Influence of a Socially Assistive Robot on Physical Activity, Play Behavior, and Toy-use Behaviors of Children in a Free Play Environment: A Within-Subjects Study

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Keywords: child development, assistive robotics, robot-mediated play

Posted Date: July 30th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-704373/v1

Abstract

Background: Play is critical for children's physical, cognitive, and social development. Technology-based toys like robots are especially of interest to children. This pilot study explores the affordances of the play area provided by developmentally appropriate toys and a mobile socially assistive robot (SAR). The objective of this study is to assess the role of the SAR on physical activity, play behavior, and toy-use behavior of children during free play.

Methods: Six children (5 females, M_{age} = 3.6 ± 1.9 years) participated in the majority of our pilot study's seven 30-minute-long weekly play sessions (4 baseline and 3 intervention). During baseline sessions, the SAR was powered off. During intervention sessions, the SAR was teleoperated to move in the play area and offered rewards of lights, sounds, and bubbles to children. Thirty-minute videos of the play sessions were annotated using a momentary time sampling observation system. Mean percentage of time spent in behaviors of interest in baseline and intervention sessions were calculated. Paired-Wilcoxon signed rank tests were conducted to assess differences between baseline and intervention sessions.

Results: There was a significant increase in children's standing (~15%; $Z = -2.09$; $p = 0.037$) and a tendency for less time sitting (~19%; $Z = -1.89$; $p = 0.059$) in the intervention phase as compared to the baseline phase. There was also a significant decrease (~4.5%, $Z = -2.70$; $p = 0.007$) in peer interaction play and a tendency for greater (~4.5%, $Z = -1.89$; $p = 0.059$) interaction with adults in the intervention phase as compared to the baseline phase. There was a significant increase in children's interaction with the robot (~11.5%, $Z = -2.52$; $p = 0.012$) in the intervention phase as compared to the baseline phase.

Conclusions: These results may indicate that a mobile SAR provides affordances through rewards that elicit children's interaction with the SAR and more time standing in free play. This pilot study lays a foundation for exploring the role of SARs in inclusive play environments for children with and without mobility disabilities in real-world settings like day-care centers and preschools.

I. Background

The Office of Disease Prevention and Health Promotion reports that physical activity for children improves bone health, cardiorespiratory and muscular fitness, cognitive skills, concentration in tasks, and body fat content [1–3]. Yet, about half of preschool-aged children do not engage in the recommended amount of physical activity throughout the day [4]. The U.S. Department of Health and Human Services recommends that preschool-aged children be active all day [5]. Preschool-aged children spend a considerable amount of time in free play. However, it is concerning that only a portion of free play time is spent in moderate to vigorous physical activity [6]. Our work considers the use of robots as a potential means to encourage children to engage in moderate to vigorous physical activity during free play.

The affordance of a play area, defined as the environment it provides to a child, plays an important role in the child's active engagement in play [7]. Modifying the play area with children's evolving interests to

l interactions are strategies to keep children excited about play time [8]. In the past decades different kinds of robotic toys, including socially assistive robots (SAR) have made their way into play spaces [9–11]. In a closely related work by our study team using a complementary set of annotated data compared to the current manuscript, we observed greater engagement of children with a SAR that was mobile in the play area, and provided visual, tactile, and auditory rewards to children, as compared to SAR stationary conditions [12].

This paper presents a study that introduces an infant-sized mobile SAR in a free play environment. The objectives of our study are to enhance the affordances of the play area by providing developmentally appropriate toys and a SAR. We aim to assess the influence of a mobile SAR with rewards of lights, sounds, and bubbles on physical activity, play behavior, and toy-use behavior of children in a free play environment. The study consists of a baseline phase and intervention phase. In the baseline phase, the SAR is an inactive (i.e., immobile and powered off) part of the play area. In the intervention phase, the SAR is mobile and adds to the affordances of the play space by offering rewards (lights, sounds, and bubbles) to children. In this paper, we describe related work (Section II) that informed our aims, outline the methods (Section III), report our main findings (Section IV), discuss the results (Section V), note limitations and future work (Section VI), and summarize the conclusions from our study (Section VII).

Ii. Related Work

Key past work discussed in this section has enabled us to develop our study objectives and design our study. Broadly, we are interested in exploring the affordances provided by the SAR in children's play behavior. The United Nations recognizes the importance of play and recreational activities and regards them as a child's basic right [13]. In describing play, Pellegrini and Smith summarize play as an enjoyable activity that children engage in without a specific purpose [14].

Play Behavior and Child Development

Play has a vital role in a child's life and development [15, 16]. Play helps a child grow physically, emotionally, and cognitively [17], and serves as a conduit to explore the environment and interact with peers, adults, and objects such as toys [18, 19].

Play behavior advances as a child grows and develops, as listed in Table 1. For example, play during infancy is associated with exploration of the environment [20], engagement with adults, and interaction with objects, including toys [21]. Infancy (three to 18 months) is typically associated with solitary play that mostly occurs independently of nearby people. Although it is most dominant in early months of life, children also engage in solitary play later in childhood [22]. Toddlerhood (18 to 24 months) is typically associated with parallel play that occurs when children start playing in proximity with other children, but without actively interacting with them [23]. Early childhood (three to four years) is typically associated with peer interaction that may be associative or social play. Associative play is when a child becomes interested in a peer's toys and interacts with them with the intention of playing with their toys. Social play is more cooperative, wherein children cooperate with each other to share their toys [22]. Apart from toys

 in the play area. Adults interact actively or passively with children in the play area, especially in early stages of development [24]. Our study seeks to explore changes in play behavior in children at various developmental stages as a function of the affordances provided by the SAR in the play area.

Table 1
Predominant play behavior based on age

Age Range	Predominant Play Behavior
3–18 months	Solitary Play
18–24 months	Parallel Play
3–4 years	Peer interaction play, Adult interaction play

Affordances and Child Development

Affordances within a play area provide children with opportunities to explore the world. These may include substances, objects, and persons in the environment [25]. In a child's play area, affordances may be provided by toys, peers, and adults who facilitate play. The availability of developmentally appropriate toys enhances the quality of play [26]. The number and variety of toys available during play contribute towards improving the child's development, including cognitive [21] and motor [27] skills. Children up to the age of eight prefer exploratory, building, pretend play, physical activity and recreational, learning, sensory, and technological toys [28]. Among technology-based toys, one that is of broad interest to toddlers and older children alike are robotic toys. Although these toys appeal to children, little work to date has explored the influence of mobile robots on children's play.

Socially Assistive Robots

SARs have been used extensively to teach children cognitive, social, and motor skills [29]. Fitter et al. reported that infants as young as six months of age could imitate knee extension ball-kick behavior demonstrated by the Aldebaran NAO SAR [30]. While some infants in this study imitated the SAR without any rewards, others showed greater kicking acceleration when rewarded by lights or sounds generated by the robot. Guneysu and Arnrich [31] demonstrated feasibility of using the humanoid NAO robot in one-on-one exercise instruction and imitation by children. In another study, the NAO and the Wonder Workshop Dash (a small, wheeled toy robot) were part of a robot-assisted learning environment in a child rehabilitation setting [32]. Two infants and a toddler supported by a body weight support system exhibited complex motor tasks like climbing when following the robots. Children also aided the robots to complete motor tasks like going up an inclined surface, tasks that these toys were unable to complete without assistance.

Among the few studies that explored the impact of robots in a social setting was the work by Kozima and Nakagawa [33] who introduced an interactive Keepon robot to a group of preschoolers. They report initiation of interactions between the robot and children, and among children themselves in the presence

sm of robots plays an important role in captivating the interest of children [34, 35]. Researchers and practitioners capitalize on children's interest in robots to teach skills for which traditional teaching/therapy techniques may not be as effective. For example, there are multiple interventions for children with autism that employ robots to teach psychomotor skills such as movement in the four main directions [36], coach children on the recognition of social and gestural cues and enhance communication skills [37, 38]. Many of these interventions use SARs to engage participants in social interactions [39]. There is, however, a dearth of research using mobile SARs, particularly those with a base-motion speed capable of eliciting moderate to vigorous physical activity during play. Our SAR, which includes a TurtleBot 2 base, is capable of faster motion speeds than the previous robots discussed in this subsection.

Iii. Methods

The study involved seven weekly free play sessions with a within-subjects group design. During the first four sessions (baseline phase), the SAR was powered off. In the last three sessions (intervention phase), the SAR was teleoperated to move in the play area and offered rewards of lights, sounds, and bubbles to children.

Participants

Six children between the ages of one and seven (Range = 1.6 to 6.7 years; M = 3.6; SD = 1.9; five females; all Caucasian), who attended two or more play sessions during both the baseline and intervention phases were included for analyses.

Procedure

IRB and Informed Consent

Approval for all study procedures was obtained from the Oregon State University Institutional Review Board. Written informed consent from parents was obtained prior to the start of the study.

Play Area

The play area (approximately 440 sq. ft or 41 m^2) was lined with alternately colored blue and green foam squares (each 2' X 2' or 0.6 X 0.6 m), and children were instructed to remain in the play area for the entire session. At the start of each play session, the same set of developmentally appropriate toys was set up in the same location, as shown in Fig. 1. Toys for the age range included physical activity and recreational toys, sensory toys, learning toys, pretend play toys, and the SAR.

Play Session Description

There was a total of seven weekly sessions with four baseline sessions (weeks one to four) and three intervention phases (weeks five to seven). A fourth planned weekly session for the intervention phase was cancelled due to the COVID-19 pandemic. Each weekly session was approximately 30 minutes long wherein children engaged in free play. In this study, free play is defined as play behavior that is controlled by the child, with minimal involvement of adults [40]. Parents and research team members intervened minimally during play time.

The SAR used in the study was an infant-sized mobile robot which is capable of providing configurable rewards of lights, sounds, and bubbles. During the baseline phase the SAR was powered off, and during the intervention phase, a research team member used a teleoperation interface to maneuver the SAR to approach each child in the play area at varying intervals and activated the rewards of lights, sounds, or bubbles. We randomized the order in which children were approached each session using a random number generator. Every child received all three rewards during every play session in the intervention phase.

Data Collection and Video Coding

Overhead GoPro cameras were used to record the 30-minute play sessions, and these videos were used for data analyses.

Measurement

As summarized in Table 2, physical activity, play behavior, and toy-use behavior variables were annotated based on a predefined codebook, and the child and robot positions were tracked using computer vision.

Physical Activity

Physical activity behaviors were adapted from a direct observation system called the Observational System for Recording Physical Activity in Children: Elementary School (OCRAC-E) [41] to add more behaviors like catching/throwing, riding, and walking on knees based on observed behaviors during playgroup sessions (Table 2). The OSRAC observation system is used commonly to record children's physical activity behaviors [18, 42].

Play Behavior

Play behaviors were adapted from the Parten's Stages of Play [24], and Peer Play Scale [23]. The adaptations from both of these scales were made to include behaviors of interest for the current study. Similar coding systems have been used to assess play behavior of children at various stages of development [18, 43, 44]. Play behaviors were categorized as unoccupied play, solitary play, parallel play, peer interaction play, and adult interaction play (Table 2).

Toy-use Behavior

Toy-use behaviors were annotated based on the type of toy children were interacting with. Developmentally appropriate toys for the age range included physical activity and recreational toys, sensory toys, learning toys, pretend play toys, and the SAR (Table 2).

Child and SAR Positioning

Positional data for the child and SAR were extracted using the OpenCV multi-object tracking function [45] in a custom Python script. This region-of-interest tracker is commonly used in several different contexts such as traffic surveillance, surgery, and medical imaging since it allows for position monitoring for entities of interest [46]. To use the script, a research assistant selected bounding boxes for the SAR and each child in the play area. If a child or the SAR left the play area, the research assistant would re-select this target of interest when that child or robot re-entered the frame. At a rate of 25 frames per second, position data was automatically recorded at each timestep based on the position of each bounding box's center.

Table 2 Behavior Assessments with Categories

Behavior	Categories
Physical Activity Type	• Standing • Sitting/Squatting • Walking • Kneeling • Climbing • Sliding Down • Crawling • Running • Lying • Bending • Lifting • Pulling/Pushing • Jumping • Riding • Throwing/Catching • Walking on Knees
Play Behavior	• Unoccupied play - Child not engaging in any play behavior • Solitary play - Child playing independently without interaction with anyone • Parallel play - Child playing within three ft of another child without deliberate interaction with the peer • Peer interaction play - Child engaging in direct verbal or physical interaction with peer • Adult interaction play - Child engaging in direct verbal or physical interaction with adult
Toy-use Behavior	• Physical activity and recreation toys - Mini basketball unit, slides, walkers, balls, and trike • Sensory toys - Sensory table and bean bag chair • Learning toys - Play unit and activity tables • Pretend play toys - Play kitchen, play food, play mobile phone, hand puppets and shopping cart • SAR

Data Analysis

The videos were annotated using a momentary time sampling observation system [18, 47]. This technique involves breaking down the 30 minutes of video into 10-second consecutive intervals, observing the child behavior for the first two seconds of each interval, and recording the observed behaviors during the remaining eight seconds of each interval. The protocol used in this study was adapted from previous studies where the first five seconds of 15-second intervals [18] or 25-second intervals [47] were annotated for child behaviors. Shorter epochs of 10 seconds were used for recording behaviors in the present work based on accelerometer-based cut-point estimations for moderate to vigorous physical activity of toddlers [48]. Six observation intervals were annotated for each minute, resulting in 180 observations per child for every session. This yielded in a total of 5,400 observation intervals across the study.

Two trained coders annotated all the video recordings for behaviors. One coder annotated the physical activity behaviors, and the other coder annotated play behavior and toy-use behavior. An inter-rater

 ablished between an additional expert coder and the two trained coders for 10% of the video recordings. Agreement of 85% or higher is considered acceptable in observational studies of children [18]. Percent agreement was calculated as the following:

$$PercentAgreement = \left(\frac{\#ofagreementsbetweencoders}{\#ofagreements + \#ofdisagreements}\right) \times 100$$

For physical activity, play behavior, and toy-use behaviors, the percentage of total intervals when the child was in the field of view is reported. For child and robot positioning, the percentage of total frames when the child was within three feet of the robot in the field of view is reported. For each child, mean percentage of time spent in each behavior in each individual phase is calculated as follows:

$$Mean\%ofTimeinBehavior = \left(\frac{\#ofobservedintervalsforthebehavior}{Total\#ofintervals}\right) \times 100$$

For the computer vision-generated data the distance between the SAR and each child was calculated for every timestep. Then, the percentage of frames where the child was within three feet of the SAR was calculated to determine time spent by the child in parallel or more complex play behaviors within close proximity of the robot [43]. For each child, mean percentage of time spent that the child was within three feet of the SAR is calculated as follows:

$$Mean\ \%\ of\ Time\ frames\ when\ child\ was\ within\ 3\ ft\ of\ SAR$$
$$= \left(\frac{\#\ of\ time\ frames\ when\ the\ distance\ between\ child\ and\ SAR\ is < 3ft}{Total\ \#\ of\ time\ frames}\right) \times 100$$

Statistical Analyses

A within-subjects group design was used to analyze the data. Due to the non-parametric nature of the data, paired-Wilcoxon signed rank tests were conducted using the SPSS statistical software (version 25).

Iv. Results

In this section, we provide the breakdown of coding results for each behavioral assessment of interest. In each of the figures below, we first report behaviors for individual play sessions during the baseline and intervention phases. Then, we report behaviors combined across baseline and intervention phases. All of the SAR technology worked correctly for all sessions except the bubble-blowing attachment, which had reduced functioning during Session 6, the second session of the intervention phase.

Physical Activity Type

Children engaged in all types of physical activity during the play sessions (Fig. 2a and b). Much of the play time was spent in three types of physical activity including sitting/squatting (~ 40%) standing (~ 27%), and walking (~ 12%). The other physical activity types accounted for a combined total of ~ 21% of time intervals. Time spent in standing was significantly greater (~ 15%; Z = -2.09; $p = 0.037$) in the intervention phase as compared with baseline phase (Fig. 2b). Conversely, time spent in sitting tended to be lesser (~ 19%; Z = -1.89; $p = 0.059$) in the intervention phase as compared with baseline phase. There were no significant differences in time spent in other physical activity types between baseline and intervention phases.

Play Behavior

Children spent majority of the play time engaged in parallel play (~ 48%) followed by solitary play (~ 37%; Fig. 3a and b). There was a significant decrease (~ 4.5%, Z = -2.70; $p = 0.007$) in peer interaction play in the intervention phase as compared to the baseline phase (Fig. 3c). There was a tendency for greater (~ 4.5%, Z = -1.89; $p = 0.059$) interaction with adults in the intervention phase as compared to the baseline phase.

Toy-use Behavior

Children played with a variety of toys including physical activity and recreation toys (~ 26.5% of time intervals), learning toys (~ 18% of time intervals), pretend play toys (~ 17% of time intervals), the SAR (~ 5% of time intervals), and sensory toys (~ 4% of time intervals) throughout the study. They also played with multiple toys (~ 16.5% of time intervals) at a time and engaged in play with no toys (~ 12.5% of time intervals). There was a significant increase (~ 11.5%, Z = -2.52; $p = 0.012$) in interaction with the robot in the intervention phase compared to baseline phase. These interactions included touching, following, looking at, pushing/pulling, or going towards the robot or its rewards [12]. There was also a significant decrease (~ 6 %, Z = -2.40; $p = 0.017$) in play with pretend-play toys in the intervention phase as compared to baseline phase (Fig. 4).

Child and SAR Positioning

While interacting with the robot, children spent ~ 10.5% of time within three feet of the robot throughout the study. Children spent significantly greater time (~ 12.9%; $p = 0.02$) within three feet of the robot in the intervention phase as compared to the baseline phase (Fig. 5b).

V. Discussion

This is the first study to introduce a mobile SAR in a free play environment to assess children's physical activity, play behavior, toy-use behavior, and proximity to the robot. Enhanced child behaviors during the intervention phase when the robot was active suggest potential effects of the affordance provided by the mobile SAR in its design and the rewards of lights, sounds, and bubbles.

Children spent more time standing and had a tendency to sit less in the intervention phase compared to the baseline phase. A parallel segment of this study with the SAR reports that children look at and touch the robot more when it is mobile [12]. It is possible that children were captivated by the novelty of the SAR

 ding and engaging with it as it approached them and their peers [24]. Children spent less time standing and more time sitting in the second and third intervention sessions (Session 6 and 7 of the current study, respectively), as compared to the session when the SAR was first activated. This observation implies that the novelty of the robot dwindles over time. The fading of ‘novelty effect’ is common especially in studies involving children [49, 50]. Strategies to address the declining novelty effect include using SARs with life-like properties, staggered introduction of SAR novel behaviors, and making the SAR more adaptive to child behaviors. Gradually introducing children to different robot behaviors, rather than all at once is also likely to keep them more engaged with the robot. Kokkoni et al. noted that children are more likely to look at the robot if it exhibits unexpected behaviors [32]. Finally, reciprocal behavior from the SAR in the form of verbal or non-verbal social interactions may also be key to keep children interested in the SAR [51].

In the intervention phase, peer interaction play decreased with a corresponding tendency of increased adult interaction as compared to baseline phase. Over the study period, as children familiarized themselves with the play environment and adults (including research staff and parents), they initiated more conversations, pretend play, and other play behaviors with adults. For example, a child brought play food on a plate to one of the research team members, while another child initiated a game of catch with other research team members. Additionally, in the intervention phase, children interacted more with the robot teleoperator to initiate more robot rewards, especially bubble rewards. Although research team members were in the outer perimeter of the play area, this finding suggests that adults are an important affordance of a child’s play area [52]. Solitary play, parallel play, and intervals when children were not playing did not vary significantly between the baseline and intervention phases.

Vi. Limitations And Future Work

A limitation of our study is the small sample size (n = 6) with limited diversity (five females, all Caucasian, all typically developing). Also, we had limited intervention sessions owing to the COVID-19 pandemic and could not incorporate a withdrawal phase following the intervention with the robot turned off again, similar to the baseline phase. Our study design consisted of non-randomized baseline and intervention phases, leading to possible ordering effects in our observations. Finally, we had minor technical difficulties with the SAR in Session 6, leading to reduced functioning of the bubble-blowing attachment during the latter part of that session.

This pilot study contributes towards the limited literature on affordances provided by a mobile SAR in a free play environment. Future work needs to expand on the current findings by increasing the sample size and purposefully recruiting children for a more diverse and inclusive playgroup. These findings also demonstrate the feasibility of using mobile SARs in social settings like classrooms, daycare centers, playgrounds, and parks for purposes apart from education and skill-development. The next steps will be to study the role of mobile SARs on physical activity, play behavior, and toy-use behaviors in these natural settings with a broader user base, including children with disabilities.

Vii. Conclusion

The current study incorporated an infant-sized mobile SAR in the play space to assess its influence on children's physical activity, play behavior and toy-use behavior. Results of the current study suggest that the SAR is capable of engaging children's attention through increased proximity and play with the SAR during the intervention. Interest in, and engagement with the SAR when it moves and provides rewards demonstrates the affordance it provides to engage children in the play area. Greater interaction and closer proximity to the robot may also be attributed to the novelty of a mobile SAR with rewards. These findings pave a path for employing SARs in combination with assistive mobility technologies like the body weight support system, walkers, motorized wheelchairs and orthoses to augment engagement and exploration of the environment by children with mobility disabilities. Furthermore, toy companies can focus on developing SARs that offer a wide array of developmentally appropriate rewards, to engage children with and without disabilities in various kinds of moderate to vigorous physical activity.

Abbreviations

SAR: Socially Assistive Robot

Declarations

Ethics Approval, Consent to Participate, and Consent for Publication

Approval for all study procedures was obtained from the Oregon State University Institutional Review Board (Study #: IRB-2019-0313). Written informed consent from parents was obtained for participation of their children in the study, and for publication of their data and images, prior to the start of the study.

Availability of Data and Materials

Based on the terms of our IRB protocol, datasets collected from this study are not publicly available. These datasets are only available to those individuals added to the IRB protocol.

Competing Interests

The authors declare that they have no competing interests.

Funding

Not applicable

Author's Contributions

JRV co-designed the study along with NTF and SWL. She also led the primary data collection, contributed towards data analysis, and led the writing of the manuscript. NTF and SWL provided guidance for designing the study and for data analysis. They also reviewed the manuscript multiple times and provided final approval of the manuscript to be submitted. AH, CZ, EO and TV aided in data analysis. MW and SN aided in data collection and backing up the videos from play sessions.

Acknowledgements

The authors would like to acknowledge the contributions of Ashwin Vinoo for developing the initial robot prototype, Gabriela Zott for training the team on SAR use, and all the undergraduate who helped with setting up the play sessions.

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Figures

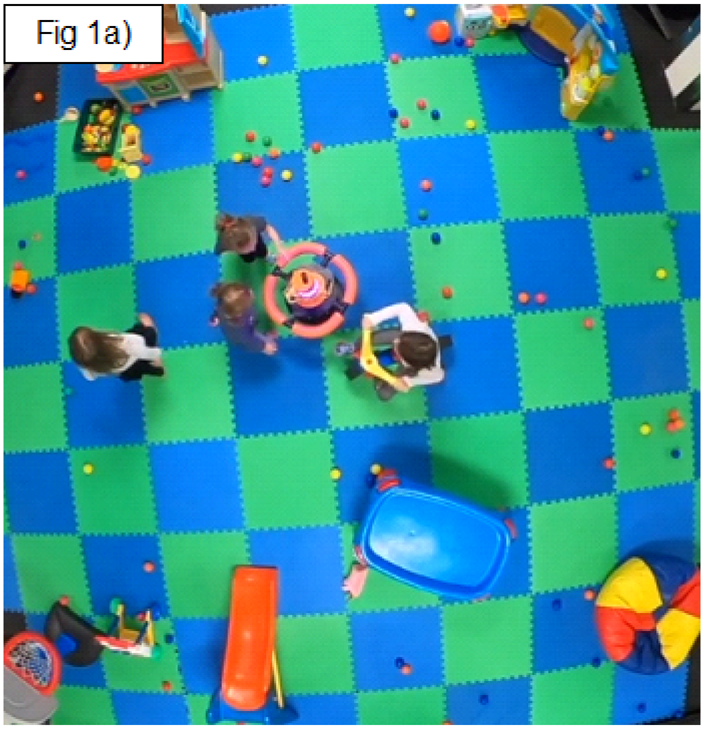

Figure 1

a. Overhead view of the play area with developmentally appropriate toys and the SAR; Fig. b. SAR in the play area

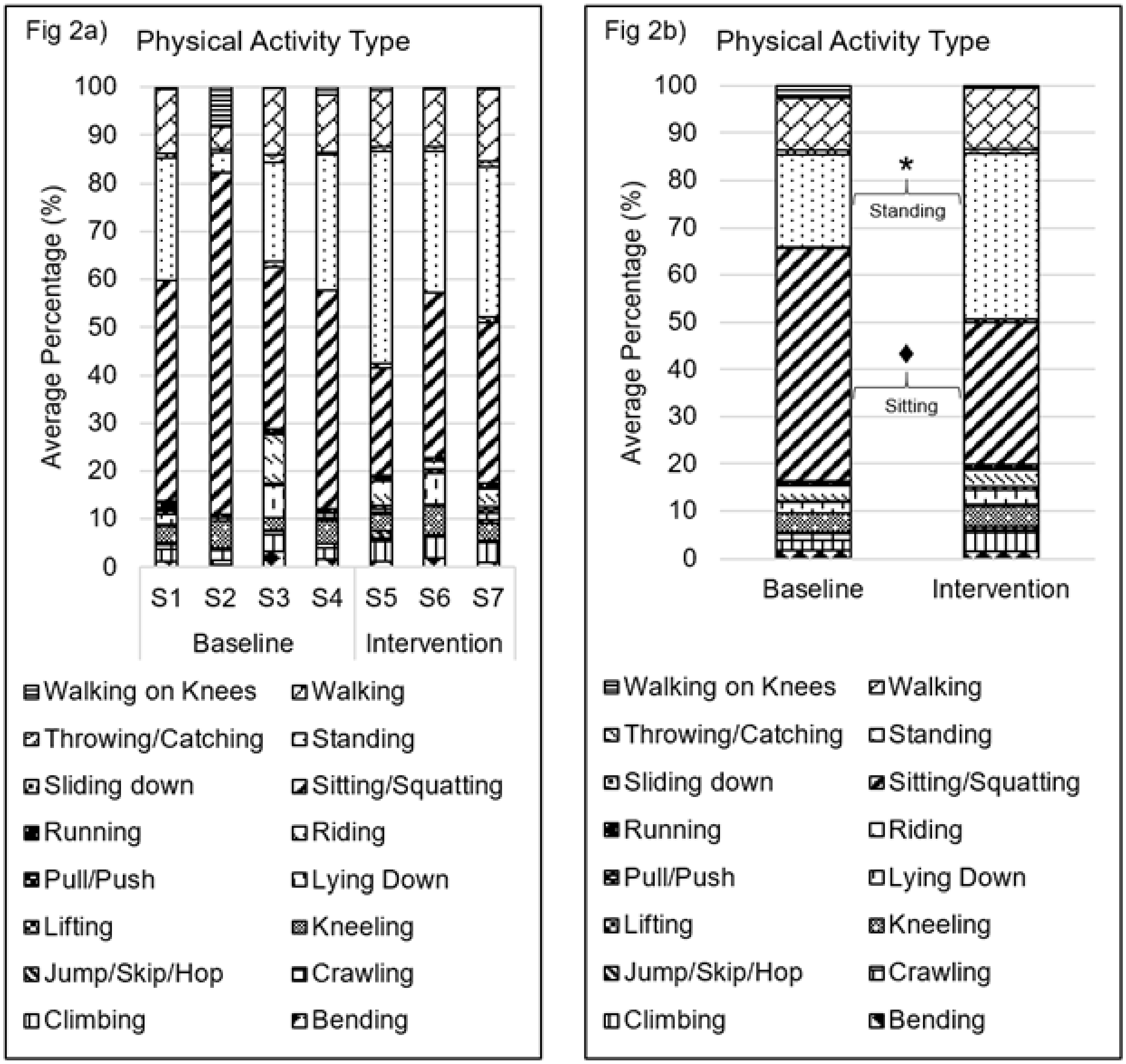

Figure 2

Physical activity type. a) Average percentage of intervals spent in each type of physical activity across sessions. S# on the x-axis represents the session number. b) Average percentage of intervals spent in each type of physical activity during baseline and intervention phases. * → $p < 0.05$; ♦ → $p < 0.06$.

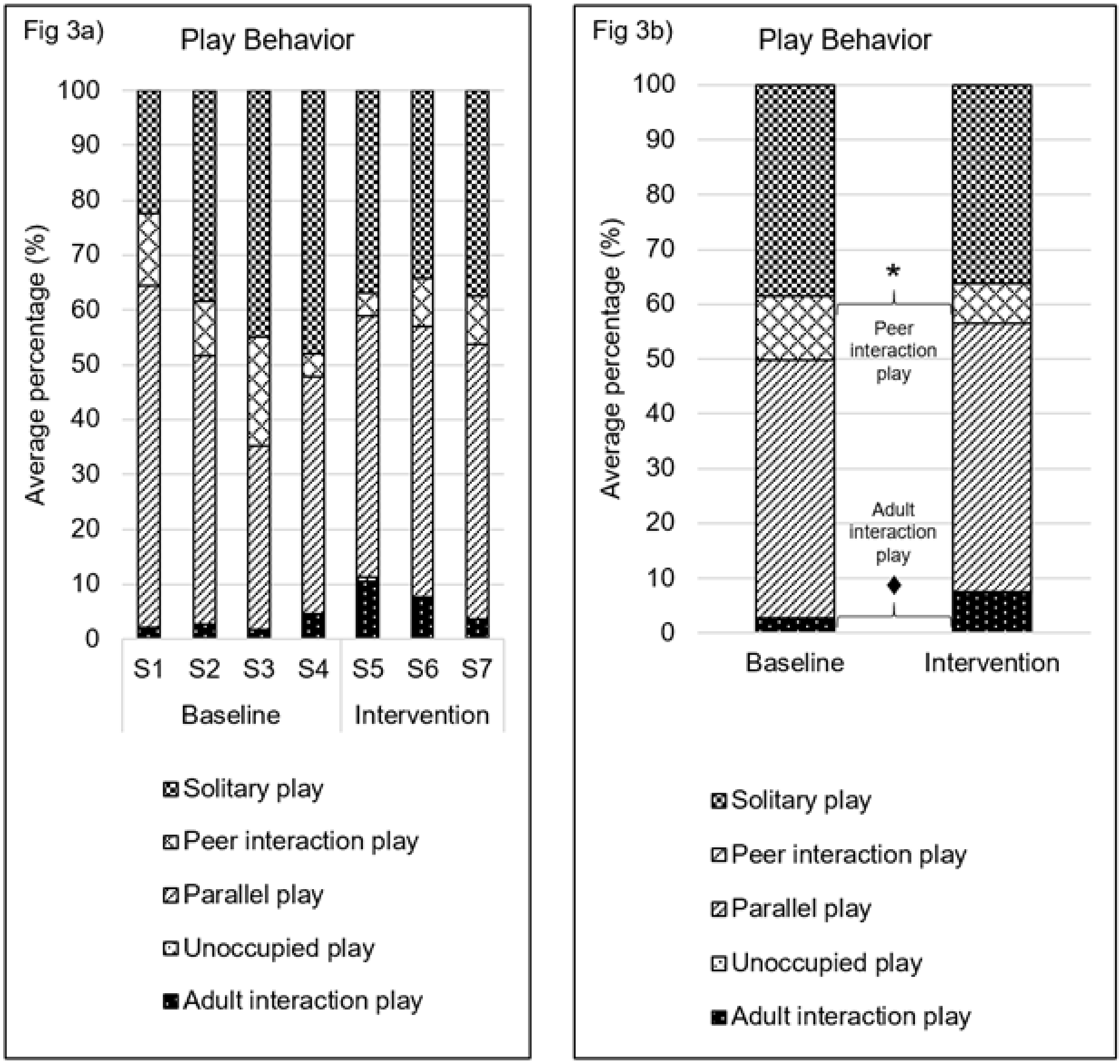

Figure 3

Play behavior. a) Average percentage of intervals spent in each type of play behavior. S# on the x-axis represents the session number. b) Average percentage of intervals spent in each type of play behavior during baseline and intervention phases. * → $p < 0.05$; ♦ → $p < 0.06$.

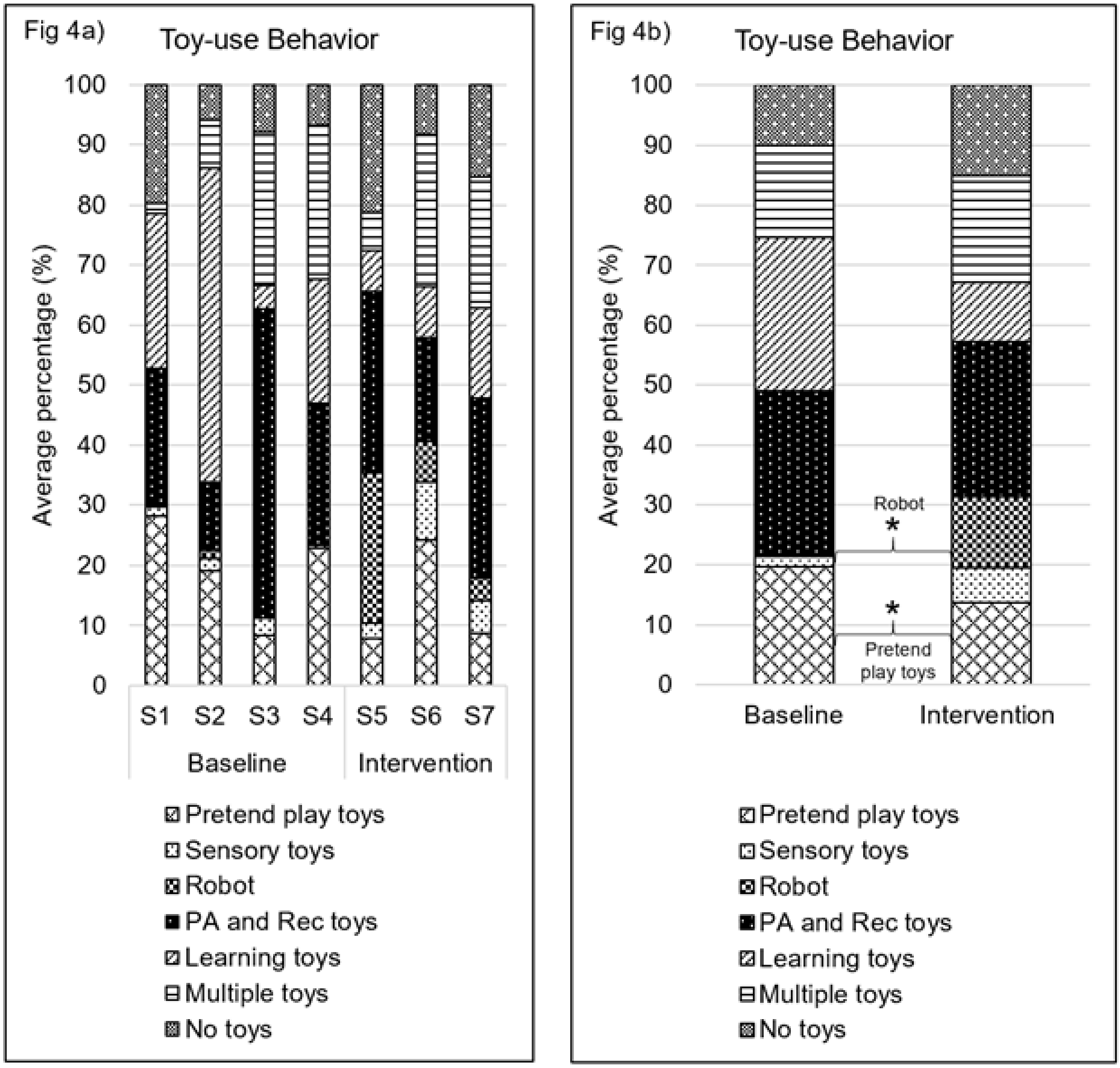

Figure 4

Toy-use behavior. a) Average percentage of intervals spent interacting with each type of toys. S# on the x-axis represents the session number. b) Average percentage of intervals spent playing with each type of toy during baseline and intervention phases. * → $p < 0.05$.

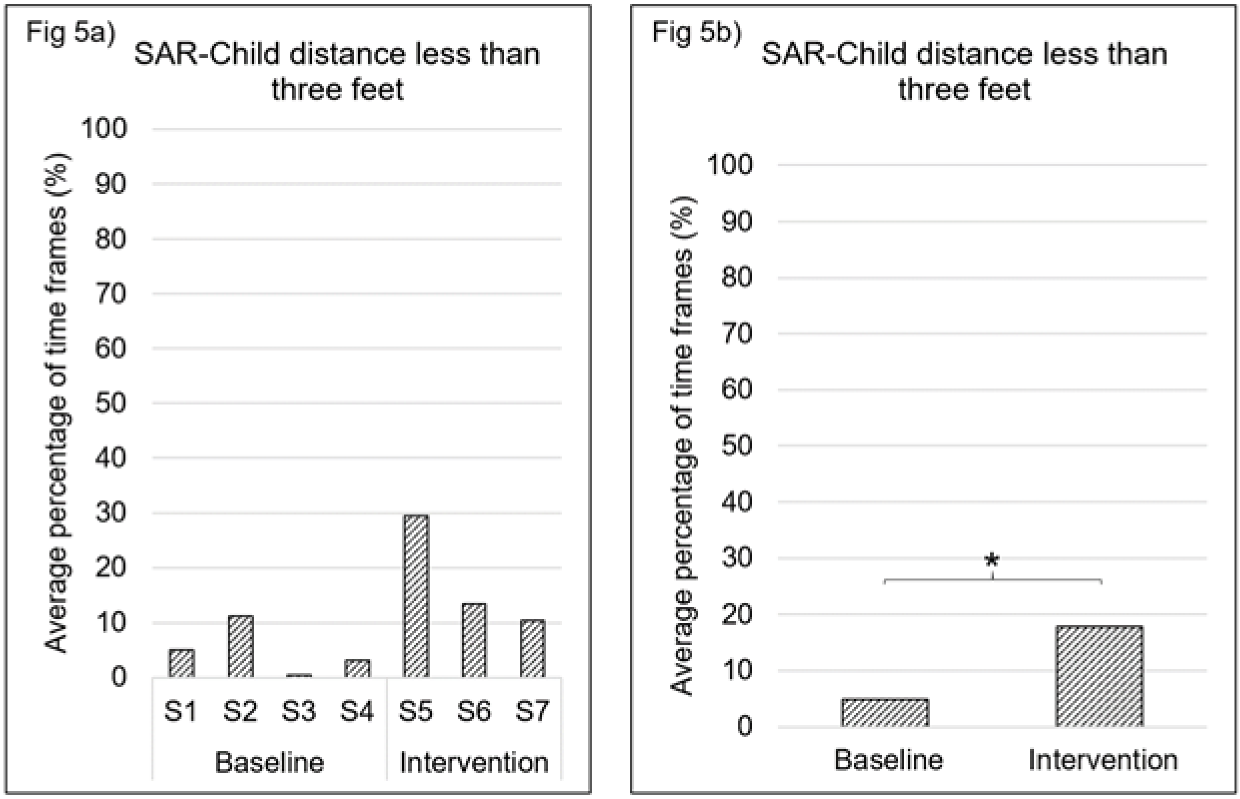

Figure 5

SAR-child positioning. a) Average percentage of time frames when children were within three feet of the robot. S# on the x-axis represents the session number. b) Average percentage of time frames when children were within three feet of the robot during baseline and intervention phases. * → $p < 0.05$.