-mobile SAR interaction behaviors show that the robot was successful in facilitating and encouraging movement and play within the environment. Examples of robot interactions that could explain the increase in standing were the children holding onto the roll cage as support while the robot was moving around and running around to pop bubbles from the bubble reward. Findings from the current study align with previous research regarding physical activity in preschool aged children; physical activity showed marked increases when children were provided with more activity opportunities (Gubbels et al., 2011).

The robot is unlike any other toy that was available in the play space because of its ability to move and interact with the participants, therefore providing different play experiences that were not available during the baseline stage. In the previous study done with the SAR, there was a notable decrease in effectiveness of promoting movement due to the decrease in the robot's novelty for the participants (Vinoos et al., 2021). Having the same objective and robot rewards for all sessions contributed to decreased movements of the children completing the task of reaching the other end of the track. The SAR's increased effectiveness in this study in comparison to the previous one could be attributed to the fact that there is more novelty with this study's environment (an unchanging track vs. a free play environment). Although the same toy set was present for all sessions, the opportunities for activities were increased with the presence of imaginative play toys. Children's usage of imaginative play toys led them to do a variety of physical activities such as sitting, standing, and walking for the same task. Tasks that prompted multiple types of physical activity were playing with the pretend kitchen set and playing catch with the robot. The participants' increases in physical activity were associated with increases in child-initiated play which aligns with the results of a previous study regarding environmental effects on preschool-aged children's physical activity (Gubbels et al., 2011).

### 8.2 - Play Behavior

One unexpected observation was how peer interaction decreased while adult interaction increased during the intervention phase when the SAR became active in the play space. Because the SAR served as an extension of the researchers in the sense that the researchers were able to use the robot to interact with the participants, the children's continued interaction with the adults

during the intervention phase shows how adults are an integral part to a child's learning. As the sessions continued through the weeks, the participants got used to the play area and the adults on the perimeter of the play space (these adults being researchers and the children's parents). With this, the participants themselves initiated conversations, pretend play, and more with adults. Examples of this are a child initiating a game of catch with the researchers or bringing a plate of pretend food to a researcher. There was also a significant amount of interaction with the robot teleoperator to prompt more rewards from the robot. With the participants interacting with the teleoperator to acquire desired rewards, there could be a translation of these incentives prompting movement or demonstration of a skill. This shows that despite the decrease in peer interaction, adult interaction is tied with engagement with the robot similar to the educational videos discussed in Section 6.3.

An initial reaction to this result could be to question the effectiveness of the SAR because of this decrease in peer interaction considering that it is a children's free play space. However, the increase in adult interaction and novel play opportunities shows that the SAR can help facilitate a child's increased comfort within a play environment. The mobile SAR functioned as another toy or extension of a playmate (playmate being the adult) to prompt play. Limited research can be found regarding child-robot interactions and play behavior. Most research has been focused on children's individual skill practices and acquisitions, but the results of this study show that the SAR was an effective bridge between the children and others occupying the place space.

### **8.3 - Toy-Use Behavior**

As mentioned in Section 6.3, the focus of developmentally appropriate play for preschoolers is fostering imagination and more intricate movements like running and jumping (*Smart Toys for Every Age (for Parents) - Nemours KidsHealth*, 2018). Despite the fact that engagement with pretend play-based toys had a significant decrease from baseline to intervention, the participants still engaged in pretend play as a result of increased interaction with the robot. This is reflected in the pretend play scenarios involving the robot such as children preparing food for or playing catch with the robot. Because of the open-ended play the robot offers in its structure and function, the children were able to expand their play opportunities based on their imagination.

Reprogramming parts of the reward system of the robot (i.e. having the sound rewards be instructional or call-and-response songs) could allow the robot to be adapted for a wider range of age groups and provide learning through play at multiple levels. Previous studies have shown that SARs consistently showed benefits for immediate learning gains in problem-solving activities when children initiate interactions with them, reflecting its viability as a learning tool in free play environments for situations like imaginative play that require creativity and problem-solving (Charisi et al., 2020).

#### **8.4 - Child-Mobile SAR Interaction**

Interesting interactions that occurred as a result of the participants' proximity to the robot included children playing catch with the robot and making pretend food for the robot. The robot helped to encourage imaginative play, similar to the computers discussed in Section 6.3 and fit well into the structured play framework found in cooperative or organized play as described in Section 6.2. While the robot fulfills its role as a tool for developmentally-appropriate play, the way in which the participants interact with the robot as another playmate within the space shows its viability as a support for integrating into or getting familiar with a classroom environment.

In comparison to the previous study involving this SAR, this study had better retention of children's attention. Reasons for why the effectiveness of the robot maintained throughout the intervention could be due to the different natures of the studies. The previous study was a more traditional lab setting with set markers for movement (Vinoos et al., 2021) whereas this study was a free play environment. The nature of this study allowed for novel interactions between the children and the SAR since there was not a clear objective for the participants. This shows that the SAR can only guide learning to a certain extent on its own and that it benefits from the interpersonal interactions within the space in order to be effective.

Parent attitudes towards the SAR also impacted the robot's effectiveness as their encouragement to play with the robot helped children return to the play space and stay engaged. This differs from the previous study with the robot where parents were instructed to only provide minimal encouragement for all trials. While the study was centered around the child's motivation to move, the comparison of the two mobile SAR studies showed that novelty and interactions with others contribute to a child's engagement with the SAR and the play space. Hesitant attitudes associated with AI as noted in the previous study may have contributed to the varying engagement and support of parents as their children engaged with the robot; parents reported less feelings of comfort after the previous study while the parents in this study seemed more open to the presence of and interactions with the robot (Vinoos et al., 2021).

These results align with related work on child-robot interactions that demonstrates that a SAR is effective at guiding learning when children voluntarily interact with it. SARs are useful for encouraging exploratory movements in problem solving scenarios where the child initiates interaction as shown by the outperformance of children who engaged in voluntary SAR interaction (Charisi et al., 2020). In classroom scenarios where children are learning through play, the mobile SAR can be considered a useful tool for facilitating children's immersion in a play space and progression through stages of play.



## **9 - Limitations and Future Work**

While this pilot study contributes towards the limited amount of research on the effects of a mobile SAR within a children's free play space, this study has some limitations and requires that future work be done in order to expand on its findings.

The study was limited by the sample, minor technical difficulties with the SAR, and the COVID-19 pandemic. Firstly, the sample was small ( $n = 6$ ) with limited diversity (five females, all White, all typically developing). In order to address this in future studies, sample size will be increased and children will be recruited to create a more diverse and inclusive playgroup. Secondly, the researchers encountered reduced functioning of the bubble-blowing attachment during Session 6 of the study. In order to address this, more thorough cleaning of the bubble attachment will be done following use during play sessions. Finally, the study had limited intervention sessions due to the COVID-19 pandemic. The original study design included a withdrawal phase with the SAR turned off in the play space after the intervention. Possible ordering effects in observations could have occurred from the study design's non-randomized baseline and intervention phases.

Addressing limitations of this study and looking forward to expanding on the research in this field, next steps will build on the SAR's feasibility to be used as a teaching tool in social settings like classrooms, day care centers, playgrounds, and parks for educational and skill-development purposes. In the future, the SAR will be used to study mobile SARs' impact on physical activity, play behavior, and toy-use behaviors in the aforementioned settings with a wider range of users including children with and without disabilities.

Although being able to provide children with the ability to interact with their peers and environment is the end goal, the SAR is meant to be used as a tool to help children practice using a mobility device which can be done in free play environments or clinical settings.

## **10 - Conclusions**

This pilot study set out to determine the viability of a mobile SAR within a children's free play environment. The researchers constructed a mobile SAR to occupy the same play space as participants and offer rewards for interactions with/near the robot. Comparing physical activity, play, toy-use, and child-mobile SAR interactions of the participants across baseline and intervention phases, the presence of the robot was associated with a decrease in time spent standing and an increase in time spent sitting. Despite the decrease in peer interaction, the increase in adult interaction and the variety of creative play scenarios between participants and the mobile SAR shows the viability of the robot as a learning tool and guide within new environments.

## 11 - Back Matter

### 11.1 - References

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