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PLAYFULNESS IN CHILDREN WITH LIMITED MOTOR ABILITIES WHEN USING A ROBOT

ABSTRACT. Aims: Children with motor impairment have fewer opportunities to engage in free play. We investigated the effect of a robotic intervention on the playfulness of children with cerebral palsy (CP). **Methods:** We used a partially non-concurrent multiple baseline design with four children and their mothers. Children were classified in level IV or V on the Gross Motor Function and Manual Ability Classification Systems.. The intervention was the availability of an adapted Lego robot during a 15 minute free play session between the child and mother. There were two sessions per week for about 14 weeks. Playfulness was measured using the Test of Playfulness. **Results:** Statistical comparisons using the 2 SD band and X-moving range chart methods revealed that all the children's levels of playfulness increased significantly while they played with the robot. Comparison of baseline and follow-up phase indicated that three children had retention of improved level of playfulness. **Conclusion:** Play with adapted Lego robots increased the level of playfulness in all four children during free play with their mothers. The findings have implications for providing children with limitations in motor abilities opportunities for free play with family and friends. .

KEYWORDS. play, playfulness, cerebral palsy, adapted aids, technologies.

Playfulness indicates children's engagement in free play (Skard and Bundy, 2008). In contrast to planned structured activities led by an adult, free play is characterized by children's spontaneous engagement in an activity is that is intrinsically motivating and self-regulated (Missiuna and Pollock, 1991). Typically developing children who are playful tend to demonstrate creativity and flexibility in problem solving, positive affect (Bundy, 2010), and adaptive behaviors (Saunders, Sayer, & Goodale, 1999). Due to limitations in mobility and manual ability children with cerebral palsy (CP) may have fewer opportunities for free play. Without opportunities for self-initiated and spontaneous play, children can develop a learned helplessness and assume that they are unable to perform a task even though they may have the required physical abilities (Harkness and Bundy, 2001). Playfulness is affected in children with CP (Harkness and Bundy, 2001; Chang, et al., 2014; Okimoto et al., 1999). Children with CP who are more playful are more self-determined than those who are less playful.Ref Self-determination includes behaviors oriented towards meeting personal life goals and includes identifying desires, actively pursuing interests, making decisions, and solving problems (Chang, et al., 2014). Promoting playfulness in children with CP, therefore, might have a positive effect on self-determination, adaptive behaviors and problem solving in creative ways.

Assistive technology (AT) refers to devices, services, strategies and practices used to improve functional capacity of people with disabilities (Cook and Polgar, 2008). Assistive robots are an AT that can potentially improve the functional capacity of children with disabilities to have an active role in play activities, and possibly influence their playfulness. Assistive robots can be programmed to move in different axes (Cook et al., 2010) and are more versatile than switch toys and environmental control systems (Cook et al., 2002). Children with motor impairments have used robots to manipulate play materials by using one or more switches (Cook et al., 2011;

Kronreif et al., 2007). Lego robots are inexpensive, portable, and appealing to children making them useable at home or in schools (Cook et al., 2010).

Although the need for interventions to promote play in children with CP has been widely stated (Chang, et al., 2014; Missiuna and Pollock, 1991; Pfeifer et al., 2011), few studies have investigated changes in their play or playfulness following an intervention. Some behaviors related to playfulness such as enjoyment, curiosity and active engagement, have been observed while children with motor impairments interacted with robotic arms and Lego robots (Cook, et al., 2000, Cook et al. 2011). In contrast, two studies reported that using a robot during structured occupational therapy sessions with children with developmental disabilities (including CP) did not significantly improve playfulness (Besio et al. 2013; Klein et al., 2011). There is no direct evidence that a robot increases children's playfulness during free play.

This study investigated the effect of a robot-based intervention on a child's playfulness. Based on the theoretical approach to play as self (Sutton-Smith, 2001) where play is valued for its enjoyment and fun, the main contribution of the study was being the first to investigate a robotic intervention during free play of children with CP with limited mobility and manual ability. The hypothesis was that Test of Playfulness (ToP) scores of children with CP would increase <u>during</u> the intervention when a robot as an augmentative manipulation device was available for free play with their mother in a natural environment compared with ToP scores in baseline. We also explored whether ToP scores increased <u>following</u> the intervention compared with baseline scores.

METHODS

Study Design

This study used a non-concurrent multiple baseline design where measurement begins at different times (Watson and Workman, 1981; Kazdin, 2011). There were three phases; baseline (5 to 8 sessions), intervention (10 sessions) and one month follow-up (three sessions). During the baseline and follow-up phases, children and their mothers were instructed to play together for 15 minutes using the child's toys. During the intervention phase, the child and mother also were instructed to play together and could choose to include the robot in their play.

, sessions were conducted twice per week, planned at the same time of the day.

Participants

The participants were a sample of convenience of four children with CP and their mothers. The families lived in Bogotá, Colombia and spoke Spanish. The inclusion criteria for the children were: a) between 4 and 9 years of chronological age, b) severe motor impairment defined as level IV or V of the Gross Motor Function Classification System (GMFCS) (Palisano et al., 2007) and level IV or V of the Manual Ability Classification System (MACS) (Eliasson, et al., 2006), c) ability to express choices and answer yes/no questions, d) able to follow a two-step instruction, and e) able to make the robot move forward and turn using two switches. . Children were excluded if: a) they were unable to identify objects four feet away due to vision impairments, b) they were unable to hear conversations with parents due to hearing impairments, c) their mother had cognitive, communication or sensory impairments, and d) the family did not play with the child at least twice a week. Ten families who expressed interest in participating did not meet the inclusion criteria. The study was approved by the Health Research Ethics Board at the relevant Universities. Mothers gave consent to participate. Table 1 describes the participants.

[Insert Table 1 about here]

Materials and Measures

The Lego Invention "roverbot" vehicle with a scoop was used (Figure 1). As in previous studies (Cook et al., 2011; Poletz et al., 2010), children operated the robot (programmed using the Lego Intervention System 2.0) using Jelly Bean^{TM} switches through an adapted infrared remote control. The switches were placed according to each child's motor skills considering position, movement patterns (voluntary and consistent), and control site (Angelo, 1997). Details of the position, switch location, and robot programs, and training protocol can be obtained from the first author.

[Insert Figure 1]

Test of Playfulness (ToP) version 4 (Skard &Bundy, 2008). Indicate how the TOP is administered and scored. The TOP has 29 items reflecting four elements: Intrinsic motivation (e.g., engaged, persists); Control- self-control (e.g., decides, transitions) and shared control (e.g., negotiates, social play); Freedom to suspend reality (e.g., mischief, pretends); and the Frame (e.g., gives cues, reads cues). Each item is rated from 0 to 3 for extent, intensity and/or skillfulness, as applicable (Bundy et al., 2001). The validity, reliability and responsiveness of the ToP have been supported for children with CP (Skard & Bundy, 2008).

Inter-rater reliability for the TOP was established by having a second rater independently score 19 randomly selected sessions (27.9% of the baseline, 20% of the intervention, and 33.3% of the follow-up sessions). Both raters were occupational therapists who were proficient in Spanish and English and trained and calibrated in the ToP application and scoring as done in previous studies (Chiarello, et al., 2006; Rigby and Gaik, 2007). Reliability was calculated as the percentage of sessions in which the scores of each rater overlapped (A. Bundy, personal communication, December, 5, 2013). Inter-rater reliability for all participants across baseline, intervention and follow-up sessions was 95%. The confidence intervals of the ToP overall score of the two raters overlapped in 18 out of 19 sessions.

Canadian Occupational Performance Measure (COPM) (Law, et al., 1998). The COPM – brief description Children younger than 8 years of age have difficulty using the COPM format (Missisuna, Pollock, Law, Walter, & Cavey, 2006). Additionally, valid respondents about the client's performance can be caregivers (Law et al., 1998). The COPM has good reliability and validity (Law et al., 1998). In our study the COPM was used to provide social validation of change (Kazdin, 2011).

Procedure

The study was conducted in children's home or treatment setting. The sessions were carried out as convenient for the families and during the time the mother usually did activities such as playing with the children, reinforcing skills, doing homework or resting after school. The TOP was scored during all baseline, intervention, and follow-up sessions by the first author who observed the child and mother engage in 15 minutes of play. Add the instructions provided to mother regarding play. The COPM was used to assess mother's perceptions of her child's performance in play and her satisfaction with the child's performance at four times; enrollment, and at the end of the baseline, intervention and follow-up phases.

After the baseline sessions, each child was taught to make the robot move and carry objects according to previous protocols (Adams and Cook, 2014; Cook et al., 2012; Encarnação et al., 2014; Poletz et al., 2010). For example, children learned to press and hold a switch to make the robot move forward and knock over blocks and release the switch to stop the robot. The number of training sessions depended on how quickly each child reached the highest skill level (sequencing using forward, backward and turns) (Cook et al., 2012; Encarnação et al., 2014) but did not exceed two and a half weeks. Each mother was trained in technical aspects such as how to turn the robot on, position the remote control so the infrared signal reached the robot, and re-assemble the robot if it came apart. Since we were interested in the effects of the intervention on children's playfulness during free play with mothers, only the mother was in the room during the sessions.

Participant assignment to the number of baseline sessions was made once the stability in the baseline scores was assessed at the fifth session (participants were randomly assigned five, six, seven or eight sessions) rather than assuming stable baselines a priori to the data collection as suggested by Watson and Workman (1981). This modification to the traditional non-concurrent design was used to ensure that one of the main requirements of single-case design, stability in baseline, was met.

During intervention, the child and mother were instructed to play together. They could choose to include the robot in their free play.

Procedural Fidelity

A detailed protocol guided the setup of every session (baseline, intervention and follow-up) (Gresham, 1996) and a checklist assessed adherence to the protocol. The first author conducted the sessions and checked the protocol at the beginning and at the end of each session and noted events during the session. Two different raters proficient in Spanish and English assessed the protocol integrity in 20 randomly selected sessions (32.9% of baseline, 20% of the intervention, and 33.3% the follow-up sessions) using the videos, the check list, and session notes taken by the first author. Adherence to the protocol was high, ranging between 91.27 % and 100% for all participants across baseline, intervention and follow-up sessions.

Data Analysis

All ToP raw scores were sent to the ToP's developer for conversion into a single ToP score of playfulness which ranged from +3 to - 3 based on Rasch analysis using Facets 3.71.3 (Bundy et al., 2001). Scores with a negative sign indicated that the child was expressing low levels of playfulness and scores above zero indicated more playfulness (Bundy, et al., 2001; Rigby and Gaik, 2007). The Rasch ToP scores were used to create the plots.

Data were evaluated according to the guidelines for single-case research (Kratochwill et al., 2010). Baseline stability was assessed using the X-moving range chart (Portney and Watkins, 2008). Data autocorrelation was assessed by running a lag-1 autocorrelation for the series of data at baseline and intervention (Ottenbacher, 1986). Levels, latency, trends and overlap were assessed through visual analysis of each phase and compared with the other phases (Kratochwill, et al., 2010; Ottenbacher, 1992; Portney and Watkins, 2008). Statistical significance of the change was established as at least two consecutive data points of the intervention phase and the follow-up phase falling outside the two standard deviation (2 SD) band calculated with the baseline data (Brien and Sveistrup, 2011; Øygard et al., 2011; Portney and Watkins, 2000;.

Additionally, to minimize the probability of committing a Type I error (0.26%), the X-moving range chart was used to compare the ToP scores at baseline, intervention and follow-up phases (Portney and Watkins, 2000). Limits were calculated as a ±3 standard deviation (3SD) band from the baseline mean (Orma and Cox, 2001). Statistical significance was defined as any one point that fell outside of the upper or lower limits (Portney and Watkins, 2008). If the study provided either strong or moderate evidence, the effect size was calculated (Kratochwill, et al., 2010) using the Improvement Rate Difference (IRD) (Parker, et al., 2009). All of the statistical analyses were calculated using Microsoft Excel 2010. Clinical significance was assessed using the 2SD band method and normative comparison (Kazdin, 2011).

RESULTS

The fit statistics of the playfulness data indicated that 87% of the data was within acceptable limits of the Rasch model. While less than the desired 95% fit, it is similar to research with children with motor impairments (Harkness and Bundy, 2001), attention deficit hyperactive disorder (Leipold & Bundy, 2000), or sensory processing dysfunction (Bundy, et al., 2007).

The baselines of each participant for the ToP Rasch scores were stable. There was no evidence of a significant autocorrelation between data points on the ToP at baseline or the intervention phase. Rasch scores for each participant for each phase are presented in Figures 2 to 5 along with the 3 SD band. Visual and statistical analyses revealed that all the children's playfulness increased significantly during the intervention. When comparing the baseline with the follow-up phase, retention of improvement in level of playfulness was observed for participants P01, P02, and P03 but not for P04. Regarding latency, graphs revealed that once the intervention began, the level of playfulness immediately improved for P02, P03 and P04.

Visual analysis of trends revealed that there were no evident trends in the baselines for P01, P02 and P03 and a slight accelerating trend in P04's baseline. During the intervention all ToP scores showed an accelerating trend. Since P04 demonstrated an accelerating trend during the baseline, the baseline was extended to the intervention to visually compare the trend of data across these two phases. All of the data points in the intervention phase fell above the extended celeration line demonstrating, according to Bloom's criterion, that the change during intervention was statistically significant (p value< 0.05). Effect size, calculated using the Improvement Rate

Difference (IRD) was moderate :0.58 (58%) for PO1 and large: 1 (100%) for P02, P03, and P04. Most (87%) of the data fit within acceptable limits of the Rasch model. Exceptions were five baseline (three P01 , one P03 and one P04 session), three follow-up (all P01), and two intervention sessions (both for P04).

[Insert Figures 2, 3, 4, and 5 about here]

Mothers' rating of play performance and satisfaction with performance increased for all children during the intervention and some carry over effects were perceived by mothers after the intervention. Most (81%) of mothers' COPM scores improved more than two units during the intervention indicating that the change in those children's identified problem areas was clinically relevant (Law, et al., 1998). Improvements identified by mothers were: attention and persistence with the activity, coordination and manipulation skills, posture, and communication during play.

The interviews revealed that all mothers were satisfied with the intervention. They stated that during the intervention their child was controlling the play, doing what the child wanted, playing independently, choosing the activity, and interested in interacting with toys.

DISCUSSION

In keeping with the hypothesis, ToP scores of the four children with cerebral palsy significantly increased during the intervention compared with baseline. In single case research "at least three demonstrations of the intervention effect along with no non-effects" are needed (Kratochwill, et al., 2010). Thus, the results provide strong evidence of a causal relationship between play with the robot and playfulness. Children's playfulness also significantly increased in three of four children in the follow-up sessions compared with baseline.

The baseline ToP scores provide information about the initial level of playfulness. P02 and P03 had all negative scores and P01 had negative scores during 75% of the sessions. These children with CP were generally expressing low levels of playfulness, consistent with previous research (Harkness and Bundy, 2001; Okimoto et al., 1999; Rigby and Gaik, 2007). Only P04 had positive playfulness values during the baseline. Children with lower levels of cognitive and motor functions had the lowest ToP scores. Chang et al. (2014) reported that cognitive-behavioral problems and gross motor function explained 41% of the variance in playfulness of children with CP at levels III to V on the GMFCS.

Playfulness of all of the children increased during play with the robot. P01, P03 and P04 had positive playfulness scores with an increasing trend. P02's ToP scores remained negative with an increasing trend, indicating that she still expressed low levels of playfulness despite statistically and clinically increased scores. According to the criterion of normative comparison (Kazdin, 2011), the results are clinically significant since children's playfulness trend was positive.

Mothers observed that it was easier for children to control the robot as the intervention advanced. Operating a Lego robot using three switches can be cognitively demanding for typically developing children younger than five years old (Cook et al., 2012; Poletz et al., 2010). Children with motor impairments gain skills for operating a robot as they practice (Cook, et al., 2011). In this study, the robot allowed children to learn through free play. As they developed more skills to operate the robot, they became more playful. This finding supports Sutton-Smith's (2001) assertion that free play is a powerful means of learning by innovative problem solving strategies where children learn while using their skills and enjoying the play.

In order to explore the changes, individual items were examined while recognizing the limitations of results at this level (e.g., reliability, validity). Most of the items that consistently improved belonged to the elements Intrinsic Motivation and Control (self and shared). Within Intrinsic Motivation, the robot had a positive impact on the items of *Engages*, *Persists* and

Interacts with objects with increases for all children during intervention and follow-up. Engagement likely increased because the robot was very motivating as reported by all the mothers. Children commented about the robot to relatives, teachers and neighbors. All children were very excited when the first author arrived with the robot and they focused on the robot rather than the researcher. P01 asked his mother every night “Is tomorrow a robot day?” The children had relatively high scores for *Persists* during baseline and scores increased during intervention. They were persistent about what they wanted to do with the robot and the toys. P01, P03 and P04’s mothers perceived an increase in their children’s persistence during and after intervention, consistent with Harkness and Bundy (2001).

The item *Interacts with objects* was low due to fine motor limitations, and all children showed low interest in toys. During baseline, the mothers of children with MACS level V (P02, P03) often manipulated all of the toys and children simply observed, as in Gowen et al. (1992). Scores improved and were more intense as all children used the robot for interacting with their toys. The children wanted to see what happened when they tried to knock, push, carry or drive over toys. They planned and executed interaction between the robot and the toys. For example, P03 asked his mother to load a toy on to the robot that was about five times bigger than the robot. Initially his mother refused but he insisted. The robot could carry the toy a short distance. Thus, children were able to explore an object’s properties while playing with the robot. Reilly (1974) describes this kind of behavior as curiosity that leads to exploration through which children test reality.

During intervention all children had an increase in Control-self, specifically the items *Decides*, *Modifies*, *Initiates* and *Transitions*. Harkness and Bundy (2001) previously found that children with CP scored unexpectedly low on *Decides*. Our results at baseline are consistent with these findings. Mothers tended to quickly offer toys, perhaps because the children had difficulty moving to get objects they wanted. Others choosing the toys may explain the relatively low engagement that Harkness and Bundy (2001) found. However, during the intervention, all children made the robot go to a desired toy and mothers tended to ask children how they wanted to play and then commented on the child's selections. All children initiated more play activities, especially P02 and P03 who initiated few activities during baseline. All children except P02 made modifications to the activity in order to explore different objects. During the follow-up, all children showed carry-over effects reflected in improvement in the items *Decides* and *Initiates*. This suggests that after the intervention children were more confident initiating and were able to decide about the activity they wanted compared with baseline.

When using the robot all children improved in *Responds to other's cues* and *Gives cues*. They wanted to communicate exactly what they required in order to use the robot and the toys. This is consistent with previous research where children tried new communication strategies (Cook et al., 2000). All children were active and had ideas about what to do. This suggests that having the robot as a tool to support their independence and participation during free play allows them to be more responsive, active and less compliant; they provide ideas and can lead the play. This change in the interaction was retained during follow up for P01 and P03. With the robot, P01, P03 and P04 improved in *Unconventional* (use of objects or people in unconventional ways). For example, P04 used the robot to coil a toy car spring and release the car. There were no carry over effects in this item. Children with severe motor impairments can interact with objects in creative ways but they need alternative means (e.g., the robot as assistive technology) to express it.

From a theoretical point of view, during the intervention children may have been in a psychological state called the flow channel (Csikszentmihalyi, 2008) in which the person feels enjoyment because there is a balance or a good match between a person's skills and the challenges of the environment. Bundy (2010) has associated the flow channel with the Intrinsic Motivation and Control-self elements of playfulness. Munier et al. (2008) pointed out that the flow channel is present in children's object play. During our intervention children were intrinsically motivated, controlled the activity, and experienced enjoyment due to a better match of their skills and challenges imposed by the objects. The robot was an augmentative manipulation device that allowed children to perform in a flow channel. Coplan et al. (2006, p. 75) suggested that children's free play is driven by the question "what can I do with this object or person?" In the present study, children explored "what can I do with these objects using the robot?" The robot allowed children to experience control, to create play activities, to solve problems, to try, and to lead the play. It allowed them to experience how playing feels.

The observed carry over effects may reflect an increase in mastery motivation or self-efficacy since Intrinsic Motivation and Control elements of play are associated with mastery motivation (Jennings et al., 1988; Majnemer et al., 2010) and self-efficacy (Reid, 2002). Following intervention items from the element Intrinsic Motivation and from the Control element of play were scored higher. Changes in mothers' perceptions of their child's ability might also contribute to the carry over effects.

Clinical implications

This study adds to the limited evidence for the effectiveness of interventions for play, addressing families' concerns about the type of toys and family activities that are best for promoting development (Munier et al., 2008). It provides evidence that adapted Lego robots promote playfulness in children with cerebral palsy who have limitations in mobility and manual ability o through free play in family routines.

Limitations and Recommendations for Research

The first author was not blinded to the study phase because she collected data, provided intervention, and scored sessions. This was unavoidable due to restricted availability of raters trained in the ToP and research methods and proficient in English and Spanish. The second rater was blind to the phase for the baseline and the follow-up measures; however, participants sometimes revealed aspects of the phase by comments about their robot use.

The inexpensive Lego Invention robots have many advantages, but they are not 100% accurate in their movements. Some children were momentarily disappointed when the robot did not go in the exact expected direction, similar to previous research (Encarnção et al., 2012). Children expressed frustration when the infrared signal did not reach the robot sensor in some sessions. A robot wheel and the robot scoop fell off in some sessions.

P01 took a taxi to the rehabilitation centre each session, which was a new experience. He was excited and incorporated the taxi in his play, e.g., "I am the taxi driver". Since taxis in Colombia are yellow as was the robot, it was easy to find similarities, which improved his pretend play. However, the taxi was a factor for all the phases. Children with cerebral palsy are more playful at home than in other community environments (Rigby & Gaik, 2007) and use of the rehabilitation centre imposed more restrictions in terms of scheduling than occurred for other participants.

This study met the minimum requirement of three subjects for a multiple baseline design, but the results are limited by the small sample of four Colombian children. Replications are needed.

Further research is recommended to identify strategies to maintain improvements in playfulness over time. Previous studies that found changes in playfulness in children with cerebral palsy after interventions did not explore retention of the effects over time (Okimoto et al., 1999; Reid, 2004). There is a need to find other play activities and strategies that will also allow children with limitations in mobility and manual ability express their playfulness.

CONCLUSION

This study demonstrated that Lego robots improved playfulness of four children with CP with limitations in mobility and manual ability (GMFCS and MACS levels IV and V) during free play with their mothers. All four children showed significant improvement in their playfulness when using a robot for play. They used the Lego robot to interact with their toys and explore, interact with and impact their physical environment in a playful manner. This finding provides support to the play theories and approaches that explain play from a psychobiological perspective (optimal arousal) (Coplan, Rubin, and Findlay, 2006), and from a cognitive and social perspective (Skard and Bundy, 2008; Reilly, 1974; Sutton-Smith, 2001). As the intervention progressed children had the opportunity to practice their skills; to experience self-control and intrinsic motivation; and to demonstrate persistence, concentration, and creative problem solving during free play. After the intervention children's playfulness showed some carryover with a tendency towards the baseline levels. Further research is recommended identify other play activities and strategies that will also allow children with limitations in mobility and manual ability to express their playfulness.

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Table 1. Description of Participants

Child						
Code	CA	Cognitive age according to PTI-2	Gender	GMFCS Level	MACS Level	Language
P01	5 y/ 5 m	VA: 7-0 FD: <3-0 QC: <3-0 PIQ: 89 (80-89= below average)	Male	V	IV	Good level of spoken language.
P02	9 y/ 4 m	VA: 3-3 FD: 3-3 QC: 3-3 PIQ: 42 (35-69= very poor)	Female	V	V	Very limited spoken language. She does not initiate a conversation but responds to questions using few words (e.g. yes, no, OK, good)
P03	6 y/ 4 m	VA: 4-6 FD: 3-6 QC: 4-6 PIQ: 74 (70-79= poor)	Male	V	V	Limited spoken language, tries to communicate other ways.
P04	8 y/ 11 m	VA: 6-9 FD: 6-9 QC: 6-9 PIQ: 83 (80-89= below average)	Male	IV	III-IV	Very limited spoken language, tries to communicate other ways.

Notes:
CA: chronological age. PTI-2: Pictorial Test of Intelligence -2 (French, 2001).
VA: Verbal Abstractions; FD: Form discrimination; QC: Quantitative Concepts; PIQ: Composite Quotient (M=100, SD=15?)

Table 2. Research conditions for each child

Child	**Setting / Child's position**	**Control site**	**Robot programs**	**Switch location**	**Robot design for easy switch use**	**Type of switches**
P01	Rehabilitation centre / Sitting on floor in sitter chair	Right hand	Forward: while pressing the switch	Yellow switch (with eyes drawn on it) located on a tray	Eyes on the front of robot	Jelly bean
		Right hand	Turn right: 45 degrees	Blue switch on right side of tray	Blue arm on robot's right side	Jelly bean
		Left hand	Turn left: 45 degrees	Red switch on left side of tray	Red arm on robot's right side	Jelly bean
		Head	Backward: While pressing switch	Blue switch behind right side of child's head, attached to chair using a mounting arm	Nothing	Jelly bean
P02	Home / Sitting on floor in a sitter chair	Right hand	Forward: While pressing switch	Yellow switch located on tray	Eyes on the front of robot	Jelly bean
		Right hand	Turn right: 45 degrees	Purple switch on right side of tray	Purple eyebrow on robot's right eye	Jelly bean
		Right or left hand	Turn left: 45 degrees	Blue switch on left side of tray	Blue eyebrow on robot's left eye	Jelly bean

Child	**Setting/Child's position**	**Control site**	**Robot programs**	**Switch location**	**Robot design for easy switch use**	**Type of switches**
P03	Home / Sitting in wheelchair due to recent hip dysplasia	Left forearm	Forward: while pressing the switch	Blue switch (with eyes drawn on it) attached to wheelchair using a mounting arm.	Eyes on front of robot	Jelly bean

	surgery	Head	Turn right: 45 degrees	Green switch attached on wheelchair's right side using a mounting arm.	Green arm on robot's right side	Jelly bean
		Head	Turn left: 45 degrees	Blue switch- on wheelchair's left side using mounted arm.	Blue arm on robot's right side	Jelly bean
		Left feet	Backward: While pressing the switch	Blue switch- on wheelchair foot-rest.	Nothing	Jelly bean
P04	Home / Sitting on a chair using hip straps. He was able to sit on floor without support but felt unsafe.	Right hand	Forward: while pressing the switch	Blue switch on a tray.	Eyes on front of robot	Jelly bean
		Right hand	Turn right: 45 degrees	Blue switch on right side of tray	Nothing	Jelly bean
		Right hand	Turn left: 45 degrees	Blue switch on left side of tray	Nothing	Jelly bean
		Head	Backward: While pressing the switch	Blue switch on left side of tray	Nothing	Jelly bean

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Figures

Figure 1. The roverbot with scoop used by P01 during one of the play sessions.

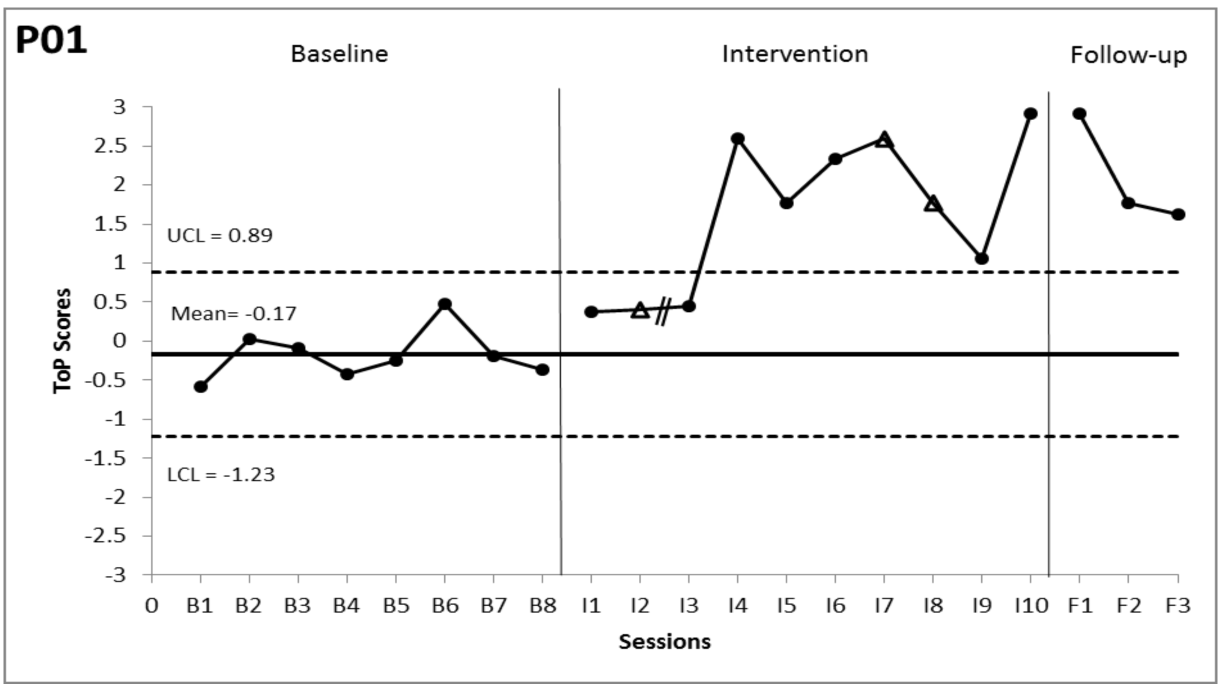

Figure 2. Comparison of ToP scores at baseline, intervention and follow-up phases for P01 using X-moving range chart.
UCL: Upper Control Limits (+3 SD). LCL: Lower Control Limits (-3 SD).
// = two sessions missed. Δ= P01 used the robot for only part of the session

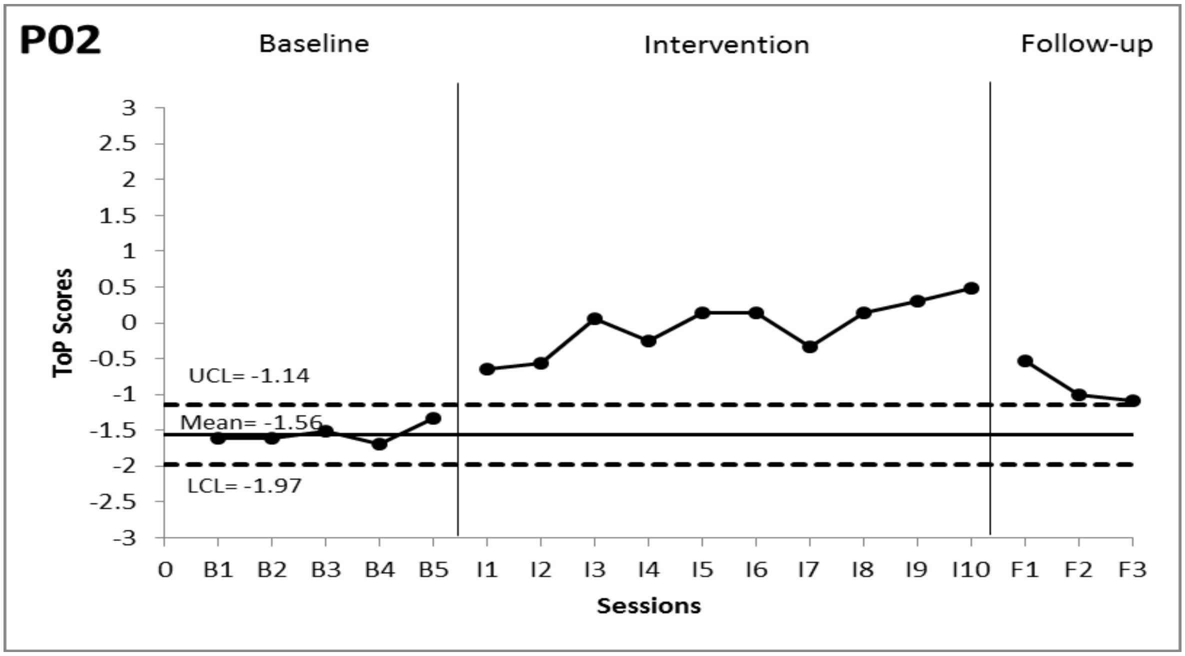

Figure 3. Comparison of ToP scores at baseline, intervention and follow-up phases for P02 using X-moving range chart. UCL: Upper Control Limits (+3 SD). LCL: Lower Control Limits (-3 SD).

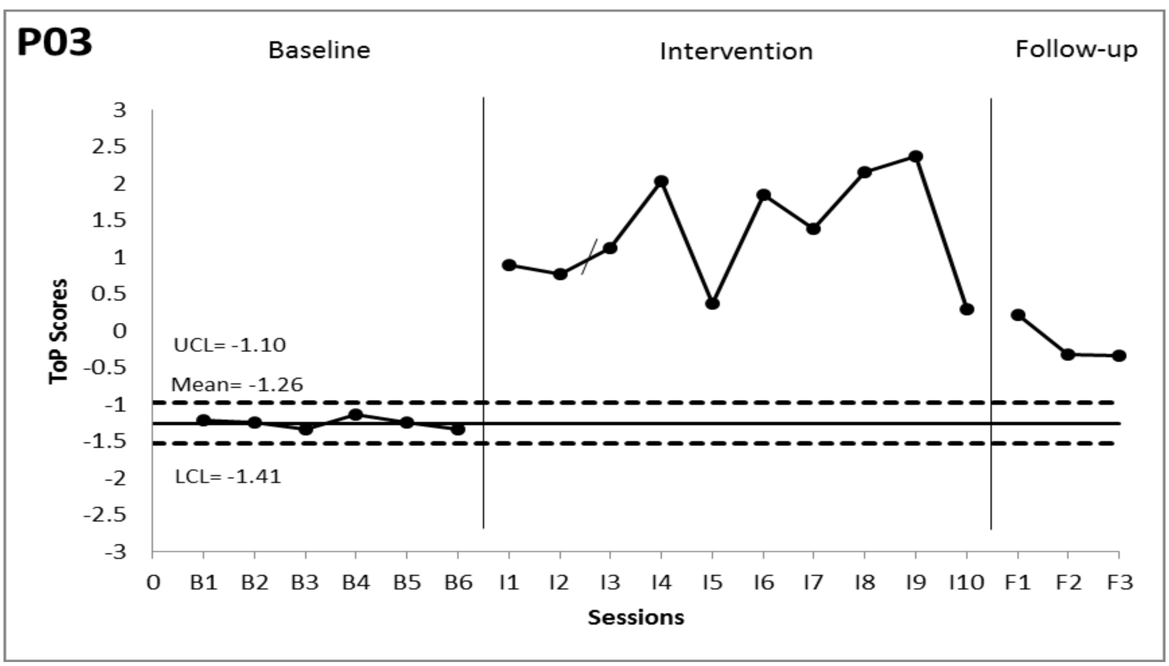

Figure 4. Comparison of ToP scores at baseline, intervention and follow-up phases for P03 using X-moving range chart. UCL: Upper Control Limits (+3 SD). LCL: Lower Control Limits (-3 SD).
/ = one session missed

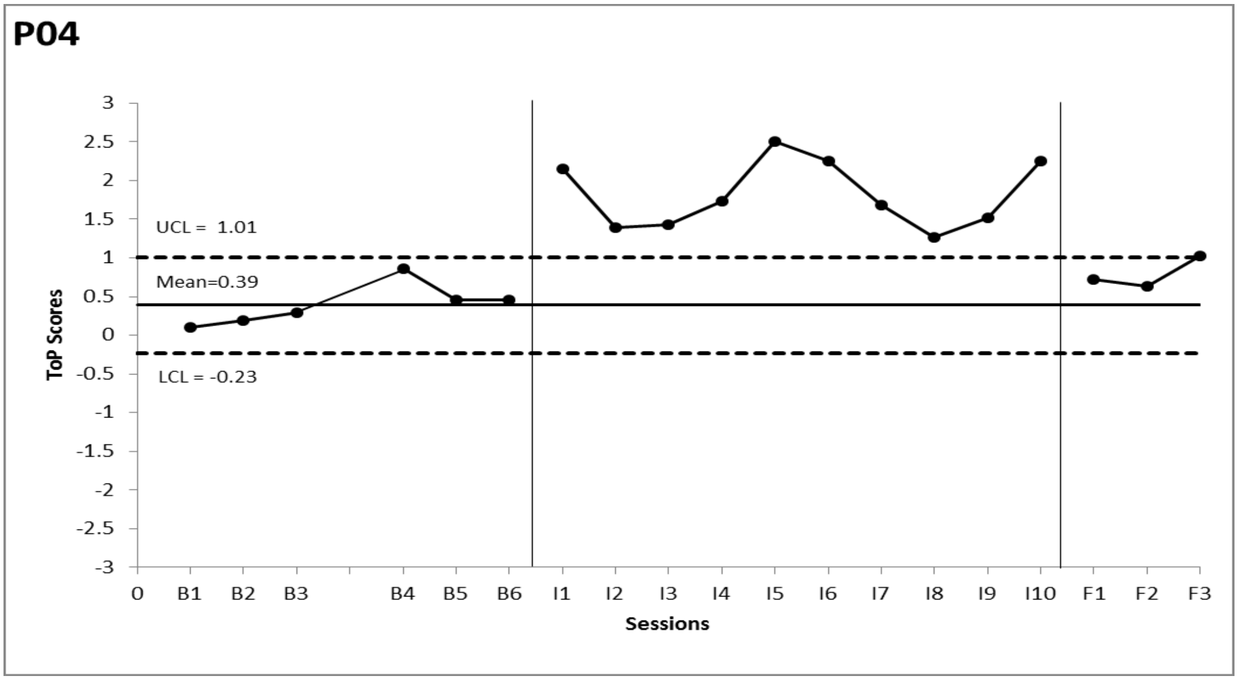

Figure 5. Comparison of ToP scores at baseline, intervention and follow-up phases for P04 using X-moving range chart. UCL: Upper Control Limits (+3 SD). LCL: Lower Control Limits (-3 SD).