A Robotic System to give Prompting to Children with Disabilities when using a Lego Robot

by

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Abstract

Play is a crucial activity in which children explore and interact with the environment through the manipulation of objects, developing cognitive, social and linguistic skills. Play in children with physical disabilities may be compromised due to their physical limitations and the lack of opportunities to play, resulting in delays and other effects on their cognitive and social skills. Studies using robots for children with disabilities to access play have found that children enjoyed playing with robots, and they felt more independent. However, most of these studies reported that using a robot could be cognitively demanding for young children, which could lead to frustration when using it. Successfully performing manipulation using a robot requires that children have some basic skills that they may not have fully acquired at young ages.

Prompting from adults has been used to facilitate play in children with disabilities. However, adults tend to over-prompt, thus taking away the opportunity from children to learn and to try out experiences themselves. Technology could provide a more consistent way to prompt children with disabilities by giving prompts only when they need it.

The objective of the present study was to develop and test a robotic system to give prompts to children when they are controlling a Lego robot to perform a set of tasks. The long-term goal is for the robotic system to give the prompts by itself using a learning algorithm. A single subject design with a baseline and two intervention phases was performed with six typically developing children and one child with physical disabilities. In the baseline phase children used the robot to perform the tasks with no prompting. In the first intervention phase, children performed the same tasks but with simulated prompting from the robot (the researcher actually determined which prompts should be given and sent the commands to the robot). Comparisons between baseline and the first intervention phases showed that there was no significant difference when children used

the robots in terms of the success rate of the task. However, the robotic prompting did impact children’s performance in the first intervention sessions. It took them one or two sessions to get used to the robot giving the prompts and talking.

In the second intervention a time threshold algorithm that gave the prompts to participants automatically after an estimated time was tested. Results showed that such an algorithm with only time as a variable was not able to give the prompting when the children actually needed it. For that reason, eye gaze, face gestures, what participants say and the position of the participant´s hands were the suggested variables that a learning algorithm could use to determine what prompts should be given to children so that in future work, a learning algorithm can be applied to the robotic system.

From the interaction of the robot with children it was possible to conclude that children responded fairly well to the robot giving the prompts. However, the robotic system needs improvements to make it more interactive to keep children engaged in the activities. Also, a familiarization phase with the robot talking and giving prompts to children was suggested, so children can get used to how the robot works.

Preface

This thesis is an original work by Maria Fernanda Gomez Medina under the supervision of Dr. Kim Adams. The research project, of which this thesis is a part received research ethics approval from the University of Alberta Health Research Ethics Board, Project Name "Using prompting to help children with disabilities control a robot", Pro00077531, January 4, 2018. Also, ethics approval received from the Ethics Research Committee of the School of Medicine and Health Sciences at the Universidad del Rosario in Bogota, Colombia. Project Name "Utilizando un Sistema robótico para asistir niños con discapacidad durante el uso de robots Lego", April 10, 2018.

I was responsible for the data collection and data analysis as well as the writing of the manuscript. Dr. Adams contributed to the manuscript edits.

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1. Introduction

Play is a vital and natural activity in which children can learn and explore the environment through object manipulation, while developing cognitive, social, and linguistic skills (Besio, Dini, Ferrari, & Robins, 2007). According to the Treaty Series in the Convention on the Rights of Persons with Disabilities, play is a fundamental right for every child and it is the most important occupation during childhood, being necessary for occupational roles later in life (Missiuna & Pollock, 1991; United Nations, 1999). During play activities, children receive information via their senses to develop an awareness of relationships with people and objects in the environment (Missiuna & Pollock, 1991). Play promotes learning, discovery, mastery, adaptation, creativity, and self-expression in children (Ferland, 2003).

Children with physical disabilities may have difficulties when manipulating objects and participating in play activities due to their limitations, such as difficulties in reaching and grasping. These limitations can result in developmental delays across different areas, including sensory, motor, cognitive, interaction, communication, and social development (Klein, Gelderblom, de Witte, & Vanstipelen, 2011; B Robins et al., 2012). The Global Burden of Diseases estimated that, in 2004, 5.1% (some 93 million) of the worlds' population of children between the ages of 0 and 14 years live with a disability, and 0.7% (13 million) live with a severe disability (WHO, 2011). Unfortunately, children with physical disabilities tend to become spectators of play rather than active participants (Blanche, 2008). During play activities, children tend to be dependent on their parents or playmates, who oftentimes are the ones that manipulate the toys (Musselwhite, 1986). Additionally, children may be perceived as being more developmentally delayed than they actually are because they often cannot demonstrate their skills through independent play (Harkness &

Bundy, 2001). This can lead to an underestimation of their cognitive abilities (Yin Foo, Guppy, & Johnston, 2013).

Children with physical disabilities will enjoy a play activity if the toys they use are interesting and physically accessible to them (Brodin, 1999). The use of assistive technologies such as robotic systems can help children with physical impairments have control over activities, the environment, and objects, thus enabling access to play and demonstration of their cognitive skills (Cook et al., 2005). Robotic systems allow children to perform actions such as reaching for objects, turning them, stacking them, and others (Cook, Meng, Gu, & Howery, 2002). In addition, robots are flexible when interacting with the environment, since they can manipulate objects and perform more than one repetitive action (Adams, Alvarez, & Rios, 2017).

When designing robotic systems for people with disabilities, it is important to consider that these assistive technologies should meet the needs and abilities of the users (Cook & Polgar, 2015). In the case of robots for children, it is important to consider the skills that robot systems require of children to control them, as they often exceed the developmental level of young children (Cook, Adams, Volden, Harbottle, & Harbottle, 2011; Poletz, Encarnação, Adams, & Cook, 2010). It is necessary that children learn how to control a robot before they can use it to perform specific activities successfully (Howell, Martz, & Stanger, 1996). Forman (1986) observed typically developing children using battery-operated robots in structured and spontaneous situations. He found that causality, spatial relations, binary logic relations, and the coordination of multiple variables are the required cognitive skills that children need in order to successfully use a robot. However, these skills vary with children’s ages, where older children demonstrate a better understanding of the concepts than younger children (Forman, 1986). More assistance, such as prompting, could be a way to help children at early ages to complete tasks that require these skills.

When adults support and give assistance to children during play, they can enhance children's capacity by performing different roles, such as mediators, directors, observers, or players (Blanche, 2008; Musselwhite, 1986). One form of assistance is prompting, which can be defined as actions given by adults to children in order to increase children's engagement in a desired behavior (Lang et al., 2016). Adult prompting has been used in studies to support people with intellectual disabilities to complete tasks (Savage & Taber-Doughty, 2017), to help children with disabilities when using a robotic arm to do classroom activities (A Cook et al., 2005), and to support children with disabilities when using robotic systems to do play activities (Besio, Carnesecchi, & Converti, 2013; A Cook et al., 2011; Encarnação et al., 2014, 2016; Larin, Dennis, & Stansfield, 2012). Nevertheless, oftentimes adults overprotect children with disabilities and intervene unnecessarily, inhibiting and limiting children´s play competences (Missiuna & Pollock, 1991). Several studies reported overprotection from adults, where they were overeager when helping children to play (Harkness & Bundy, 2001; Jennings & MacTurk, 1995; Levitt, 1975). This overprotection may result in adults acting too quickly (over-helping) and taking away the opportunity for children to explore the play situation (Blanche, 2008). In this thesis the word "prompting" will be used when referring to assistance for children.

Providing the prompts in a structure way can help prevent over-prompting. According to a review of functional and symbolic play in children with autism (Lang et al., 2016), all the studies that used prompts to help children during play activities utilize a least-to-most prompting hierarchy. In this hierarchy, prompts that are less intrusive are used first (e.g., the helper looks at a location to let the child know a location to place a toy). Then, if the lesser prompts failed to help the child to do the play activity, more intrusive prompts are given (e.g., the helper gives a verbal instruction to the child to know what toy needs to be used or the helper uses modeling to play with the toy and show the child how to do it). Finally if the previous prompts still do not help the child during the activity, the most direct prompts are given (e.g., the helper physically guides the child's hand to place a toy in a location).

Technology could help to provide prompting to children with disabilities in a structured way, making a better match between the child's abilities and the help the child needs. When technology is the one providing the prompting, children could be more independent since they will not require help to perform an activity from adults. However, adults can always be present and play the role of playmate during an activity. Self-operated systems designed to give prompting assistance (e.g., "insert the coin" and "press the green button") have been used to support people with intellectual disabilities, and have decreased their dependence on others and increased their task performance (Post & Storey, 2002; Savage & Taber-Doughty, 2017). This type of prompting assistance could be applied to robotic systems to give assistance to children with disabilities only when they need it, avoiding overprotection and increasing their independence.

Machine learning methods could be a way to provide prompting to children to help them to control robots. Machine learning consists of programming a computer using learning algorithms that can predict or optimize data using data from past experience (Alpaydin, 2004). These algorithms can be applied to machines to carry out tasks in a similar way to humans. Some of these tasks include speech recognition, machine vision, localization, robotic control and others (Alpaydin, 2004; Bogue, 2014). Learning algorithms could also decide when a robotic system should give a prompt and what level. The system could prompt the child only when it is required (e.g., if the child performs the wrong action or is not doing anything) and could provide the level of prompting necessary to help him/her achieve the next step of a specific task, adapted to their understanding of the skills required to control a robot.

The concept of a robotic system giving the prompts to children is aligned with Parasuraman, Sheridan and Wickens (2000) idea about automation in machines. They state that machines can automatically execute tasks or functions that humans cannot perform accurately. Similar to prompting with lower to highly intrusive prompt levels as described above, automation in machines can have different continuous levels, where lower levels represent the human having the majority of control over an action, and higher levels represent an increased autonomy of the machines over the human actions. For example, at level one, the human has the control over the activity and the machine does not do anything. At level two, a machine gives several options to the human, but it does not have the authority to decide which option to take; only the human can decide. At a medium level, the machine suggests one of the options, but the human still has authority to choose the suggested option or another one. At a high level, the machine gives the human a limited time to pick an option before it acts autonomously and makes a decision by itself (Parasuraman et al., 2000).

In this study, the robot acted according to different levels of automation. Meaning, at the lowest level, the robot did not give prompts when the child performed the correct action independently. At intermediate levels the robot provided prompts if the child made a mistake, for example, the robot asked “Do you think a switch would make the robot move?", allowing the child the chance to perform an action independently. Finally, at higher levels, the robot acted automatically and performed the action if the child was not performing any action or if the child made the same mistake several times.

The aim of this study was to test the robotic system as it provided prompting as needed to children for controlling a Lego robot. A single subject research design with a baseline and two interventions was performed (Portney & Watkins, 2015). In the baseline children used a Lego robot to perform a set of tasks without any prompting. In the first intervention children used the robot in the same tasks but they received prompting from the "robot". A Wizard of Oz technique was used to make it seem like the robot was the one giving the prompting (i.e., giving the prompts and talking), but in reality the researcher was the one controlling the robot without letting the child know. The prompts given by the researcher (via the robot) were given according to the child's level of understanding of the task as well as their actions (e.g., reaching for a switch) during the task. This Wizard of Oz technique is used to provide participants with the experience of interacting with a system and to see if it works as it is supposed to, even if the system is not fully developed yet (Martin & Hanington, 2012).

A benefit of using the Wizard of Oz technique was it gave an opportunity to explore the variables that would be required from the human as well as from the robot as inputs for a future learning algorithm. In order for a robotic system to give the appropriate prompting using a learning algorithm, it should be able to understand the children's intentions and their actions. However, understanding social cues, such as attention and body language, and interpreting them is a difficult task for computers (Burke, Murphy, Rogers, Lumelsky, & Scholtz, 2004; Tahboub, 2006). There are many variables that could be used to recognize user's actions or intentions, including eye gaze, brain computer signals, face gestures, stress levels and others. Nevertheless, the processing of all these variables could be slow and expensive and difficult for a computer to interpret. Also, the devices needed to obtain the variables could be expensive. For that reason, a first step towards developing a learning algorithm was to examine the most useful human variables that the algorithm could use to predict user's actions so a prompting system could give the appropriate level of prompting to children. Once the necessary human variables are defined, future research in this topic can focus only on those variables.

It is possible that a simple algorithm that does not use learning methods could be enough to adequately provide prompting to children. The implementation of such an algorithm would decrease the cost of the robotic system since it would be less computationally expensive (i.e., less data to process) and no devices would be needed to obtain variables from the environment (e.g., no cameras, etc.). A simple algorithm that used time thresholds was developed to give the prompts to children: if a wait time for the child to do an action was exceeded, then the robot gave a prompt. In the second intervention children performed the same set of tasks as in the baseline and the first intervention, but in this case the robot gave the prompts automatically via this time threshold algorithm.

Objectives

1. To compare the performance of children when controlling a Lego robot with no prompting with the performance of children when the Lego robot provided prompting via the Wizard of Oz technique.
2. To test the performance of an algorithm based only on time variables to give prompting to children.
3. To examine the experience of children when they received the robotic prompting.
4. To explore potential variables that could be used to implement a learning algorithm to give prompting automatically.

2. Literature Review

The first two sections of this literature review are focused on robotic systems that have been used to support play in children with disabilities, and the required cognitive skills that children need to use robots. The next section is a review about prompting assistance and the effects that prompting can have on children. Finally, the last section presents a review of how learning algorithms has been applied in the field of assistive technology for children with disabilities.

1.1. Robots and children with disabilities

Several studies have demonstrated the potential that robotic technology has for children with disabilities to interact with the environment, to promote exploration and learning situations, to develop social and interactive behavior, to improve independence, and to engage in play (Adams et al., 2017). For example, the IROMEC is a robotic platform designed to give support in play for children with autistic spectrum disorder, severe motor impairments, and children with mild mental disabilities (Klein et al., 2011; Marti & Iacono, 2011). The IROMEC is a mobile robot that works by remote control or by moving autonomously based on information from infrared and ultrasound sensors (Marti & Iacono, 2011). A study conducted with children with disabilities showed that when the children played with the IROMEC, they became the main protagonist of the play session, had fun and were equally active partners when playing with their typically developing peers (Marti & Iacono, 2011;Robins et al., 2012). Additionally, according to the teachers, the robot promoted social inclusion and produced a new and engaging learning situation (Marti & Iacono, 2011). Another study showed that the IROMEC had a positive effect on the achievement of predetermined goals, such as the children being able to independently control the robot, to visually follow the robot, and to use language during play (van den Heuvel, Lexis, & de Witte, 2017).

A system developed by Kronreif and colleagues (2007), called PlayROB, was used to help children with disabilities play with different kinds of Lego bricks. The PlayROB had a mechanism with three degrees of freedom, a special gripper and a play area, and was controllable with any device that had joystick functionality (Kronreif et al., 2007; Prazak, Kronreif, Hochgatterer, & Fürst, 2004). When using this system, most of the children enjoyed the play activity, and it was reported that independent play had a positive effect on their self-esteem. Furthermore, the authors theorized that long term use of the system would have positive implications on the development of perception and spatial sense of children (Kronreif et al., 2005).

Cook et al. (2000) used the CRS A465 robotic arm to evaluate how children with physical disabilities engage in a play and exploration activity. The robotic arm could rotate, flex, extend, and open and close a gripper based on switch presses. Results from the study showed that children with disabilities were able to independently manipulate objects during the play activity, and it also allowed them to engage with an adult in cooperative play (Cook, Meng, Gu, & Howery, 2002).

Lego robots were used to allow children with physical disabilities to manipulate toys. Children with physical disabilities enjoyed interacting with a truck-like mobile Lego robot and it increased participants' attention to tasks and their social and language skills (Cook, Adams, Volden, Harbottle, & Harbottle, 2011). In addition, participants were able to demonstrate their cognitive skills, changing the perception of teachers and parents about their competency. In another study, the level of playfulness of four children with cerebral palsy increased significantly when they controlled a Lego robot during play with their mothers, compared with playing with their mothers not using the Lego robot (Ríos, Adams, Magill-Evans, & Cook, 2016).

Some studies have taken first steps towards using haptic robots to assist children with disabilities while playing, by first testing system functionality with participants who are not the target population. A robotic haptic system with virtual assistance was used by Jafari and colleagues (2017) with the final goal of enhancing accuracy for children in a coloring task. The system was tested with an adult with cerebral palsy and results validated the effectiveness of the virtual assistance in the coloring tasks. Becerra (2017) performed a study where non-disabled adults, typically developing children and an adult with disabilities recognized object properties (e.g., hardness, roughness) in a play scenario using a teleoperated haptic robotic system. Results showed that participants were able to explore the objects with the haptic system and get information about their properties. Sakamaki et al. (2017) performed a study in which non-disabled adults and one individual with physical impairments used a haptic robotic system with virtual assistance to do a sorting task. Comparison between virtual and no virtual assistance was done and results indicated that virtual assistance was able to restrict the movements of the users inside a region, providing guidance to perform a task. However, some considerations such as rigidity and shape of the virtual assistance features needed to be taken into account for participants with physical disabilities (Sakamaki et al., 2017).

1.2. Robotic control and required cognitive skills to control a robot

The aforementioned studies suggested that the use of robotic systems can promote independent play in children who have physical disabilities; however, they also found that not all children were able to understand how to control the robot. For example, the IROMEC robot was complicated to control for children with a developmental age between 2 and 8 years, decreasing their interest in the robot (van den Heuvel et al., 2017). Prazak et. al (2004) found that some children who had multiple physical impairments had some difficulties comprehending the PlayROB. Additionally, manipulating a robot was quite difficult and affected the playfulness of a 4 year old girl who had cognitive delays and cerebral palsy (Rios, Adams, Magill-Evans, & Cook, 2013). Even though she could use a switch-controlled Lego robot for basic movements with prompting, she got frustrated in one of the sessions, and she did not want to play with the robot anymore. Another study conducted by Adams et al. (2016) found that when typically developing children used a Lego robot to manipulate toys it was harder for them to exhibit pretend play, compared to when they used their hands to manipulate the toys. Researchers stated that robot control required a set of cognitive skills that children may not have acquired at young ages. They also recommended assistance, such as the robot automatically grasping objects when close to them, thus making it easier to control the robot (Adams et al., 2016) .

The cognitive skills that are required of children when using a robot for functional manipulation have been studied. The first characterization was done by Forman (1986) in a study where children were observed in structured and spontaneous situations using a battery-operated robotic arm and computer graphics. Poletz et al. (2010) explored the ages when typically developing children were able to demonstrate the cognitive skills of causality, negation, binary logic, and sequencing in switch-controlled mobile Lego robot tasks. The same tasks were also performed in other studies using the Lego robot and virtual representations to assess the cognitive skills in typically developing children and children with disabilities (Cook, Encarnação, Adams, Alvarez, & Rios, 2012; Encarnação et al., 2016; Encarnação, Piedade, Adams, & Cook, 2012). Results from these studies showed an increased in the cognitive skills with children's age using both the physical and the virtual Lego robot. The terminology used in Poletz's study was consistent with that used by Forman (1986). This terminology was later modified in Cook et al. (2012) to be more consistent with that used in cognitive psychology. The modification included the use of cause and effect instead of causality, inhibition instead of negation, and laterality instead of binary logic. This updated terminology will be used in this thesis.

There were three robotic tasks that tested the mentioned cognitive skills in aforementioned studies (Cook et al., 2012; Encarnação et al., 2014, 2012). The skill of cause and effect was tested in the first task when children were asked to knock down a pile of blocks by pressing and holding a switch to move the robot until it knocked the pile down. In this task, children understood that pressing the switch caused the robot to move. In the second task, inhibition was tested when children were asked to help the researcher build a tower of blocks using the Lego robot. For this task, children used the same switch as in task 1, but in this case they had to stop the robot (i.e., release the switch) beside some blocks (so the researcher could load the blocks onto the robot), and then drive the robot until the end of the table (so the researcher could unload the blocks and build the tower). In this task, children understood that by inhibiting a response (releasing the switch) they could achieve a specific goal (stop the robot). The last task included two piles of blocks placed on the right and left side of the robot, and two additional switches, to turn the robot right or left. For the first part of the task, children were asked to choose a pile of blocks to knock over, and they were expected to press the appropriate left or right switch to face the pile, this task tested laterality. For the second part of the task, to test sequencing, children had to subsequently press the forward switch to drive the robot towards the pile of blocks and knock it down. Results showed that cognitive skills increased with children's age, as it was expected from Forman's study (1986).

1.3. Prompting assistance

Prompting has been used to teach children new skills and is a strategy that can increase the probability of children in completing a task correctly or to give the correct response (Meadan, Ostrosky, Santos, & Snodgrass, 2013). Prompting was used to teach children with autism names of objects by identifying the objects in different pictures (Leaf et al., 2016). Results from the study showed that participants acquired 100% success when identifying the objects after being prompted by the adults (Leaf et al., 2016). In another study, it was found that self-operated auditory prompting interventions were effective and could be used as a strategy to help individuals with intellectual disabilities in task completion and behavior management (Savage & Taber-Doughty, 2017).

Prompting is also recommended when children participate in play activities, and it has been shown to be helpful when children with disabilities play, since it can provide and facilitate play opportunities and competencies (Besio et al., 2013; Crawford, Stafford, Phillips, Scott, & Tucker, 2014; Hamm, 2006). Prompting can also allow children with disabilities to perform play activities on their own. Verbal prompts, modeling and physical engagement (e.g., adult physically guiding the child's hand) were successfully utilized in an inclusive classroom to increase toy play in young children with disabilities (DiCarlo, Reid, & Stricklin, 2003). Additionally, researchers found that the frequency and diversity of pretend play in children increased when a more-to-less prompting system was implemented by teachers (Barton, 2015; Barton & Wolery, 2010).

Prompting has also been used when children use robotic systems. When children with disabilities used a robotic arm to dig objects out of a tub with dry macaroni there was decrease in the amount of prompting (physical, auditory and visual) that adults gave to the children over time (Cook, Bentz, Harbottle, Lynch, & Miller, 2005). This finding was interpreted as the children becoming more independent in the task. Larin and colleagues (2012) found that it was possible to enhance self-initiated mobility on mobile robots in young typically developing children and children with disabilities with the help of tactile and/or verbal prompting from adults (parents and researchers).

In another study, Cook and colleagues (2011) found that children with disabilities needed prompts to accomplish some activities using a mobile Lego robot. The prompts given to children changed over the course of the study from direct commands telling children exactly what to do, such as “press this switch”, to indirect statements, such as “move the robot” (Cook et al., 2011). A more defined prompting hierarchy with different levels of prompting has also been used in robot studies. The hierarchy went from no prompting given to the child at the lowest level, to exemplification using hand-over hand support at the highest level (Encarnação et al., 2014). Additionally, Encarnação et al. (2016) used a prompting hierarchy developed by Clarke and Schneider (2014) to give prompts to children during robot tasks. The hierarchy had four levels, where the higher the level, the more prompting the child received. The level of prompting decreased for some children and increased for others through the sessions. The increase in the level of prompting could have been because the task complexity increased during the sessions or because participants started to lose interest in the task (Encarnação et al., 2016).

Lindsay and Lam (2017) observed children with disabilities when they were taking part in an adapted robotics program using Lego robots. They found that the Lego robotic program helped children with disabilities to develop play skills. However, the development of these skills could have been influenced by the prompting they received from adults (e.g., modelling, physical assistance or verbal cues) during interactions with the Lego robots (Lindsay & Lam, 2017). Other researchers evaluated a prompt fading technique when children with cerebral palsy used three robots, including the IROMEC, Wall-e and ISOBOT to do play activities (Besio et al., 2013). Results showed a reduction in the number of prompts given by the adults to help children to understand how to play. However, prompts to keep children interested in the play activity (prompts to generate a playful experience) remained the same or increased in some cases from the first to the last session. The authors highlighted the need to develop technology to support the actions of adults when giving prompting to children, so the level of understanding of children with disabilities can be taken into account when they are using a robot to play.

1.4.Learning algorithms and assistive technology

Learning algorithms have been applied to robotic systems in the field of assistive technology for different purposes, including to give assistance as needed to users (Xu, Huang, Wang, Tao, & Cheng, 2015), to predict actions that users want to perform (Chalvatzaki et al., 2014), and to adapt to the environment or to the users (Rivera, DeSouza, & Franklin, 2013). In these studies, the participants and the users of the technology were adults with disabilities and the elderly.

Other research in this field has been done with children with autism as participants. Park and colleagues (2014; 2015) implemented a system based on learning from demonstration that can learn and adapt to different tasks chosen by typically developing children and children with autism. They asked the children to teach a strategic game (Angry birds ™) to the robot, called Darwin. In this game, children had to control a launching angle and how much power a bird needed to destroy pigs by hitting them or knocking down structures. A shared touchscreen tablet was used by the child and the robot during the sessions. For the learning system, researchers applied an interactive-based learning framework with artificial neural networks, k-nearest neighbor and linear regression methods for retrieving the human demonstrations. The variables from the game and the variables that users chose on the tablet were the inputs for the algorithm (e.g., launching angle, amount of remaining pigs, pig's location and others). The robot was trained to improve its skills in the game by giving it accumulated experience from the interaction with children through the tablet (Park et al., 2014; 2015).

In another study, a humanoid robot, called Robota, was used to increase the social interaction of children with autism with their peers and with adults, to assess the children's imitation abilities, and to teach them simple coordinated behaviors (Billard, Robins, Nadel, & Dautenhahn, 2007; Ben Robins, 2005). Artificial neural networks were implemented so Robota could engage in complex interactions where children taught the robot simple vocabulary as well as how to dance and how to dress up. Variables such as eye gaze, eye contact, touching (if the child touched the robot), vocalization (sounds such as yells, mumbling), speech and others were recorded from the participants as inputs for the neural networks. Results from studies using this humanoid robot showed that children with autism exhibited interaction skills when Robota was assuming a role of social mediator between the children with autism and others (adults and children). Additionally, social interaction skills and communicative competence were shown by children during the interaction with the robot.

Leo and colleagues (2015) used machine learning methods to evaluate the behavior of children with autism during a robot-child interaction, and to evaluate the effectiveness of the therapy. In this study, a facial recognition program was implemented to track and detect the child's face, and then the system used this information to recognize the emotions of the child. Results showed that the proposed machine learning method could be used to effectively evaluate the emotions of children with autism (Leo et al., 2015). A computerized device was developed by Bimbrahw, Boger and Mihailidis (2012) to autonomously assist children with autism in self-care activities. This system used learning algorithms and computer vision to guide the child during an activity by providing audio and visual prompts as required. Results showed that the device responded correctly to 74% of the situations where children needed help, however they recommended that more effort was needed to refine the device.

As a first step towards developing a robotic system to support play in children with physical disabilities, Castellanos, Gomez and Adams (2017) analyzed the eye gaze of adults to predict the toy they wanted to reach when using haptic robots. According to Ruhland and colleagues (2015) the eyes can provide information about where the attention of a person is focused. The predictions were made using a double Q-learning and a Multi-Layer perceptron algorithm. In another study performed by the same researchers, five able-bodied adults played a whack-a-mole game using a telerobotic haptic system (2018). One of the objectives of this study was to use a multi-layer perceptron neural network to predict the target mole the user wanted to go towards. Eye gaze and the position of the robot were used to train the neural network. Results from both studies showed that learning algorithms could be accurate when predicting the toys the users are looking at; therefore they recommended it was feasible to use that information to inform the guidance control of the robot.

Summary and gaps

Studies using robotic systems showed that robots can promote independence in children with disabilities as well as improvement in their social skills with other children and adults. Additionally, robotic systems can help children to demonstrate their cognitive skills (Encarnação et al., 2014; Poletz et al., 2010). Researchers studied the robotic skills that children need in order to control a robot and found that these skills increased with children's age (Cook, Encarnação, Adams, Alvarez, & Rios, 2012; Forman, 1986; Poletz et al., 2010). Young children and children with disabilities who have a low cognitive age may not have these robotic skills. This may prevent them from using a robotic system to play.

Prompting assistance from adults has been found to benefit children with disabilities when they are using robotic systems to play, helping them to increase their skills and to perform activities that could otherwise be hard to understand for them. However, adults tend to give unnecessary prompts to children with disabilities, taking away the opportunity for children to try out new experiences by themselves, and increasing the dependence of children on adults. Researchers suggested the possibility of having the robot give prompts to the child. This could solve the issue of the over prompting from adults and it could also allow more independence for children(Besio et al., 2013).

Learning algorithms have been applied in robotic systems to provide assistance as needed to users, recognize user's actions, to help children play and interact with robots and also to help children to perform self-care activities in an independent way. However, no studies where the robot gives the prompting to children with physical disabilities during a play activity were found. Learning methods applied to assistive technology robots could be used to understand the children's intentions or actions and their level of understanding during the performance of a task, and then give the appropriate prompting. Nevertheless, it is important to take into account that recognizing the user's intentions is a challenge in intelligent human-robot interaction. In the studies above, researchers used physical variables from users such as eye gaze, face gestures, speech and brain signals as inputs variables to train learning algorithms in performing different tasks. However, in this study we do not yet know what variables will be most valuable to detect children's intentions or actions when controlling a mobile Lego robot. For that reason, this study will examine potential useful variables that could be used for a learning algorithm to detect common actions children perform when controlling the robot.

3. Methods

Participants

Participant recruitment and data collection took place in Bogota, Colombia. Ethics approvals were obtained from the Ethics Review Board of the University of Alberta (Appendix 1a) and from the Ethics Research Committee of the School of Medicine and Health Sciences at the Universidad del Rosario in Bogota, Colombia (Appendix 1b). Potential participants received information about the study through institutions where they attended therapy. If therapists identified a child who met the inclusion criteria, the therapist told the parents about the study. If parents agreed for their child to participate in the study, they were asked to sign the consent forms (Appendix 2a and 2b contain the blank forms).

Inclusion criteria

- Typically developing children between 3 and 5 years of age. This age range was selected because previous studies reported that by the age of five, the majority of typically developing children have the necessary skills to control a robot (Poletz et al., 2010). However, not all the five year old participants knew how to perfectly control the robot, thus children that were five years old were included in this study.
- Children who were able to follow two-step instructions (e.g. let's choose a toy and put it at the end of the table).
- Children with disabilities who had the ability to express choices and answer yes/no to questions.
- Children who were able to press the switches to move the robot.

Exclusion criteria

- Children with experience participating in studies involving the use of switch-controlled robots
- Children with vision and hearing impairments that prevent them from seeing the play area and hearing instructions

Six typically developing children and one child with disabilities were the participants in this study. A code was assigned to the participants as they were recruited to the study, and that code will be used throughout this thesis. Table 1 shows the description of each participant. They were all native Spanish speakers.

Table 1 Description of participants

Code	**Age**	**Gender**
P1	4 y and 11 months	Female
P2	4 y 3 months	Male
P3	3 y 2 months	Female
P4	4 y and 5 months	Male
P5	3 y 2 months	Male
P6	5 y 1 month	Female
P1D	11 y 4 months	Male

The child with physical disabilities (P1D) had a diagnosis of cerebral palsy. He could sit on a special chair that had Velcro straps to stabilize his trunk on the chair and prevent him from bending forward. He could only control two switches, due to his physical limitations. One switch was placed beside his head with a mounting arm, which he pressed to make the robot move forward, and the other switch was placed next to his left hand, using another mounting arm, to make the robot turned left. The occupational therapist of P1D was present during all the sessions of the baseline and the first intervention phases. The occupational therapist gave him some assistance when he was pressing the switches (e.g., holding his head/hand or stabilizing the mounting arm close to his head/hand). For the session of the second intervention a relative of P1D was present during the study.

Study design

A single-subject A-B-C design was conducted to observe the difference in children's performance when they received different methods of prompting. Single subject design research is the "gold standard" when it comes to assistive technology interventions (Ottenbacher, 1986). This single-subject study involved a baseline (phase A), followed by a first intervention (phase B) and finally a second intervention (phase C) (Portney & Watkins, 2015). Additionally, due to the fact that children were not available for concurrent monitoring, this study was a non-concurrent design. This means that when a child became available, he/she performed the study and was observed independently from the other participants (Portney & Watkins, 2015).

In the baseline phase participants performed a set of tasks using a Lego robot with no prompting (no-robotic prompting condition). Then the first intervention was conducted whereby participants performed the same tasks, but in this case they received prompting from the researcher via the "robot" (robotic prompting condition) using the Wizard of Oz technique, explained in the procedure section below. An additional second intervention was performed where participants did the same tasks and received prompting from an algorithm (robotic prompting using the threshold algorithm) that used time thresholds to determine which prompts to give.

The aim was to perform five sessions in the baseline and the interventions since it is recommended to have a minimum of five data points per phase in a single subject design (Kratochwill et al., 2010). The baseline phase had five sessions for all the participants. However, due to participant's availability some of them had three sessions and the others had four sessions during the first intervention phase. Sessions with participants were performed two times per week as possible. There was a week off between the baseline and the first intervention phases. The second intervention only had one session and it was performed only with three typically developing participants (P1-5y, P4-4y and P5-3y) a month later after the first intervention and with P1D a week later after the first intervention.

Materials

A Lego Mindstorms (Lego Group, Billund, Denmark) robot was assembled as a car-like vehicle with a basket on the back of the robot to hold blocks. The robot was controlled via Bluetooth using three Jelly Bean switches (Ablenet, Roseville, California) connected to a Windows PC via a Switch Interface Pro 6.0 (Don Johnston, Illinois, USA) to go forward, turn right, and turn left. The forward switch made the robot move forward as long as the participants where pressing the switch. If they released the switch, the robot stopped. The left and right switches made the robot turn left or right exactly 90 degrees with a singles press. A computer program was developed with Matlab software (MathWorks Inc., Nadick, MA, U.S.) using the Lego Mindstorms EV3 support library. The program sent commands to the robot (e.g. move forward) according to the switch inputs.

Ten wooden blocks were used so children could knock down piles of blocks during the tasks using the Lego robot. The locations where the blocks were positioned for each of the tasks are shown in Figure 1.

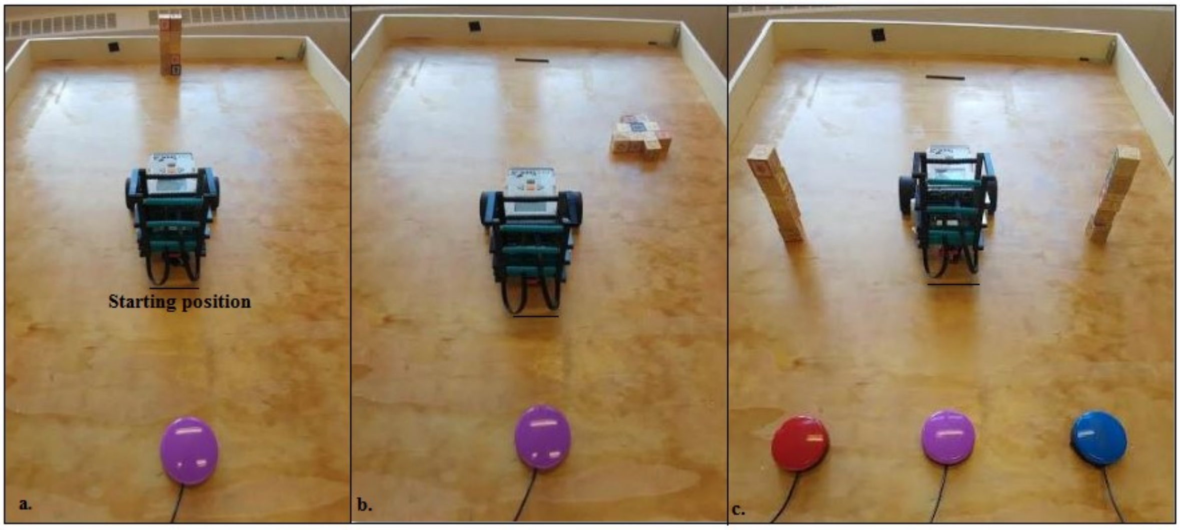


Figure 1 Setup for the robot for a) Task 1, b) Task 2 and c) Task 3

Instrumented play area

For the intervention phases, the Wizard of Oz technique and the threshold algorithm, the switches that the participants pressed and the layout of the task were augmented so the "robot" could provide the prompts. Each switch had three light-emitting diodes (LED), placed around the switch. The forward switch LEDs were green and the left and right switch LEDs were blue. The colors of the LEDs were matched to be the same color of the switches. The LEDs were connected to a breadboard to form an electrical circuit that was connected to an Arduino Microcontroller (Arduino, New York, New York). This microcontroller controlled the LEDs to turn on or off. Additional LEDs were placed near to the two piles of blocks for task 3 (explain in the procedure section and shown in Figure 1).

A mobile application was developed on a Samsung Tablet using Android studio to speak the instructions and prompts to the participants via Bluetooth over a speaker.

Set-up for each condition

No-robotic prompting

Figure 2 shows the robotic system set up for the no-robotic prompting condition used in the baseline phase. Participants pressed the switches that controlled the robot movements. The robot and the switches were on a table. The researcher was in charge of giving the instructions to the children (no prompts were given in the no-robotic prompting condition).

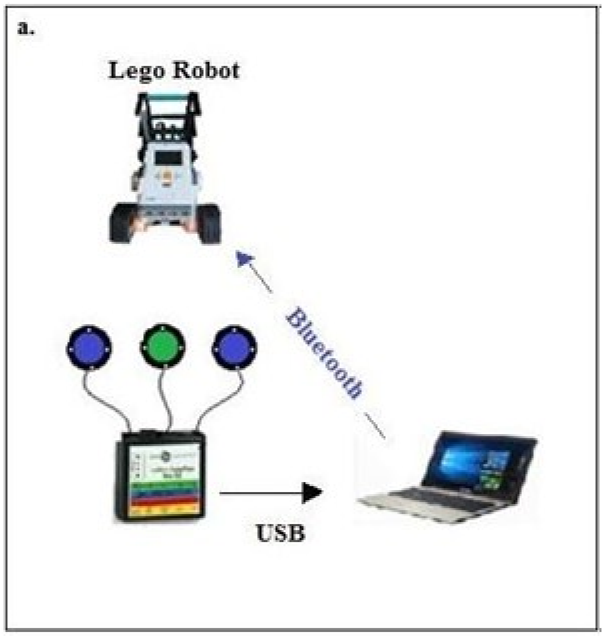


Figure 2. Robotic system for the no-robotic prompting condition

Robotic prompting with the Wizard of Oz

Figure 3 shows the robotic system set up for the robotic prompting with the Wizard of Oz condition. For this condition participants used the switches to control the robot movements (as in the no-robotic condition) but in this case the researcher gave the instructions and the prompts via the robot (robotic prompting), and the instrumented play with the LEDs and tablet for audio was used.

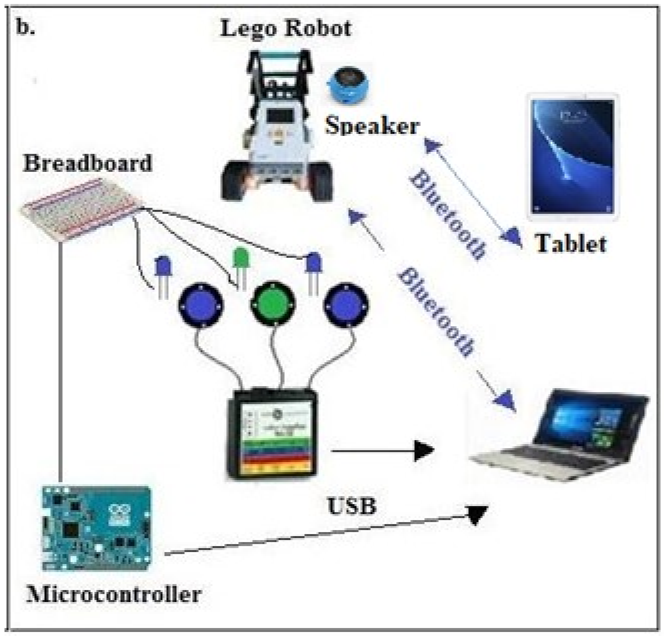


Figure 3. Robotic system using the instrumented play area

The robotic prompting was provided based on Parasunaman's levels of automation (2000) as illustrated in Figure 4. Table 2 shows the corresponding robotic prompting hierarchy and the actions the robotic system performed when giving prompts to participants. Appendix 3 shows the detailed actions the robotic system performed in each of the performed tasks.

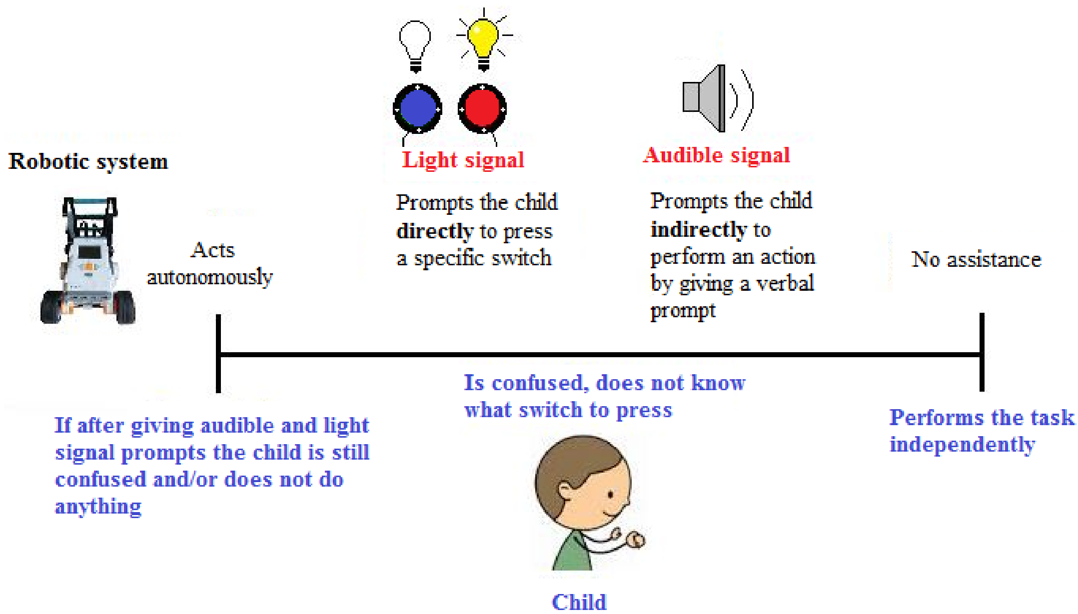


Figure 4. Levels of automation for the robotic system when giving the prompting (Based on Parasunaman´s scale of automation)

Table 2. Robotic prompts based on the prompting hierarchy (From DynaVox (2014) and Encarnação et al. (2014)

Type of prompting	**Actions the robotic system did to provide the prompt**
1. Goal met	If the child performes the task independently, the robot does not provide prompts.
2. Indirect cue	If the child is confused and/or does not press a switch, the robot says to the child "Do you think one of the switches could make me move?"
3. Direct pointer cue	If after the indirect cue was given the child still does not do anything, the robot says to the child "Let´s try pressing this switch", while the LED on the switch that needed to be pressed turns on.
4. Direct pointer cue with modeling	The robot performs the task autonomously. At the same time, the LEDs on the switches that need to be pressed turns on while the robot is moving.

A user interface was added to the MatLab program so the researcher could provide the "Wizard of Oz" robot movements, and LED and auditory prompts while the participants were pressing the switches (See Figure 5). The user interface included three buttons to send BlueTooth commands to make the robot go forward and turn left and right. Additionally, the user interface had 5 buttons to control the LEDs on the three switches and the two piles of blocks through USB to the Arduino.

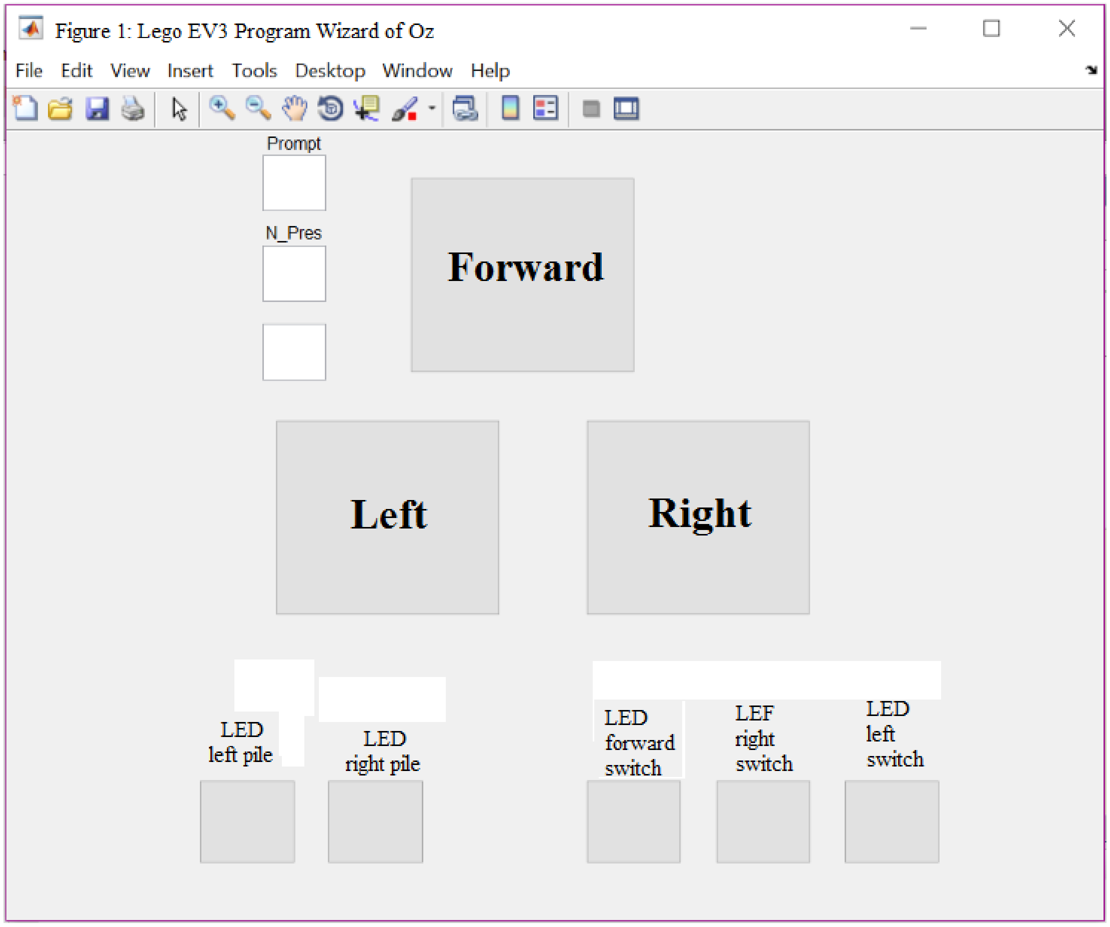


Figure 5. User interface to control the robot in the robotic prompting with the Wizard of Oz

The mobile application on the tablet for providing the auditory instructions and prompts had a user interface for each of the tasks. Figure 6 shows the user interface for task 1. Each button generated a voice recording of an instruction or a prompt. The voice recordings were processed using a voice changer application, by 302 Lock Screen downloaded from the Google Play store, to make them sound like a robot.

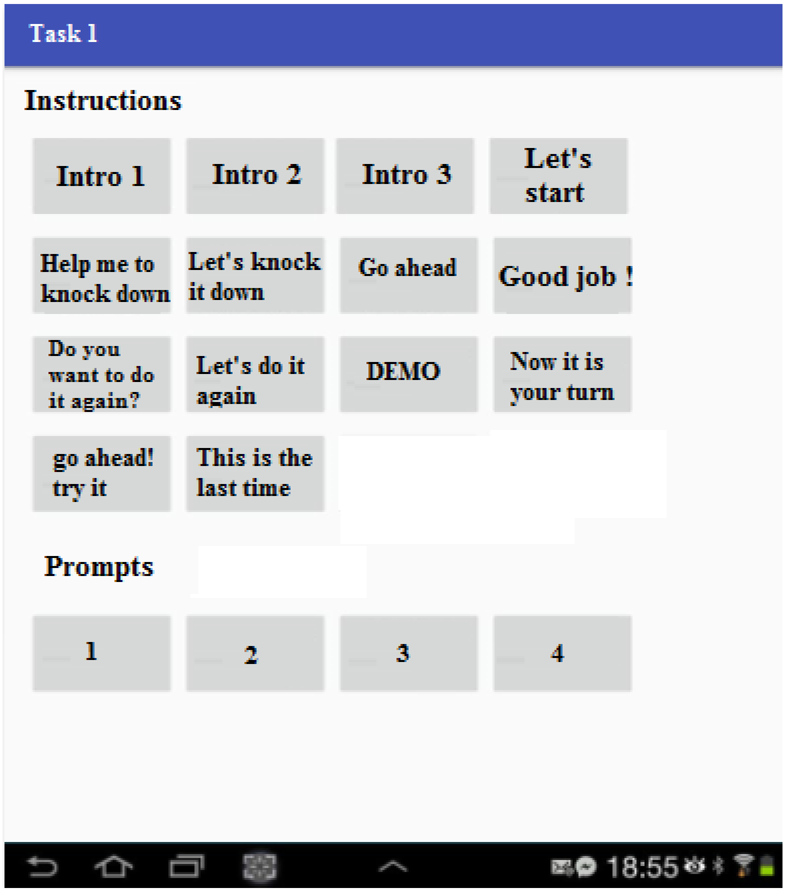
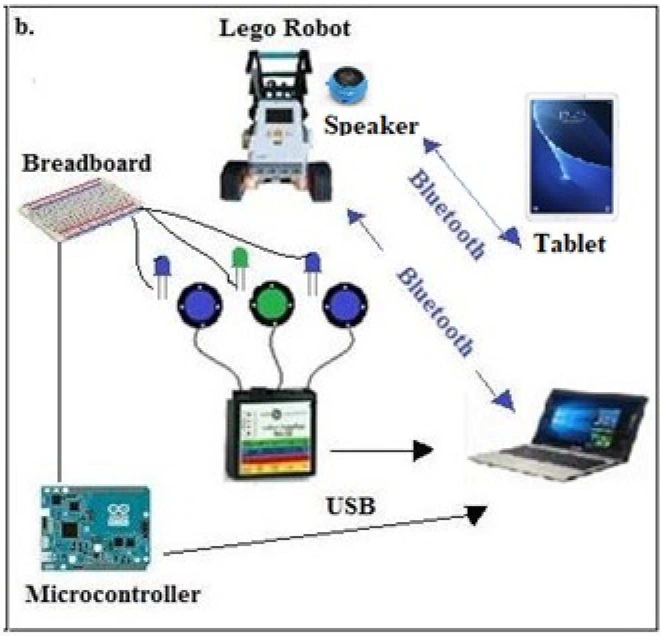


Figure 6. User interface for the mobile application on the tablet for task 1.

Robotic prompting with threshold algorithm

The instrumented play area with the LEDs and tablet for audio was used for this condition (



See Figure 3). Participants performed the task as usual by pressing the switches, and the researcher provided the instructions (via the auditory instruction buttons on the tablet), but the threshold algorithm gave prompting to participants.

The Matlab program was modified again for the time threshold algorithm intervention (see Figure 7 for the user interface). An additional button (instruction) was added to the user interface that the researcher pressed whenever she provided an instruction. From the time the instruction button was pressed (i.e. the instruction was given) a timer started and if within 5 seconds (i.e., the value used for the robotic prompting condition) the program did not detect that a switch was pressed, then a prompt was given automatically by the system. The different prompts were given depending on the last prompt the robot gave to the participant (according to Table 2). For example, if the robot already gave an indirect cue to the participant because he/she did not press a switch in the first attempt, and if for the second attempt the participant again did not press a switch, then the robot did not give another indirect cue, but a direct pointer cue.

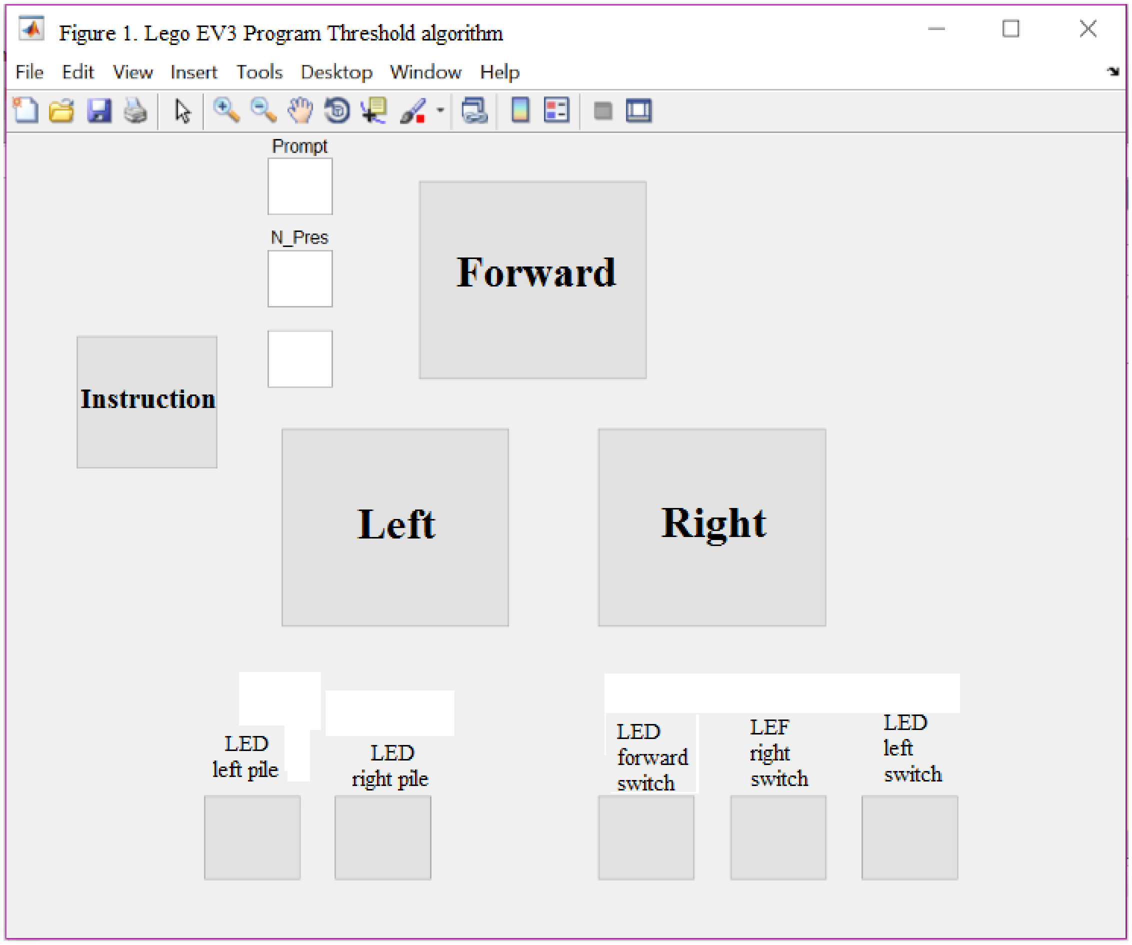


Figure 7. User interface to control the robot in the robotic prompting with threshold algorithm condition

Procedure

Before starting the trials the participant's parents were asked to complete a questionnaire to record how children were feeling that day and if they were tired or hungry (reasons that could affect their performance on the task), see appendix 4 for the questions. Additionally, if parents were present during the session, they were instructed not to prompt the children, but to feel free to make them feel comfortable during the sessions.

Participants did three tasks in every session, the Lego robot tasks from Poletz et al. (2010) described in the literature review section. In task 1 (see Figure 1a), one switch to make the robot move forward was placed in front of the child, a pile of blocks was built at the end of the table, and the robot was placed facing the pile of blocks. In this task, the concept of cause and effect was tested. For task 2 (see Figure 1**¡Error! No se encuentra el origen de la referencia.**b), the same s witch was used but the blocks were placed at a stop position located in the middle of the table. In this case, the child used the switch to drive the robot and stop at the stop location, so the researcher could load the blocks on the robot, and then the child drove the robot to the end of the table, where the researcher could place the blocks where they were stacked in task 1. In this task, the concept of inhibition was tested. In task 3 (see Figure 1c), two more switches were included to make the robot turn left and right, and two piles of blocks were placed one on each of the left and right sides of the robot. In task 3a, the child was asked to choose one of the piles of blocks to knock down, and verbally tell the researcher which one, or point to it. Task 3a tested the concept of laterality, and the child was supposed to use a switch to turn in the correct direction according to the pile selected. For task 3b, the child was expected to knock down the pile of blocks selected by pressing the forward switch. Thus, task 3b tested the concept of sequencing.

Each task was performed a minimum of four times per session. Children did the tasks until they reached their limit. Meaning, if a child could not correctly perform task 1 after four tries, then he/she did not do task 2 or task 3. In those cases the researcher said that the robot was tired and had to go to sleep and the session ended for that day. A summary of the skills the child needed to do to control the robot are shown in Table 3. The instructions that were given to the children are in appendix 3.

Table 3. Protocol – Robot-mediated tasks (Based on Poletz., et.(2010), (Encarnação et al., 2014) and Forman (1986))

Activity-Skills	Definition when using a robot	Description of the task using the robot
Task 1- Cause and effect	The child understands the relationship between cause and effect. In this case, the relationship between a switch and the effect of pressing it.	The child drives the robot forward (press and hold the switch) towards a pile of blocks until knocking them down.
Task 2 – Inhibition	The child has the ability to inhibit a response to accomplish a specific goal. In this case the child is required to inhibit the response of pressing a switch, in order to make the robot stop.	The child drives the robot forward (press and hold the switch) and then stops by a pile of blocks (release the switch when robot reaches the pile). The researcher loads the blocks onto the robot and the child drives the robot (press and hold the switch) and stops (release the switch), where the pile of blocks of task 1 was built, to build a new pile of blocks.
Task 3	This task involves two stacks of blocks positioned on the left and right sides of the robot. The robot is between the stacks of blocks and is facing away from the child. In this task, there are three switches (to move forward, turn left and turn right).	
Task 3a- Laterality	The child has the ability to orient in terms of left and right directions. In this case he/she can compare objects according to their locations in the environment.	The child chooses a pile (by pointing at it) to knock over. The child has to press the appropriate switch according to the selected pile to turn the robot 90 degrees (press the appropriate switch once).
Task 3b- Sequencing	The child has the ability to do and understand a sequence of actions to accomplish a goal.	Once the robot is facing the pile of blocks the child has to knock it down (press and hold the forward switch).

In the baseline phase, the researcher gave the instructions to perform the task to participants and they received no prompting. If participants did not understand the instructions or asked questions, the researcher gave participants additional prompts (e.g., suggestions, simple cues) that were not included in the robotic prompting hierarchy. These additional prompts did not help participants to accomplish the tasks but guided and helped them to understand what the researcher was asking for. For example, if a participant did not understand where the robot had to stop to pick up the blocks in task 2, the researcher held one of the blocks above the stop location and told the participant to stop right below the block. Also if the participant asked which switch he/she had to press, then the researcher said: “Whichever you think would make the robot move”.

Despite the fact that participants were not supposed to receive prompting in the baseline, P1D needed prompting to do the tasks. Since it was his first exposure to switches, additional prompts were given to help P1D understand how the switches worked. During the first sessions the researcher and the occupational therapist told P1D what switch he needed to press in order to do the task. Physical prompting (e.g., helping him to move the head towards the switch) was also provided to help him during the sessions.

In the robotic prompting condition with the Wizard of Oz (first intervention), the researcher used the mobile application on the tablet to give the instructions or the prompts to participants, and the Matlab program on the PC to control the LEDs and the robot movements. Thus, in this condition the "robot" was the one who gave the instructions to participants and not the researcher. If after the instruction was given in task 1 the participant did not press the switch within 5 seconds (average time that participants spent to respond to an instruction in the baseline), an indirect cue was given to the participant according to Table 2. This means that the researcher selected a prompt for the robot in the tablet, and the robot said “Do you think one of the switches can help me move?” For the participant with disabilities (P1D) the average time was 8 seconds.

In the robotic prompting condition using the threshold algorithm the researcher used the tablet only to give the instruction to participants. However, in this case the robot was the one who gave the prompts based on the threshold algorithm (i.e., gave the prompts to participants if after 5/8 seconds after an instruction was given they did not press a switch).

Data Collection

All the sessions in this study were videotaped. There were four dependent variables measured in the baseline and intervention phases:

- Success rate: The number of times the participant did the task correctly over the number of attempts (i.e. the number of times the participant tried the task)
- Number and type of additional prompts from the researcher: Prompts the researcher gave to the participants when they did not understand the task or when they asked questions.
- Number of mistakes: The mistakes participants made when performing the tasks (e.g. they pressed the wrong switch, or they did not release the switch when it was necessary). When participants wanted to use their hands, it was considered a mistake, since they were asked to use the switches.
- Number and level of robotic prompts

To obtain data to address the first objective about comparing the performance in the baseline and the first intervention, the researcher coded the data from the videos regarding the four dependent variables during the sessions. The researcher filled a spreadsheet with information about the success rate, number of additional prompts, number of mistakes and number and level of robotic prompts. To obtain the number of attempts, it was necessary to count the number of times the researcher asked the participant to perform the task.

Two raters were trained by the researcher to code the videos for the success rate variable of the tasks. The raters were in their last year of the occupational therapy program at the Universidad del Rosario. The raters coded 30% of the videos from the baseline and the first intervention (each rater analyzed 15%). Seven sessions were randomly assigned to each of the raters for analysis. Each rater calculated the success rate variable in a total of 24 tasks. To obtain the interrater reliability results, results of the success rate calculated by the researcher were compared point by point with each of the results calculated by each rater (Portney & Watkins, 2015). Interrater reliability was 87,5% (agreement on 21 out of 24 tasks) for one rater and 95,8 % (agreement on 23 out of 24 tasks) for the other rater.

For the second objective about testing the threshold algorithm, only the success rate was coded by the researcher from the videos of the second intervention. In addition to that, the types of prompts the robot gave to participants, when it gave the prompt, and the prompt that the robot was supposed to give was collected in a spreadsheet. For example, if in task 1 the robot gave an indirect cue to a participant, but it was not supposed to give any prompts, this was noted.

To address the third objective about observing the participants' experience with the robotic prompting, the researcher watched the videos again, and made a list with the reactions that participants had to the robot. These reactions were defined as responses from participants during the first and second intervention (e.g., the child got scared because the robot was talking). A code was given to each reaction for the analysis.

To address the fourth objective about exploring the possible variables needed for a learning algorithm, the researcher made a list with the actions that participants made during each of the tasks. A code was given to each action for the analysis. The actions were activities of processes that participants performed during the sessions (e.g., nodding or saying "yes" when the researcher or the robot asked him/her something).

Data analysis

For the comparison of success rate between the baseline and the intervention phases in objectives 1 and 2, the success rate in each task was plotted and analyzed to compare them between phases. Descriptive statistical measures using the mean value of the success rate during each phase were used to do the comparison between the two phases. Additionally, statistical differences between the baseline and the first intervention were determined based on a two standard deviation band with respect to the baseline. If during the intervention at least two consecutive data points were outside of the two standard deviation band, it was considered to be a significant difference from the baseline to the intervention (Portney & Watkins, 2015). This method was not used for the second intervention, since there was only one session.

Trends during the baseline were examined. If there was an accelerating trend in the baseline (i.e., success rate improving in the sessions), and if the intervention is expected to increase performance in the dependent variable (as it was expected to occur with the first intervention), then if there was an accelerating trend in the first intervention, it would be difficult to assess the effect of the intervention (Portney & Watkins, 2015).

To see if the robot had an immediate effect on success rate, visual analysis of change in level at the point of intervention and latency in the intervention phase were conducted. The change of level was analyzed by comparing the value of the last data point in the baseline phase with the value of the first data point in the first intervention phase (Portney & Watkins, 2015). Latency was analyzed by describing the time it took (number of sessions) for the dependent variable to begin to change after the baseline phase (Portney & Watkins, 2015). The change of level of success rate was the only comparison made between the first and second intervention phases, because there was only one data point in the second intervention.

A summary list was made with the additional prompts given to children during the study. The percentage of additional prompts was calculated for each task by dividing the number of additional prompts into the number of attempts for the tasks and then multiplying by 100 (to normalize the data since some tasks had more attempts). These results were plotted and visually compared between phases.

Another summary list was made with the robotic prompts given to children during the first and second intervention. Also, the highest level of robotic prompting given to participants in each task during each session of the intervention phases was plotted. For example, if P1 received an indirect cue and a direct pointer cue in task 1 during session 1, then the highest level of prompting for P1 in task 1 during session 1 was a direct pointer cue.

A summary list was made with all the mistakes children made during the tasks. The percentage of mistakes in each task was calculated by dividing the number of mistakes into the number of attempts of the tasks and multiplying by 100 to normalize it. Results of the percentage of mistakes were plotted during the baseline and the first intervention. Visual analysis was performed to observe the difference between phases for the percentage of additional prompts and mistakes participants made. A plot with the percentage of each mistake made by each participant during the study was also performed. To calculate the percentage of each mistake, the number of times the participant made that mistake was divided into the total number of mistakes and then multiplied by 100.

For objective 3 a summary list of all the reactions of participants was made. The reactions were analyzed for examining the experience of children when they received the robotic prompting. Descriptive analysis was made to observe if the reactions participants had with the robot were positive or negative. This was collected to give suggestions for future work about how to improve the experience of children with the robot.

For objective 4 a summary list with the actions of participants was made. The researcher suggested physical measures from the participant that could be used for a learning algorithm to predict their actions. For example, if the majority of the participants looked at a switch before pressing it, then the eye gaze of children could be a good measure to see where their attention was focused.

4. Results

Success rate

Figure 8 to 14 show the results of the success rate obtained from the baseline and the intervention phases of each task for the typically developing children and the child with physical disabilities. P1, P4, P5 and P1D are the only participants that have a value for the second intervention. The plots are ordered according to the participant's ages, first the 3-year olds, then the 4-year old, then the 5-year olds and last the 11 year old child who had disabilities. The plots indicate the mean of the success rate in each phase. The two standard deviation method was applied to determine if there were significant differences between phases (the solid lines represent the mean value and the dashed lines represent the mean plus and minus two times the standard deviation in each phase). Each graph has the label of the participant's ID (e.g., P1) and next to it the age in years (e.g., 3y).

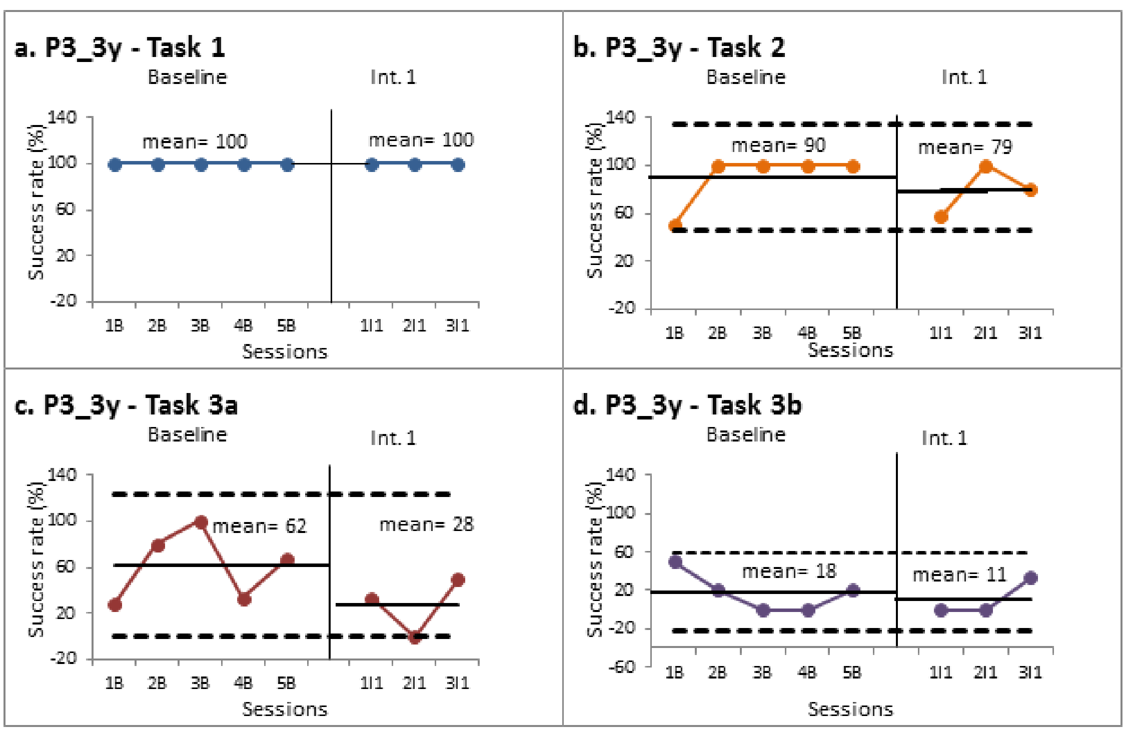


Figure 8 Comparison of success rate at the baseline and intervention phases for P3 for a) task 1, b) task 2, c) task 3a and d) task 3b.

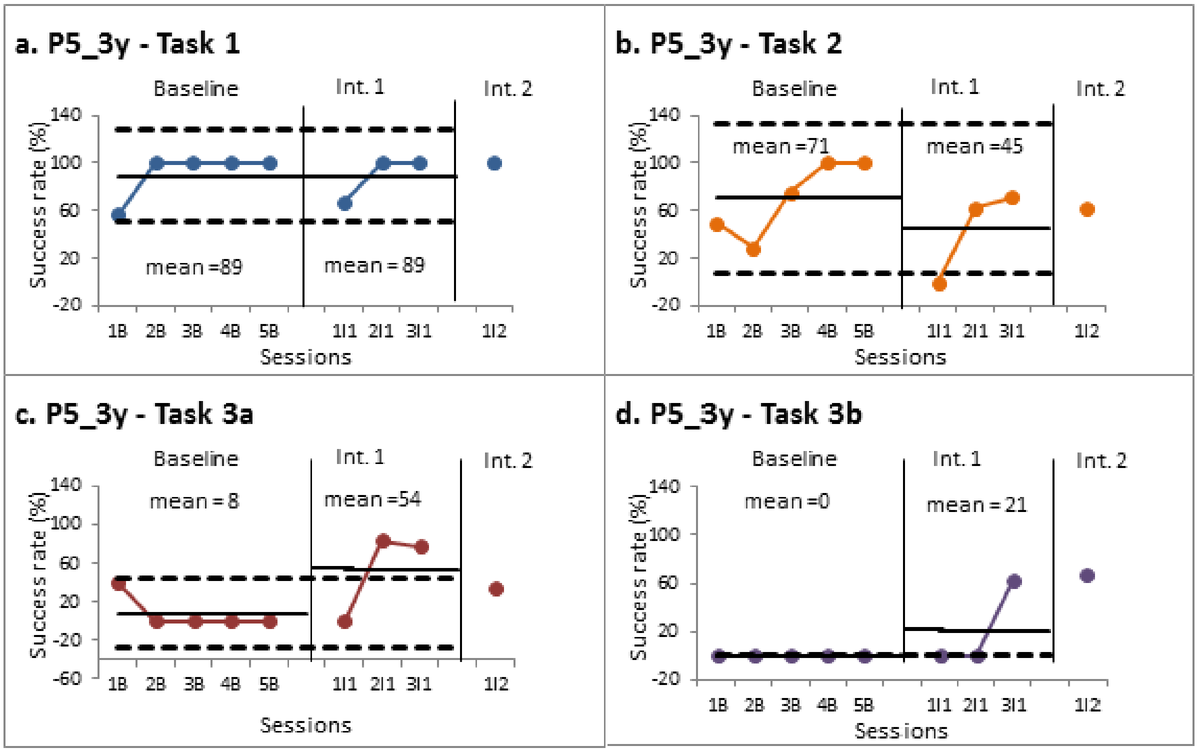


Figure 9 Comparison of success rate at the baseline and intervention phases for P5 for a) task 1, b) task 2, c) task 3a and d) task 3b.

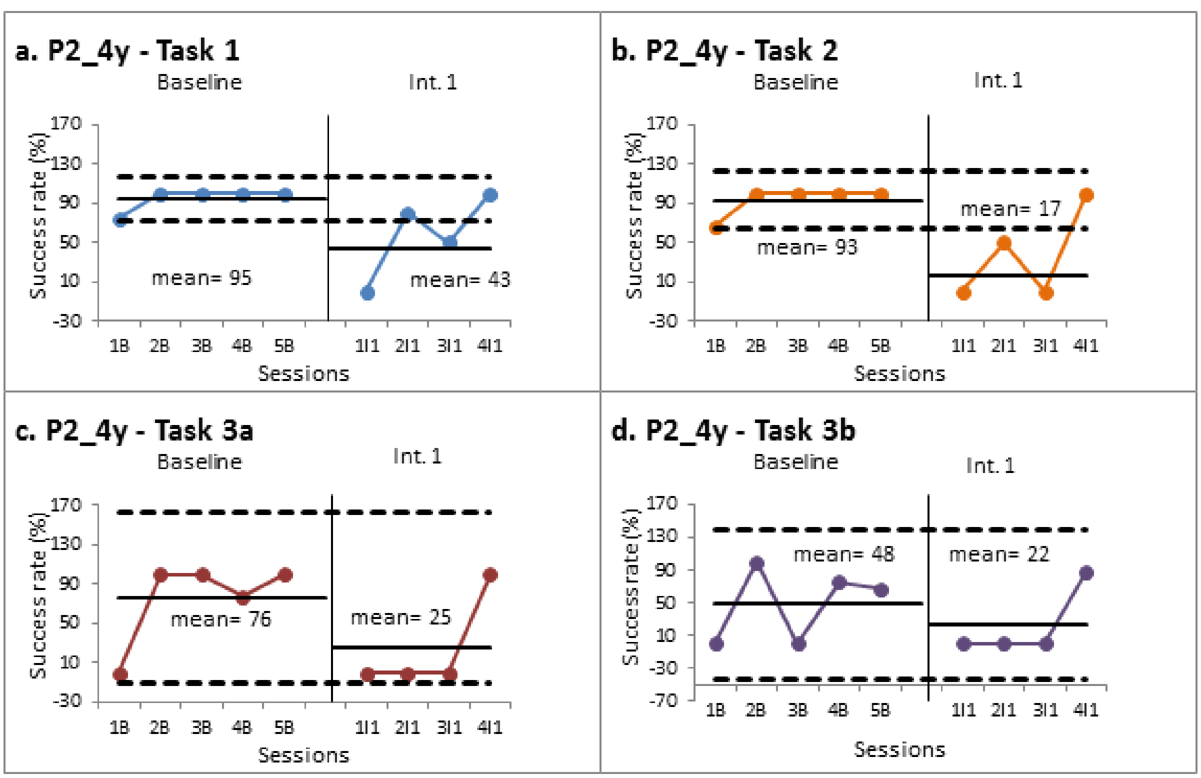


Figure 10 Comparison of success rate at the baseline and intervention phases for P2 for a) task 1, b) task 2, c) task 3a and d) task 3b.

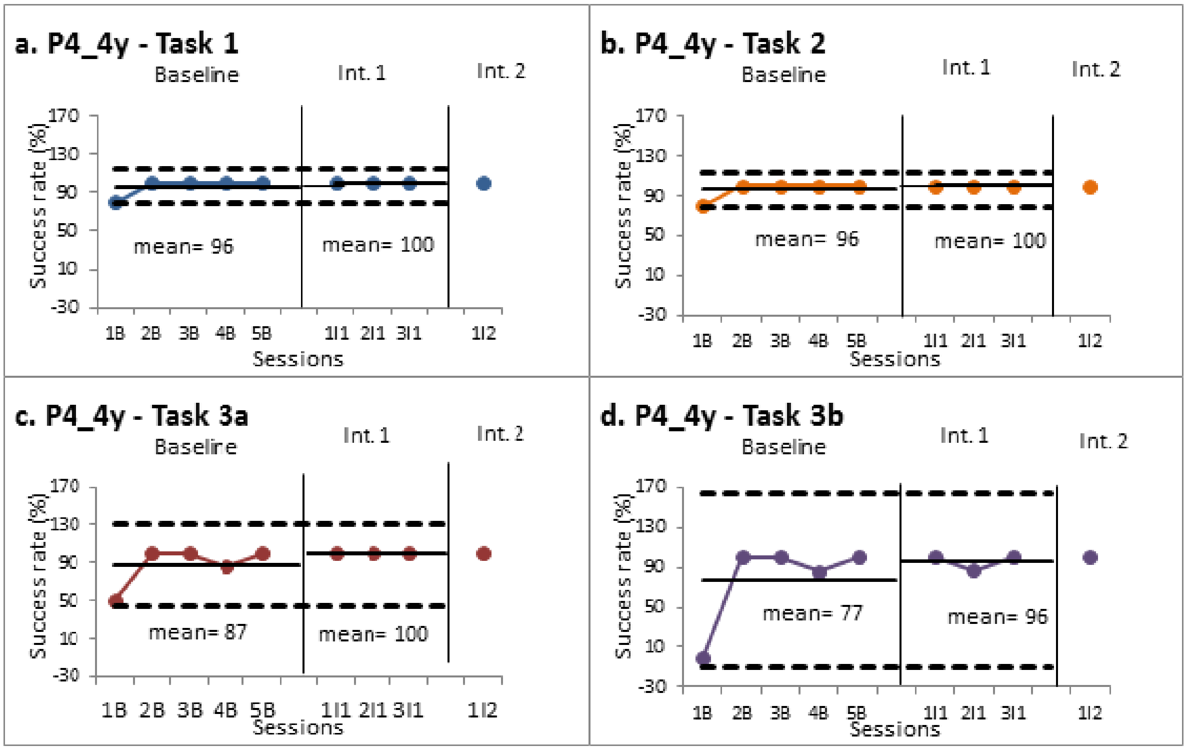


Figure 11 Comparison of success rate at the baseline and intervention phases for P4 for a) task 1, b) task 2, c) task 3a and d) task 3b.

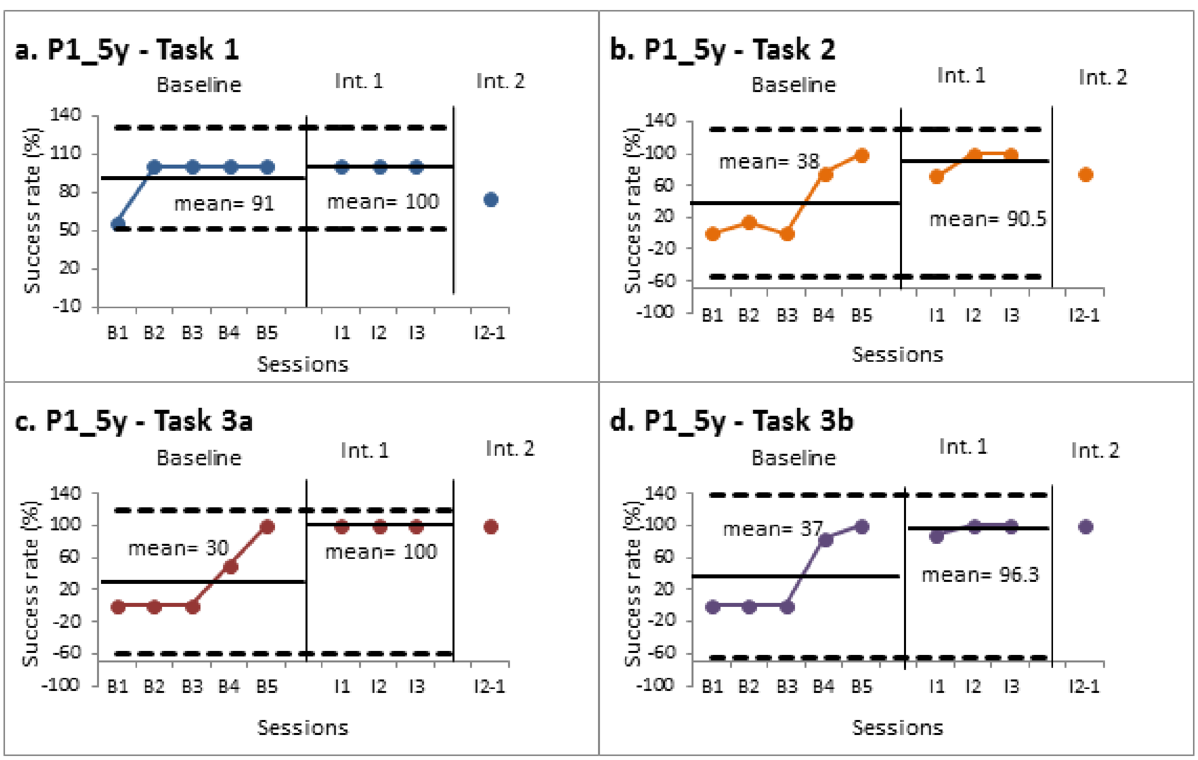


Figure 12 Comparison of success rate at the baseline and intervention phases for P1 for a) task 1, b) task 2, c) task 3a and d) task 3b.

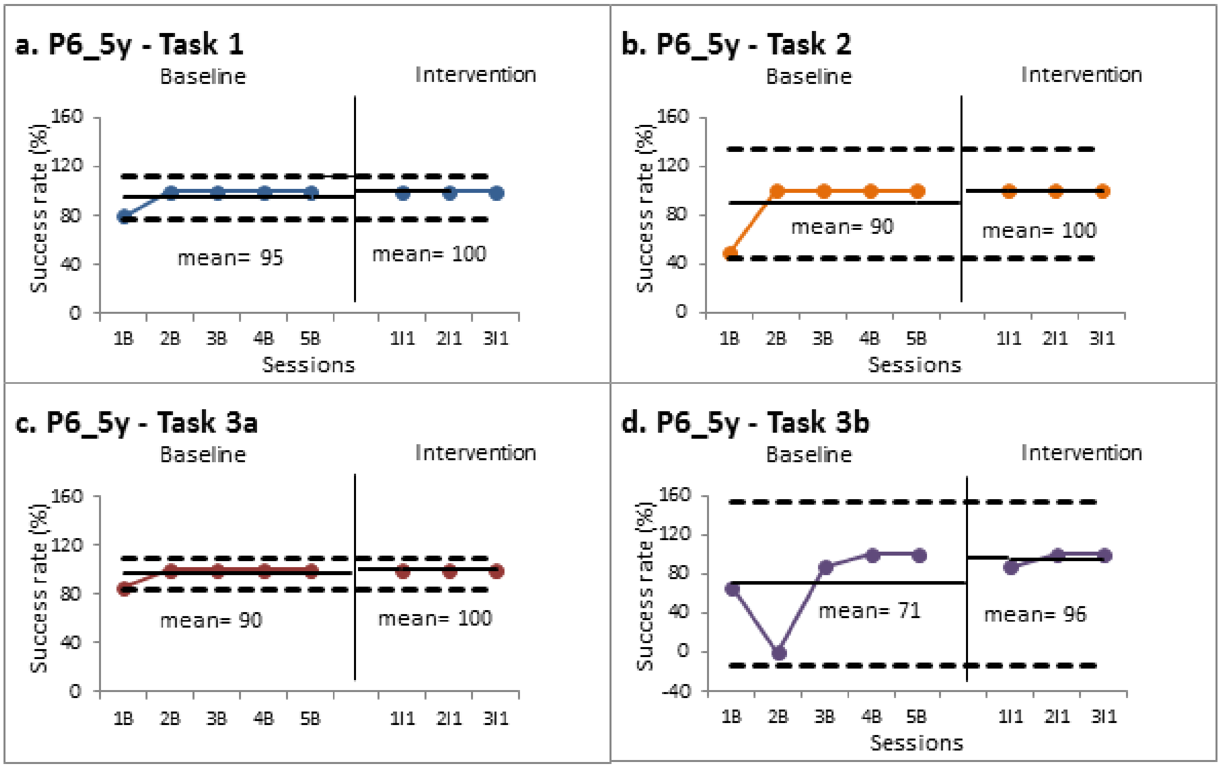


Figure 13 Comparison of success rate at the baseline and intervention phases for P6 for a) task 1, b) task 2, c) task 3a and d) task 3b.

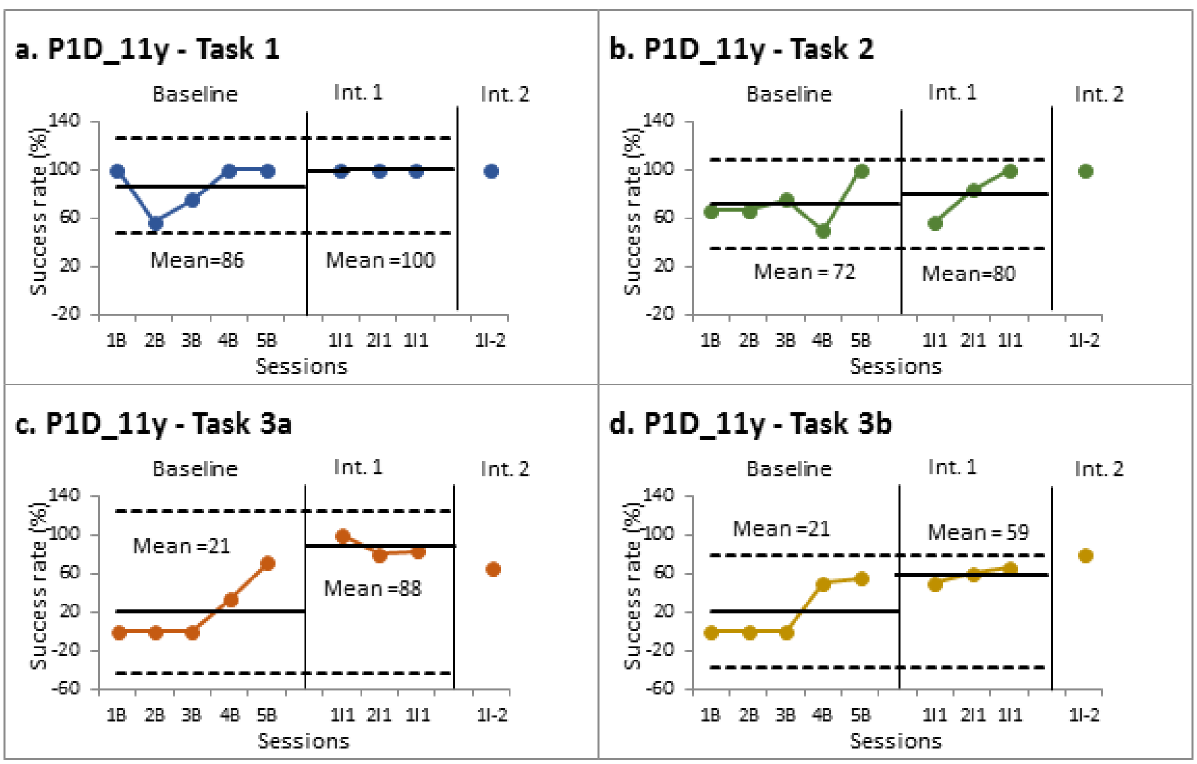


Figure 14 Comparison of success rate at the baseline and intervention phases for P1D for a) task 1, b) task 2, c) task 3a and d) task 3b.

From the figures it is possible to observe that in general all of the participants obtained 100% success rate for task 1 and task 2 in the baseline phase. Additionally, most of the participants had difficulties with the performance of tasks 3a and 3b during the baseline phase.

According to the two standard deviation method P2-4y and P5-3y were the only participants who had a significant difference in success rate between the baseline phase and the first intervention phase. P2-4y had the significant difference in task 2. Three consecutive data points in the first intervention were lower than the standard deviation band of the baseline; P5-3y had the significant difference in task 3a; Two consecutive data points in the first intervention were higher than the standard deviation band of the baseline.

Despite the fact that P1-5y, P3-3y, P4-4y, P6-5y and P1D did not have a significant difference between the phases, changes were observed in the mean value when comparing the baseline and the first intervention phases. On the one hand, P2-4y and P1D had a decrease in the mean value of success rate in all the tasks with the first intervention phase. On the other hand, P1-5y had an increase in the mean value with the first intervention for task 2, 3a and 3b. P4-4y and P6-5y did not have any difference in the mean value comparing the baseline and the first intervention. Finally results for P3-3y and P5-3y are mixed.

In terms of trend, P5-3y, P1-5y, P6-5y and P1D had an accelerating trend in success rate in the baseline for some tasks. However, during the intervention success rate decreased or remained about the same for all of them. Thus, it is possible to say that in the intervention the success rate did not follow the same trend as in the baseline.

The first one or two sessions of the baseline for most participants were often lower than the subsequent success rate values in the phase, thus there was a learning curve, which affected the mean values. Something similar happened with the first intervention for the three year olds and the youngest 4 year old, they had a decrease in the success rate of some tasks only in the first session, and in the following sessions the success rate increased. Thus, the mean value of the phase was not a sufficient description of the data, so the change in level between the last baseline and the first intervention sessions and latency were used to examine those first sessions.

To show the data more concisely for this purpose, Figure 15 shows the success rate for all tasks on one graph for each participant. The graphs are organized according to increasing age.

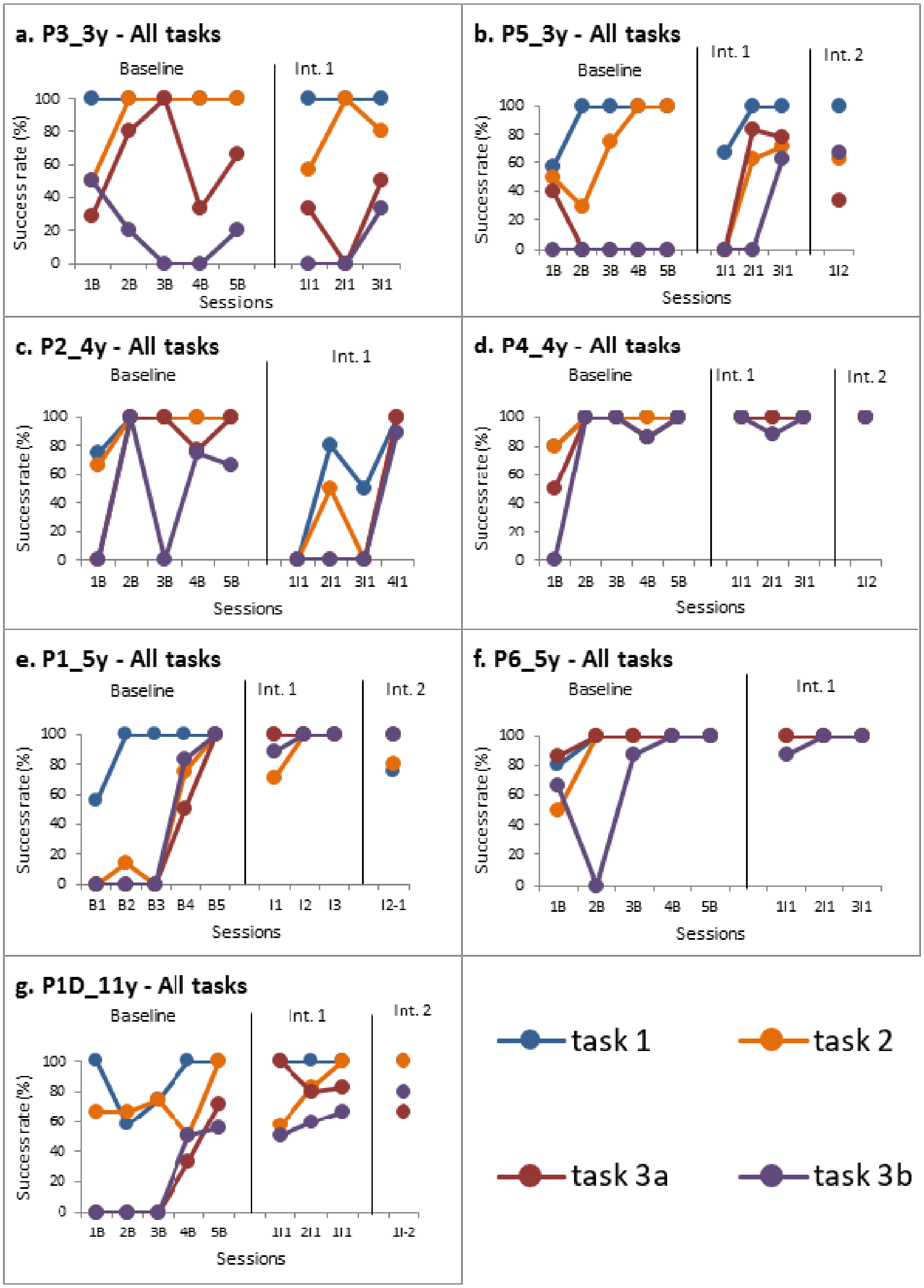


Figure 15 Comparison of success rate at the baseline and intervention phases for all the participants.

Changes in the level of success rate of the last data point of the baseline phase compared to the level of success rate of the first data point in the first intervention were observed. P3-3y and P5-3y had a decrease in the level of success rate from the baseline to the first intervention in task 1 and 2, and only P3-3y had also a decrease in the level of success rate of task 3a and 3b. P2-4y had a marked decrease in the level of success rate from the baseline to the first intervention in all the tasks. P4-4y and P6-5y did not have any change in the level of success rate comparing the baseline with the first intervention phase.

In terms of latency (the time it took for the success rate to change during the intervention), when the first intervention was introduced, it often had an immediate effect on the success rate of participants. There was an effect on the success rate in all the tasks for P2-y5, P3-3y and P5-3y. However, P3-3y did not have a change in task1 with the intervention. For the older participants P1-5y, P4-4y, P6-5y (four and five years old) and P1D the first intervention did not have an effect on the success rate in any of the tasks, with the exception of P1-5y and P1D with task 2 and task 3b.

In the second intervention the success rate of the tasks was as high as in the first intervention for almost all the participants who had a second intervention. P1-5y had a decrease in task 1 and 2 and P5-3y and P1D had with a decrease in task 3a.

Mistakes

¡Error! No se encuentra el origen de la referencia. shows a list of the mistakes that children m ade during the study from the most common to the least common. All children tried to use their hands to pick up and move the robot in the first session of the baseline (Mistake 6). Also, even though only two children kept pressing and releasing the switches when driving the robot in some of the sessions, this mistake was included in the list (Mistake 5).

Table 4 Mistakes children made during the session

Mistakes	Participants
1. Did not release the left/right switch (task 3b)	All of them
2. Did not stop to pick up the blocks (task 2)	All of them
3. Pressed the wrong switch (task 3a)	P1-5y, P2-4y, P3-3y, P4-4y, P5-3y and P1D
4. Did not press a switch	P1-5y,P2-4y, P3-3y and P1D
5. Pressed and released the switch several times	P2-4y and P5-3y
6. Use the hands	All the typically developing participants

Figure 16 shows the percentage of the numbers of mistakes (number of mistakes divided by the number of attempts) children made during the baseline and the first intervention. These plots are organized in the order that children enrolled in the study since not all of them had the same additional prompts at the beginning. Thus they might have made more mistakes, since they received less help from the researcher.

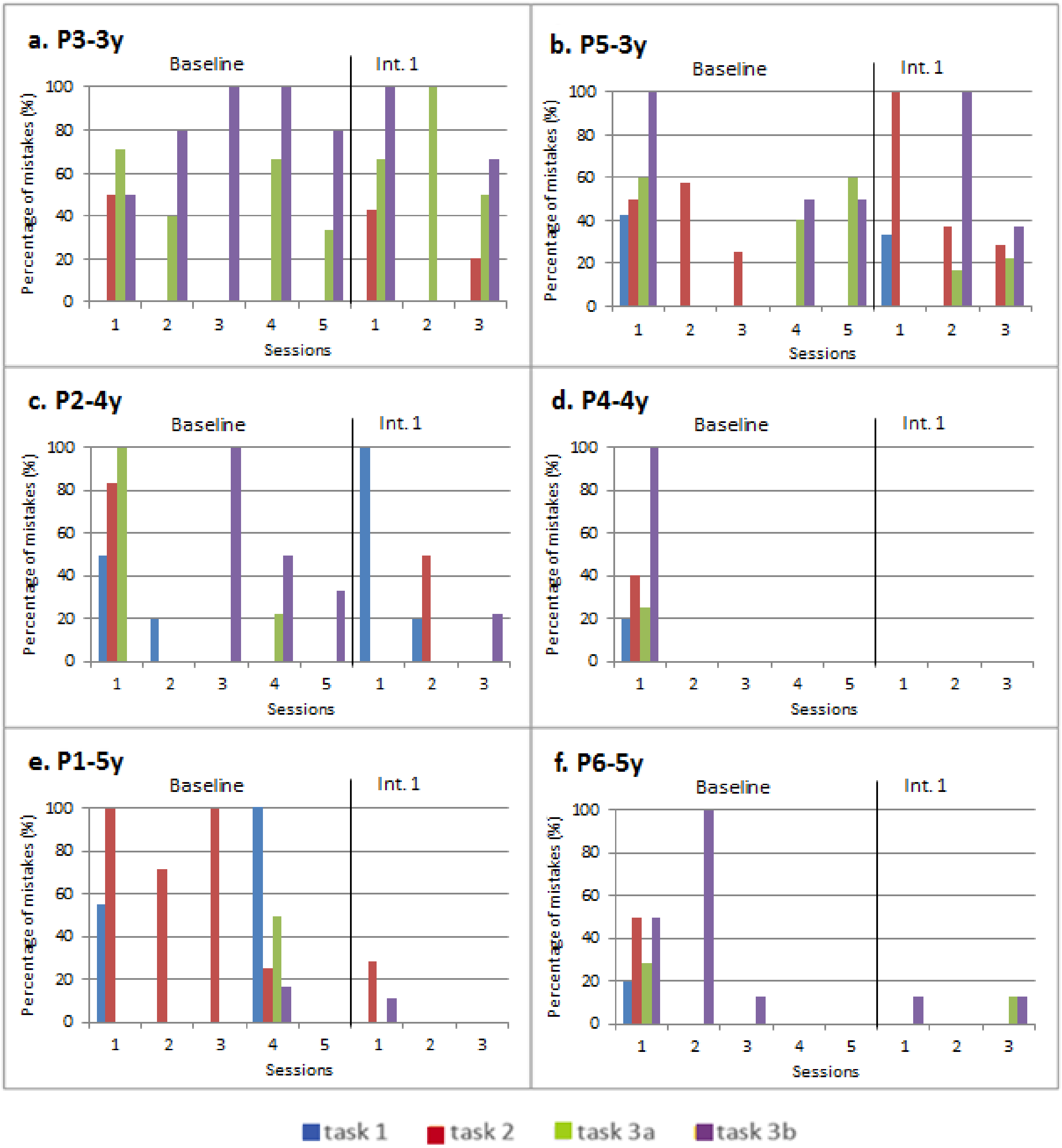


Figure 16 Percentage of mistakes children made during the baseline and the first intervention phases

Additional prompts

¡Error! No se encuentra el origen de la referencia. shows a list of the additional prompts the r esearcher gave to the typically developing participants during the study. The list is organized from the most common to the least common prompt. Additionally, the last column indicates the participants that received that prompt. When "all of them" is written in the last column it only includes the typically developing children.

Table 5 Additional prompts given to children during the baseline and the intervention phases

Prompt	When it was given	Phase	Participants
1. Remember we need to stop here	When the children did not stop at the middle of the table	Baseline	All of them
2. The robot is too far	When they stopped too far away from the blocks in task 2	Baseline and Intervention	All of them
3. Explain the task again	When they did not understand the task	Baseline and Intervention	P1,P2,P3 and P5
4. Go ahead	If the child was ready to do the task but needed the researcher's approval	Intervention	P1, P2 and P5
5. We do not have any blocks to build a pile	When the child did not stop at the middle of the table to pick up the blocks in task 2	Baseline	All of them
6. Whichever you think will make the robot move	When the child asked if a switch (pointing at it) was the one he/she should press	Baseline and Intervention	P1,P2,P4 and P6
7. Did you understand what the robot said?	When it seemed like they were distracted while the robot was talking or that they did not understand what the robot said	Intervention	P2,P3,P4 and P5
8. We cannot touch the robot	When they wanted to use their hands to pick up the robot and do the task	Baseline	P1, P2, P4, P5 and P6
9. Remember that we must knock down	When the child pressed the left or right switch for a long time	Baseline	P1, P3, P5 and P6

one of the pile of blocks	and the robot was just turning around in task 3		
10. Let's listen to the robot	When they were distracted while the robot was talking	Intervention	P2, P3 and P6
11. Remember you have to wait until the robot tells you what to do	When they were pressing the switches before the robot gave any instructions	Intervention	P1, P3, P4, and P5

Figure shows the percentage of additional prompts given to children during the baseline and the first intervention phases. These plots are organized in the order that children participated in the study. This order is used because new prompts were added to the mobile application that was used to give the robotic prompting during the study. Thus, when P1-5y and P2-4y did the study, not all robotic prompts that were available for the latter participants were programmed into the system. By the time the third participant (P3-3y) started the sessions with the robot, all the additional and robotic prompts were stablished and no more prompts were added. From the videos, it was noted that in the last sessions of the intervention children started to talk and ask questions to the robot and the researcher about the robot while the robot was giving the instructions. This resulted in children not paying attention to the instructions. In those cases, the researcher gave the prompts 7 and 10 to make sure children were listening to the robot and understood what the robot was saying.

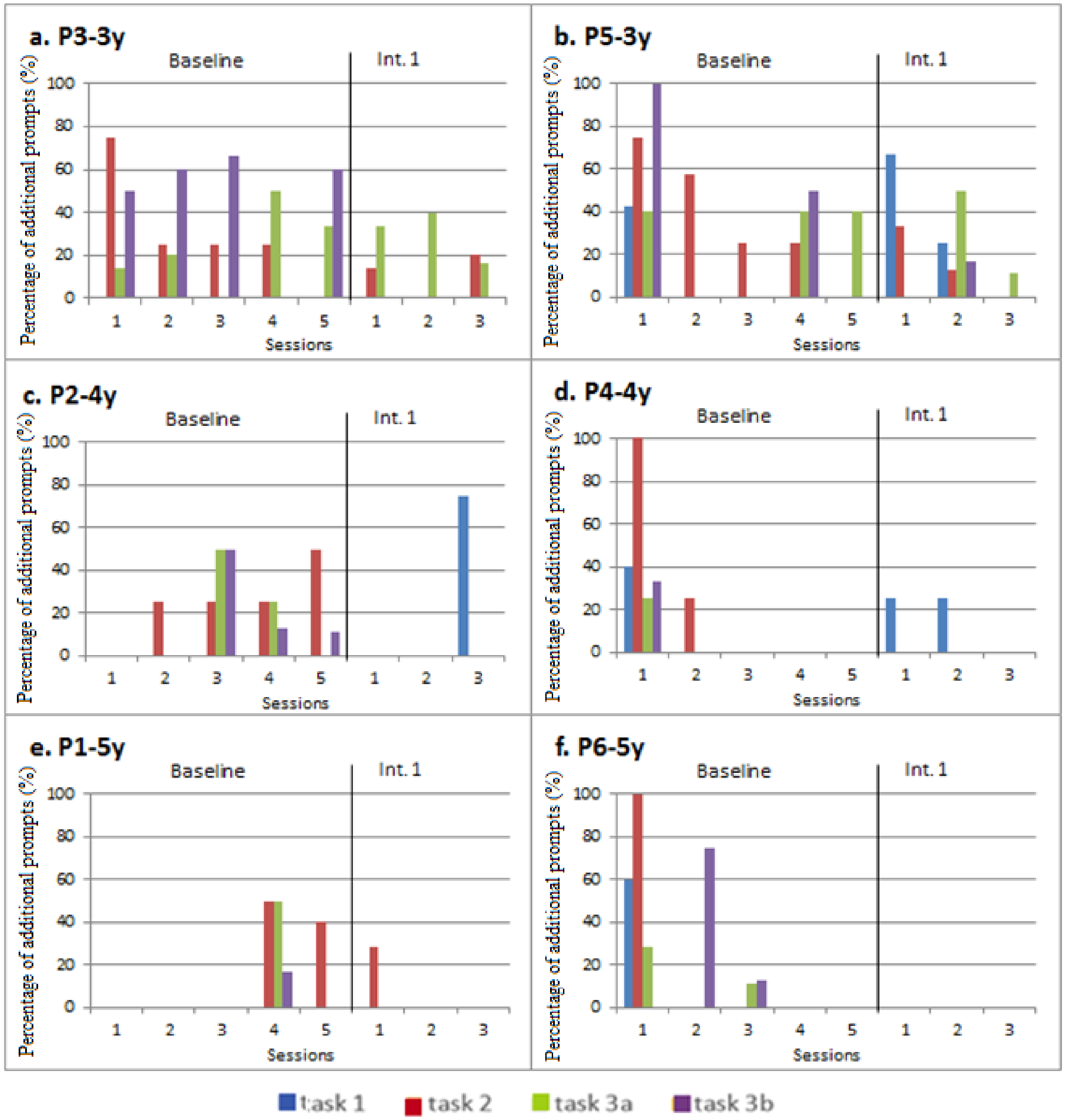


Figure 17. Percentage of additional prompts given to children during the baseline and the first intervention

In the case of P1D the prompts were different from the ones given to the typically developing participants. As explained in the methods session, he needed more direct prompts to complete the tasks. **¡Error! No se encuentra el origen de la referencia.** shows a list with the additional prompts t hat were given to P1D during all the sessions. The prompts are organized from the most common to the least common. All of the prompts were used during all the sessions for the baseline phase and the two intervention phases. For the last sessions the amount of prompt 2 decreased and the amount of prompt 3 increased.

Table 6 List of additional prompts for P1D

Prompt
1. Physical assistance by holding his head so he could reach the switch
2. Let's press the switch with the head/hand
3. Let's press the switch that make the robot move forward/turn
4. Let's release the switch

Robotic prompts

¡Error! No se encuentra el origen de la referencia. shows a list with the robotic prompts g iven to children during the first and second intervention. The first prompts on the list are the ones that were given in all the tasks, then they are organized from task 1 to task 3b. The level of prompting (assigned according to table 2 in the methods section) is also shown in the table. Additionally, the participants that received the robotic prompts are shown in the last column. At first, robotic promt number 9 was "Remember that we must knock down one of the pile of blocks". However, this prompt was changed to "Remember that we have three switches that we can use", in order to give a better prompt to children because it was a more specific prompt.

Table 7. List of robotic prompts given during the intervention phases.

Robotic prompt	Task	When it was given	Level of prompting	Participants
1. The robot explained the task again	All	If children did not pay attention to the task or did not understand the task	Indirect cue	All of them
2. The robot performed the task automatically	All	If the indirect cue prompts and the direct cue prompts did not work	Direct pointer cue with modeling	P2-4y, P3-3y and P5-3y
3. The robot said: Let's keep pressing the button	All	If children were pressing and releasing the switch several times	Indirect cue	P2-4y and P5-3y
4. The robot said: Look what happens if we keep pressing the switch. The LED of the forward switch turned on while the robot move forward for 3 seconds.	All	If robotic prompt number 3 did not work	Direct pointer cue with modeling	P2-4y and P5-3y
5. The robot said: "There is a green switch that makes me move". The LED of the forward switch turned on	1	If the instruction was given to children and they did not do aything	Indirect cue	P2-4y and P5-3y
6. The robot said: "Look what happens if we press the green switch". The LED of the forward switch turned on and the robot moved forward for 1 second	1	If robotic prompt number 5 did not work.	Direct cue pointer	P2-4y
7. The robot said: "Good try, but remember we have to stop to pick up the blocks"	2	If children did not stop to pick up the blocks	Indirect cue	P3-3y, P5-3y, P1D
8. The robot said: "Remember we have to stop	2	If robotic prompt 7 did not work	Direct cue pointer	P3-3y and P5-3y, P1D

to pick up the blocks". The LEDs close to the blocks on task 2 turned on				
9. The robot said: "Remember we have three switches that we can use"	3a	If children did not press the left or right switch	Indirect cue	P3-3y and P5-3y
10. The robot said: "Look we have two more switches that we can use". The LEDs of the left and right switches turned on	3a	If robotic prompt 9 did not work	Direct cue pointer	P3-3y and P5-3y
11. The robot said: "Good job we turned in the correct direction, but we have not knocked over the pile of blocks you chose". The LED near the pile of blocks turned on	3b	If they turn in the correct direction but did not press the forward switch	Direct cue pointer	P3-3y P5-3y and P1D

Figure shows the level of robotic prompting that each of the typically developing participants received during the first and the second intervention. Only P1-5y, P4-4y and P5-3y had a second intervention.

In the plot, level "1" means that no robotic prompting was given (Goal was met), level "2" means that children received an indirect cue, level "3" means that children received a direct pointer cue, and level "4" means that children received a direct pointer cue with modeling (i.e. the robot performed the task automatically).

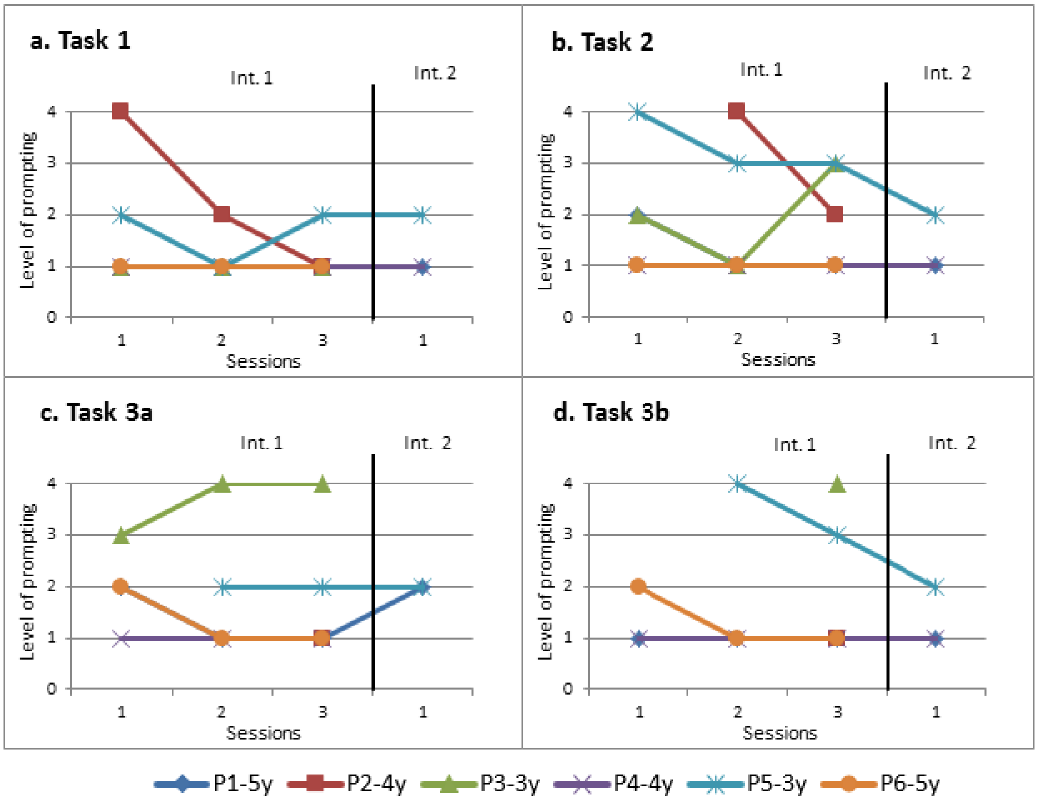


Figure 18 Level of prompting for typically developing participants during each session of the intervention phases for a) task 1, b) task 2, c) task 3a and d) task 3b.

P1D received robotic prompting during the first intervention but it seemed difficult for him to understand what the robot was saying. Thus, he kept receiving prompts from the researcher to help him to complete the task. The only robotic prompting he received were indirect cues for task 2 and task 3b.

Second intervention with threshold algorithm

When P1-5y, P4-4y, P5-3y and P1D performed the second intervention the robot gave the prompts after 5 seconds of the children not hitting any switch, but the prompt was not always needed. For P1-5y the robot gave a total of four robotic prompts and only one of them was given when the child actually needed it. The other prompts were given after 5 seconds as programmed in the algorithm, but when the robot was giving the prompt, P1-5y had already started to perform the task, so the prompt was not needed. For P5-3y the robot gave a total of 5 prompts and there were problems with three of them. As soon as the robot started to give two of the prompts, P5-3y had already started to perform the task at the same time, so these prompts were not needed. The other prompt was given when P5-3y needed it, but the type of prompt was not the correct one. In this case since the robot previously gave a prompt that was not needed (an indirect cue), the algorithm gave the following prompt based on the previous prompt, i.e., a higher level of prompting was given to the participant (direct pointer cue). For P1D a total of eight robotic prompts were given during the session, seven of them had problems. Similar to P1-5y and P5-3y as soon as the robot started to give the prompt, P1D started to move towards the switch to press it and perform the task, thus he knew how to do it and did not need the prompt. The seventh prompt was given when P1D needed it, but it was not the appropriate level of prompting.

When children pressed a switch within the expected threshold interval after the instruction was given, the robot did not provide prompting, which was appropriate. For P4-4y the robot did not give any robotic prompts because P4-4y was very fast when performing the tasks and also did not make any mistakes. The same happened when P1-5y, P5-3y and P1D pressed a switch before the time threshold elapsed, no robotic prompts were given to them.

Reactions

The reactions that participants had during the first and second intervention as well as which participants had that reaction are shown in **¡Error! No se encuentra el origen de la referencia.**. T hey are organized from the most common to the least common These reactions are actions that participants performed and that could give information about the participant´s experience with the robot (e.g., if they like it or not). The last column of the table indicates if the reactions children had, were positive or negative.

Table 8 Reactions from participants

Reactions	**Participants who made the actions**	**Effect**
1.Asking questions about the robot	All of them	Positive
2.Enjoying the tasks with the robot	All of them	Positive
3. Celebrating (clapping and/or laughing)	P1-5y, P4-4y and P6-5y	Positive
4.Getting scared	P2-4y	Negative
5. Repeating what the robot said	P1-5y, P2-4y and P3-3y	Positive
6.Thinking he/she did it when the robot did the direct pointer cue with modeling (i.e. the robot did the task automatically)	P3-3y	Negative

Actions

The actions that participants performed during the sessions are shown in **¡Error! No se e ncuentra el origen de la referencia.**. They are organized from the most common (i.e. the action that most of the participants did and that was repeated the most times) to the least common. Some of the actions were performed by only one or two participants, but they were included because other children could perform those as well and it could contribute to predict what the participant is possibly thinking or what the child wants to do. For example, action 17 was only performed by one participant, but there is still a possibility that other children would perform the same action. Some reactions from **¡Error! No se encuentra el origen de la referencia.** were included as actions in **¡Error! No se encuentra el origen de la referencia.**, since they could give information to the robot to predict the participant's intentions. They are indicated in bold.

Table 9 Actions participants perform during the study

Actions	**Participants who made the actions**	**Physical measures**
1. Nodding or saying "yes" when the researcher or the robot asked something	All of them	Face gestures and/or speech recognition
2. Looking at the researcher or to the robot when she/it was giving the instructions	All of them	Eye gaze
3. Looking at the robot while pressing the switches	All of them	Eye gaze
4. Talking	P1-5y,P2-4y,P-3y3,P5-3y and P6-5y	Speech recognition
5. Being distracted	P1-5y,P2-4y and P3-3y	Eye gaze
6. Looking at the researcher waiting for approval	All of them	Eye gaze
7. Asking to change the position of the robot (e.g. in task 3 they asked to put the robot facing one of the pile of blocks)	P1-5y,P2-4y, P3 -3y and P6-5y	Speech recognition
8. Asking "here?" (to stop the robot on task2) or "Do I press this? (pointing at a switch)	P3-3y,P4-4y, P6-5y	Speech recognition
9. Reaching for the robot	P1-5y, P2-4y, P3-3y, P5-3y and P6-5y	Position of the hands
10. Playing with the robot	P1-5y,P3-3y and P6 -5y	Position of the hands, speech recognition
11. Pressing the wrong switch and noticing that it was not the correct one and releasing it right away.	P5-5y,P3-3y and P4-4y	Eye gaze, face gestures, speech recognition
12. Looking at the switches while pressing them	All of them	Eye gaze
13. Looking at a switch before pressing it	All of them	Eye gaze
14. Answering the robots questions	All of them	Speech recognition

15. Moving a hand toward a switch but not pressing it	P3-3y	Position of the hands
16. **Getting scared**	P3-3y	Face gestures
17. Pressing two switches at the same time	P2-4y and P3-3y	Position of the hands
18. **Thinking he/she did it when the robot did the direct pointer cue with modeling (i.e. the robot did the task automatically)**	P3-3y	Speech recognition, face gestures
19. Standing up from the table	P2-4y, P3-3y and P6-5y	Position of the participant

In the case of P1D, the only actions he performed during the sessions were laughing when he heard the blocks falling down and when the researcher/robot/therapist told him he was doing a good job. Also, he laughed several times during the first session of the intervention, when the robot was talking to him. Additional actions such trying to reach for one of the switches could be taken into account to predict his intention to press a switch.

5. Discussion

The objectives addressed in this study were the first steps towards developing a robotic system to give prompting to children with physical disabilities when using a Lego robot to play. Such a robotic system would provide prompting only when children need it, letting them interact with the toys (using the robot to manipulate the toys) and giving them the opportunity to try out new experiences on the toys, by using the robot as a tool for manipulation.

Results from the baseline phase were examined to observe if participants demonstrated the skills of cause and effect, inhibition, laterality and sequencing by the end of the baseline phase. The purpose was to know if children already demonstrated the skills before the first intervention was introduced, since it would be expected that they would not need robotic prompting.

Results showed that during the baseline the 3 year old participants demonstrated the cause and effect and the inhibition skills, but not the laterality and sequencing skills. P3-3y and P5-3y reached 100% success rate in task 1 and task 2 during the baseline phase. The success rate of P3-3y in task 3a ranged from 20% to 100% during the baseline, although, she only reached 100% in one session. As her success rate at task 3a was not consistent during the baseline and she only obtained about 20% for success rate for task 3b, it is possible to say that she did not demonstrate the laterality and sequencing skills in the baseline. Participant P5-3y did not demonstrate the laterality or sequencing skills as he had a 0% success rate in 4 of the 5 sessions of the baseline for task 3a and in all the sessions for task 3b.

Success rates during the baseline phase showed that both 4 year old participants demonstrated the cause and effect, inhibition and laterality skills, but only P4-4y demonstrate the sequencing skill. P2-4y successfully performed tasks 1, 2 and 3a during the baseline phase but the success rate was lower and more variable for task 3b than for the other tasks. In his second session he attained 100% success rate for task 3b, but in session 3, his success rate decreased to 0% (he was shy and scared of the robot), and then in the following sessions of the baseline his performance increased. P4-4y completed all the tasks correctly during the baseline (and interventions), therefore, he demonstrated all four robotic skills required to complete the tasks. The only exception was the first session of the baseline phase where he obtained the lowest success rate out of the five sessions, possibly just due to the novelty of the task.

Results of success rate during the baseline for the 5 year old participants showed that they demonstrated the four robot skills at least by the end of the baseline. P1-5y achieved 100% success rate in task 1 after the first session of the baseline, but did not understand that in task 2 she had to stop the robot to pick up the blocks, so she kept driving the robot until the end of the table as in task 1. Since she did not complete task 2 in the first 3 sessions she did not perform either task 3a or task 3b (the reason why success rate was 0% in the first three baseline sessions for these tasks). However, her success rate in the tasks 2, 3a, and 3b started to increase in the fourth session of the baseline, and by the fifth session she reached 100% success rate for all the tasks. P6-5y had a success rate of 100% almost right away in all the tasks for all the sessions. For the first session of the baseline the lowest success rate was 50% and the highest 86 %. These values increased along the baseline until she reached 100% in all the tasks.

In the case of P1D, by the end of the baseline phase he demonstrated the cause and effect and inhibition skills, but the laterality and sequencing skills were not completely acquired. P1D achieved 100% success rate in task 1 and task 2 on the last sessions of the baseline. However, results of success rate for task 3a and task 3b were lower than 70% for both tasks. In his case it was difficult to distinguish if he did not accomplish a task because he did not have the skills, or because his movements due to his severe disability did not allow him to press the switches correctly. From the videos he often moves towards the switch but did not press hard enough to activate it. But, it is possible that his results do not represent if he understood the cognitive skills to perform task 3a and task 3b.

Baseline results were also compared with previous studies where children performed the same tasks using a Lego robot. In this study, the 3 year old participants demonstrated cause and effect and inhibition skills, 4 year old participants demonstrated the same skills but also inhibition and 5 year old participants demonstrated all the cognitive skills. These results are similar to previous studies where it was found that children had the skills at the same ages (Cook, Encarnação, Adams, Alvarez, & Rios, 2012; Encarnação, Piedade, Adams, & Cook, 2012; Poletz, Encarnação, Adams, & Cook, 2010). Unlike previous studies, in the present study, participants repeated the same tasks for five sessions in the baseline. It is important to highlight that the typically developing participants usually performed the tasks better after the first session of the baseline. This could be because it was their first time controlling a robot. Thus, it could be that a single session is not enough to conclude if children have or not the cognitive skills.

When comparing the success rate in the baseline and the first intervention to address the first objective, it was observed that the first intervention affected the success rate of the two 3 year old participants and one of the 4 year old participants, but there was no effect for the other participants. It was expected that success rate would increase or remain the same with the first intervention. However, the mean of success rate during the first intervention decreased for all the tasks compared to the baseline for P3-3y and P2-4y, and decreased for task2 for P5-3y. The only significant difference (decrease) in the mean was for P2-4y for task 2.

When comparing the change in level of success rate, the decreases from the last data point of the baseline to the first data point of the first intervention could possibly be because it was the first time that participants experienced the robot talking to them. There was a marked effect on the level of success rate for P2-4y: he successfully completed all the tasks in the baseline, but in the first session of the first intervention he did not even complete task 1, thus he did not perform the other tasks. The reason his performance decreased was not because he made mistakes, but because he simply did not do anything. It seems like he needed approval from the researcher to start pressing the switches. The level of success rate of the first intervention session in task 2 for P3-3y and P5-3y also decreased when compared to the level of the last session of the baseline. Since the children already had the skills in the baseline, the robot talking and giving the prompts to them seemed to have influenced their performance. However, by the end of the first intervention the level of success rate increased for the three participants, likely because they got used to the robot.

Comparison between baseline and first intervention of P1D showed that the first intervention did not have an adverse effect on his performance in the tasks. Actually, the mean value of the success rate increased in the first intervention for all the tasks. Additionally, his skills of inhibition and sequencing improved during the first intervention. However, this could be because of a learning effect since it was his sixth session using the robot.

Results from the test of the threshold algorithm showed that the algorithm was not able to provide the prompts to children exactly when they needed them. The algorithm gave the prompts on time, but sometimes the prompts were not needed. P1-5y already obtained 100% success rate during the first intervention in all the tasks, so she already had all the skills to control the robot. However, the robot still gave her prompts. This was because she was talking with the researcher after the robot gave the instruction, and the 5 seconds elapsed, and since she did not press the switch the robot gave the prompt. The same happened for P4-5y and P5-3y, since the robot did not receive any input about the switch being pressed within 5 seconds, it gave a prompt. Additionally, sometimes participants did not listen to what the robot was saying because they were distracted or not paying attention to the robot. Thus, again they did not press any switch and the robot gave the next level of prompting, but they did not need a higher level. In the case of P1D, the robot gave the prompt after 8 seconds, and though he was not distracted, the 8 seconds elapsed while he was just trying to reach the switch. These examples illustrate how it is important for an algorithm to have more information about what is happening with the participants before giving prompts, i.e., to know if the participants understood the instruction or if they have the intention to press a switch and just need longer than the usual threshold time.

Examining participant's reactions to the robot talking and giving the instructions was important so we can learn from their experience and improve future robotic systems (objective 3). The majority of the children had positive reactions when controlling the robot, only two out of six participants had a negative reaction. At the beginning of the study they were all excited to play with the robot and some of them asked what his name was. For that reason, the robot was given the name, "LegoBot". When participants knocked down piles of blocks, they were laughing and celebrating. P2-4y was the only participant who got scared because the robot was talking. In the first session of the first intervention P2-4y was always looking at the researcher and did not do anything. This is a negative effect of the robot intervention, but it could be addressed with some time to get familiar with the robot. A practice session could be done where the robot talks to participants and the researcher is involved in the conversation between the participant and the robot, but withdraws over time. This is how it happened in the third session for P2-4y where the researcher told the child it was ok to go ahead and press the switch, once P2-4y got used to the robot he started to enjoy the tasks more, and to listen to the robot without needing the help from the researcher.

An interesting and unexpected reaction was observed in one of the youngest participants (P3-3y). When the robot was giving P3-3y a direct pointer cue with modeling (i.e., doing the task by itself automatically), she thought that she was the one performing the task and she said “I did it”. In this case she did not understand that the robot was showing her how to do the task so she could try to do it afterwards. A possible reason for that is that she did not hear the robot saying “I am going to show you how to do it and then you can try”. The levels of prompting were based on Parasunaman´s scale of automation (2000), where the machine gave a limited time to humans do an action before it acted autonomously. In this case the robot performed the task by itself to show the child how to do it. However, a possible way to help participants understand that the robot is going to show them how to do the task could be to add a confirmation step from the user. For example, the robot could ask the child, “Do you want me to do the task for you?" Or, "I am going to do the task for you, okay?".

Several physical measures could be used as potential variables to recognize the actions of participants so that prompts are given just when needed (the fourth objective of the thesis). From the study it became apparent that it was important to get some information from participants to know if they understood the task in order to give them the appropriate level of prompt at the appropriate time. In the first intervention, the researcher observed several actions from participants that let her know when a prompt was appropriate to give or not, information that was not available to the time threshold algorithm, but these could be acquired automatically by technology as follows.

During the sessions, children looked at various places that gave good information about their intention, thus eye gaze would be an important variable to capture. According to Ruhland and colleagues (2015), the eyes can give information about where the attention of a person is focused. Previous studies demonstrated that it was possible for a learning algorithm to predict the targets the users wanted to go based on their eye gaze (Castellanos, Gomez, & Adams, 2017; Castellanos, Gómez, Tavakoli, Pilarski, & Adams, 2018). In the tasks used in this thesis, the eye gaze of participants could be used to detect the locations they are looking at to know if they are paying attention when the robot is talking (looking at the robot), if they are distracted (looking away from the play area), if they are waiting for approval from the researcher (looking at the researcher after the instruction is given), or looking at the switch they want to press. However, the eyes could not give us all the information about the participant's intentions.

Speech recognition of what the participants are saying would also be an important variable because participants oftentimes asked questions about how to do the task or which switch to press. Speech recognition could be used to recognize what participants are saying at different parts of the task (e.g., if they are asking a question, if they are laughing). In this study, when the robot asked questions, when the participants responded to the questions it meant they were paying attention to the robot and heard what the robot said, so a prompt would not be necessary. In the case when participants asked something, the robot should be able to recognize the question and give the appropriate response if necessary (i.e., to repeat the instruction or prompt). Also, if participants start to talk while the robot is giving an instruction, this could mean that the robot should let them know that he is talking and that they need to stop and listen to what he is saying.

From the videos it was possible to see that the position of the hands could give information about what the child is doing. The positions of the limbs have been used to recognize actions from users (e.g., sitting intents, stand-up) as well as intentions (Chalvatzaki et al., 2014). In this case, the limb's positions (e.g., the hands) could be used as a variable to know if participants are trying to stand-up or trying to touch the robot with their hands.

Finally, emotion or reactions from users could be obtained from facial expressions or brain signals (Leo et al., 2015; Saad & Perkusich, 2014). In this case, if participants are distracted it could be a signal that they are getting bored of the task, then the robot should be able to change the activity to make it more playful for them.

The combination of the mentioned physical measures as inputs for a learning algorithm could be a way to provide enough information so that the robot would prompt children only when it is needed. However, it may not be necessary to have them all. To obtain the brain signals from participants it would be necessary to use a brain computer interface. These devices are expensive and the data analysis could be complicated and could slow down the process of the prompt prediction. Additionally, to measure brain signal, several electrodes need to be placed on the user's scalp, and they need to be quite still. This could make children uncomfortable, and from the videos it was observed that they liked to move around. Thus, brain computer signals are not recommended in this case.

Limitations

The main limitation of the study was that with a single subject design it is not possible to generalize the results with other children. Replication of the study with more participants (children with physical disabilities) should be performed, so results can be generalized. Additionally, not all the participants received the same protocol along the sessions, since some of the additional prompts were established during the study, so the first participants did not receive these additional prompts. Also, the database of robotic prompts and instructions still needs improvement.

Another limitation of the study was that by the last sessions of the study older participants (5 year olds) were getting bored of the task. In this case more playful scenarios should be used to engage participants in the task, since this may affect their performance. Scenarios with princesses and castles or animals and a zoo where children can perform activities to learn the same skills of cause and effect, inhibition, sequencing and laterality could be used. Encarnação and colleagues (2012) performed such equivalent tasks, but in virtual environments.

Finally, a learning effect was observed along the study since participants performed the same tasks during the baseline and the intervention sessions. This limitation could be solved by implementing a different study design. For example, half of the participants could perform the tasks with prompting and the other half with no prompting.

Future work

This study suggested the possible variables that a learning algorithm could use to predict children's actions while performing a set of tasks using a switch-controlled Lego robot. Future work should be focused on testing different learning algorithm methods using the suggested variables to predict the prompts that should be given to children according to their intentions.

The robotic prompts sometimes were not loud enough to catch children's attention, thus children did not hear when the robot was giving the prompts. Future research should focus on the way that the robot gives the prompts to children. For example, the volume of the robot's voice could change if the environment where the session is taking place loud. Also, the visual prompts should catch the children's attention in a better way. There could be more LEDs around the switches or the LEDs could be bigger so children can see them. Additionally, the appearance of the robot could be another way to get children more involved in the activity, the robot should be attractive to children, so they want to play with it.

Additionally, this study can be replicated in order to test the database of prompting to see if there are other types of prompts that children need to complete the tasks. For example, not all children made the same mistakes during the study, in some cases only one child made one mistake that the others did not. Thus, some children may need different prompts to understand the same task. If the study can be replicated with more children, more prompts can be added to the database.

6. Conclusions

The present thesis aimed to observe if a robotic system giving the prompts to participants could be a way of providing assistance as needed to children to complete a set of tasks. One of the goals was to compare if there was a difference in the performance of children in the task when they received no prompting and when they received prompting from the researcher via the robot (Wizard of Oz technique). Results with typically developing children demonstrated that for younger children (3 and 4 year old participants), the robotic talking and giving the instructions and prompts to children had a negative effect on their initial performance. The reason for the initial decrease in the performance could be because children were not used to the robot talking to them. For that reason, a familiarization practice before the sessions with the robot should be performed where participants can talk and interact with the robot. Additionally, some aspects of the robotic system, such as more LEDs and a higher volume for the robot voice, need to be improved so children will pay more attention during the tasks.

It was also concluded that an algorithm that gives the prompts according to a time threshold was not accurate at giving the prompts to children only when they needed it. A list with suggested physical measure from the user was made, so these variables could be used as inputs for a learning algorithm that predicts actions and intentions in order to give prompting to children only when it is necessary. These variables include the eyes, face gestures, position of the limbs such as the hands and speech recognition.

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Appendixes

Appendix 1a: Letter of ethics approval from the University of Alberta

Approval Form

Date:	January 5, 2018
Study ID:	Pro00077531
Principal Investigator:	Kimberley Adams
Study Title:	Using a Robotic system to give prompting to children with disabilities when using a Lego robot
Approval Expiry Date:	Friday, January 4, 2019

Approved Consent Form:	Approval Date	Approved Document
	1/5/2018	Parent Information letter and Consent form_Children with disabilities.docx
	1/5/2018	Parent Information letter and Consent form.docx
	1/5/2018	Adults Information letter and Consent form.docx

Sponsor/Funding Agency:	Glenrose Rehabilitation Hospital	GRH

Thank you for submitting the above study to the Health Research Ethics Board - Health Panel. Your application, including the following, has been reviewed and approved on behalf of the committee;

- Recruitment Email Children with Disabilities (1/2/2018)
- Recruitment Email Typically Developing Children (1/2/2018)
- Poster Typically Developing Children (1/2/2018)
- Poster Children with Disabilities (1/2/20180
- Poster for Adults Recruitment (1/2/2018)
- Participants Information Form (11/4/2017)
- Full Proposal Ethics (11/6/2017)

A renewal report must be submitted next year prior to the expiry of this approval if your study still requires ethics approval. If you do not renew on or before the renewal expiry date, you will have to re-submit an ethics application.

Approval by the Health Research Ethics Board does not encompass authorization to access the patients, staff or resources of Alberta Health Services or other local health care institutions for the purposes of the research. Enquiries regarding Alberta Health Services approvals should be directed to (780) 407-6041. Enquiries regarding Covenant Health should be directed to (780) 735-2274.

Sincerely,

Anthony S. Joyce, PhD.
Chair, Health Research Ethics Board - Health Panel

Note: This correspondence includes an electronic signature (validation and approval via an online system).

Appendix 1b: Letter of approval from Universidad del Rosario (Bogota, Colombia)

Universidad del Rosario

COMITÉ DE ÉTICA EN INVESTIGACIÓN DE LA UNIVERSIDAD DEL ROSARIO

SALA DE CIENCIAS DE LA VIDA

MIEMBROS

CARLOS ENRIQUE TRILLOS, PRESIDENTE
MÉDICO CIRUJANO; MSC. EPIDEMIOLOGÍA

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ABOGADO; ESP. DERECHO MÉDICO SANITARIO

CAROLINA BLANCO FALLA
FISIOTERAPIA; MSC SALUD OCUPACIONAL

JAID CONSTANZA ROJAS
BACTERIÓLOGA; MSC. SALUD PÚBLICA;
MSC. BIOÉTICA

KATHERIN QUINTERO PARRA
QUÍMICA FARMACÉUTICA

LUISA FERNANDA RAMÍREZ
PSICÓLOGA- PHD PSICOLOGÍA SOCIAL Y DE LA SALUD

MAGDA MILENA GAVIRIA
BIÓLOGA; MSC EN BIOLOGÍA

MARTHA ROCÍO TORRES NARVÁEZ
FISIOTERAPEUTA, MSC BIOÉTICA

RAMÓN FAYAD NAFFAH
LIC. EDUCACIÓN PHD BIOFÍSICA

JOHANNA MAYERLY GONZALEZ
AUXILIAR ADMINISTRATIVA

DVO005-1-352-CEI922

Bogotá D. C., 10 de abril de 2018

Doctoras
ADRIANA MARIA RIOS
MARIA FERNANDA GÓMEZ
Investigadoras Principales
Estudio: "Utilizando un sistema robótico para asistir niños con discapacidad durante el uso de robots Lego"
Bogotá, D. C.

Apreciadas Investigadoras:

En el Comité de Ética en Investigación revisó el proyecto: "Utilizando un sistema robótico para asistir niños con discapacidad durante el uso de robots Lego".

Luego de haber tenido en cuenta las observaciones efectuadas, el Comité de Ética en Investigación, APRUEBA el protocolo en referencia junto con toda la información anexa.

Para el comité de ética es importante acompañarlas durante la ejecución del estudio. Por favor no dude en contactarnos en caso de tener alguna inquietud o de necesitar apoyo para el análisis de alguna situación específica.

De igual forma le recomendamos notificar cualquier modificación en la ejecución del estudio no expuesta en la aprobación inicial del proyecto.

Cordialmente,

JUAN GUILLERMO PÉREZ MD, MSc
Secretario Técnico
(CEI-UR)

Este comité se rige por los lineamientos jurídicos y éticos del país a través de las resoluciones 8430 de 1993 y 2378 de 2008 del Ministerio de Salud y Protección Social. Igualmente, se siguen los acuerdos contemplados en la declaración de Helsinki (Fortaleza, Brasil 2013) y de la Conferencia Internacional de Armonización para las Buenas Prácticas Clínicas.
Recuerde visitar nuestra página web, en donde encontrará información actualizada de los procedimientos del Comité de Ética en Investigación de la Universidad del Rosario, así como cursos en ética de la investigación de acceso libre.http://www.urosario.edu.co/Servicios-al-Investigador/Sistema-de-integridad-cientifica/

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Carrera 24 N° 63C-69 Bogotá
Teléfono: 2970200 Ext. 3295
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Appendix 2a: Parent Information letter

Parent Information letter

Investigators:

K. Adams (Faculty of Rehabilitation Medicine, Glenrose Rehabilitation Hospital)
M. Gomez (Research Assistant, MSc student, Faculty of Rehabilitation Medicine)

Purpose: We are developing a robotic system that provides prompting to children to help them control a Lego robot. We want children to try this system in order to determine if it is helpful.

Background: Robots have been used to help children with disabilities to manipulate toys when they are playing. Results from some studies have shown that robots could be difficult to control for children and this could lead to frustration. Prompting from adults has been used to facilitate play in children with disabilities, however adults tend to over prompt children, thus taking away the opportunity from children to learn and to try out new experiences by themselves. The robotic system will give prompting as needed to children while controlling a Lego robot, to help them complete a set of tasks.

Procedures: Your child will participate in one 30 to 40 minutes session. In this session the child will be asked to perform a set of tasks using a Lego robot. The tasks include to knock down piles of blocks or to build them using a switch-controlled Lego robot. The session will be in a place convenient for you (like school, day care, home or our lab). In addition, the session will be videotaped with two cameras (one with the view of the play area, and the other with the view of your child's face). The videos will be used for analysis and coding of variables. Before the session you will be asked to fill out a short survey about your child preferences when playing and about the day you are attending the session.

Benefits: Children have fun when they use robots to play. Our result can be helpful for children with disabilities.

Risks: Your child may get tired during the session. Breaks will be given as needed. The robot is battery operated and there is no danger of electrical shock. The robot is small and lightweight and will not hurt the child if it does contact him or her.

Confidentiality: All the information you provide will be kept confidential. For data analysis purposes we will use a participant code and your name and the name of your child will not be used at any time. No identifiable information will be linked to your data. We may use the videotapes or data derived from our analysis of the results for teaching or research presentations, academic publications and reports if you agree to it. As part of the analysis we want to correlate the places where your child will look with what he/she does. For this reason, the child's face will be visible in the videos. We will not provide any identifiable information related to the video. We will only report group data and we will not identify any specific participants in any presentation or report. The information will be kept for at least five years after the study has been completed, per University policy. The information will then be destroyed and only the final results will be kept. All videotapes and files will be kept in a locked cabinet and only the researchers listed above will have access to identifiable information. Electronic files will be kept in a password protected folder in the Assistive Technology Lab at the University of Alberta.

Freedom to Withdraw: You are free to refuse to participate or withdraw from this study at any time. You do not have to give a reason and it will not affect your child's program or treatment in any way.

Additional Contact If you wish to find more about the study or sign up to participate, please contact: Maria Fernanda Gomez (Phone number 780709-4917).

If you have any questions about the study please contact: Dr. Kim Adams (Phone 780-492-0309, Fax 492-1626, e-mail – kim.adams@ualberta.ca) Faculty of Rehabilitation Medicine, University of Alberta.

If you have any comments or further questions about any aspect of this study please contact Dr. Tammy Hopper (Associate Dean of Graduate studies and Research), Faculty of Rehabilitation Medicine, University of Alberta at (780) 492-0651. Dr. Hopper has no direct relationship to this study.

If you have any questions or concerns regarding your rights as a participant, or how this study is being conducted, you may contact the Research Ethics Office at 780-492-2615. This office has no affiliation with the study investigators

Appendix 2b: Blank consent Form for Parents

Consent Form for Parents

Title of project: Using a Lego robot to assess skills in children with physical disabilities

Investigators:
Kim Adams, Assistant Professor, Faculty of Rehabilitation Medicine, University of Alberta
Maria Fernanda Gomez Medina, MSc Student, Faculty of Rehabilitation Medicine, University of Alberta
E-mail: gomezmed@ualberta.ca, Phone: (780) 7094917

To be completed by the research subject.

Do you understand that you and your child have been asked to participate in a research study?	Yes	No
Have you read and received a copy of the attached information sheet?	Yes	No
Do you understand the benefits and risks involved in your child taking part in this research study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate or to withdraw from the study ad any time, without giving a reason?	Yes	No
Do you understand that information such as age, date of birth, and address will be needed if applicable?	Yes	No
Has the issue of confidentiality been explain to you?	Yes	No
Do you understand who will have access to your child's records?	Yes	No
Do you consent that the research student uses a video camera to record the session with your child for research and educational purposes?	Yes	No

This study was explained to me by:

I agree to participate in the study and to allow my child to take part in this study

______________________ ______________________

Signature of Parents **Date**

____
Printed Name

____
Name of the child

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate

______________________________ ______________________________
Signature of Investigator **Date**

Appendix 3: "Wizard of Oz" Robotic prompting - Robotic actions based on the prompting hierarchy (From DynaVox (2014) and Encarnação et al. (2014)

Type of Prompting	Actions the robotic system will do to provide the prompt
Task 1: Causality	
1. Goal met	If the child performs the task 1, the robot does not provide prompts.
2. Indirect cue	The robot will say to the child "Can we please drive to knock down the pile of blocks?", while the LED on the forward switch turns on.
3. DPC Direct pointer cue	The LED on the forward switch turns on and at the same time the robot moves one step ahead, so the child can see that if the switch is pressed the robot will move.
4. DPC-m direct pointer cue with modeling	The robot will knock down the pile of blocks autonomously. At the same time, the LED on the forward switch will be on while the robot is moving.
Task 2: Inhibition	
1. Goal met	If the child performs the task 2, the robot does not provide prompts
2. Indirect cue	- If the child drives the robot to the end of the table and does not stop it by the blocks, the robot will say to the child "Good try! but remember we have to stop to pick up the blocks".` The robot is then placed in the starting position. - If the child stops too far behind the blocks, the robot will say to the child "Do you think we can go closer to the blocks?". - If the child stops too far ahead of the blocks, the robot will say: "That was close, let's try again and see if we can stop even closer to the blocks". The robot is then placed at the starting position.
3. Direct pointer cue (feedback from switch)	- If the child drives the robot and does not stop again in the middle to pick up the blocks, an LED placed by the pile of blocks will turn on in all the Indirect Cue conditions.
4. direct pointer cue with modeling	The robot will perform and complete the task autonomously, while the LEDs on the switches and by the pile of blocks in the environment will turn on and off.
Task 3a: Laterality	
1. Goal met	If the child performs the task 3a, the robot does not provide prompts
2. Indirect cue	- If the child does not decide which switch to press, the robot will say "Remember now we have three switches that we can use". - If the child presses the wrong switch, the robot will say: "Remember that was not the pile of blocks you selected".
3. Direct pointer cue	The LED of the pile of blocks that the child selected will turn on.
4. direct pointer cue with modeling	The robot will autonomously turn in the appropriate direction according to the pile the child selected and the LEDs on the appropriate switch will turn on.

Task 3b: Sequencing	
1. Goal met	If the child performs the task 3b, the robot does not provide prompts.
2. Indirect cue	- If the child, after turning in the correct direction, persists pressing the same switch, the robot will say: "Well done, we turned the correct way, now remember that there are three switches" Researcher moves the robot back to the middle of the piles, facing away from the child.
3. Direct point cue	The forward LED will turn on.
4. Direct pointer cue with modeling	The robot will autonomously knock down the pile of blocks chosen.

Appendix 4. Blank Participant questionnaire for Parents

Date:

Questions before the session:

1. How old is the participant in years and months?

2. Does the participant have a hand preference (right or left hand)?

3. Has anything happened that you think might affect your child's performance today?

Appendix 5. Instructions for each of the task during the protocol (Based on Encarnação et al. (2014))

Task	Instructions for children
1 – Cause and effect	- "Let's see what we have here for you to play with. Look, there we have a pile of blocks, a robot and a switch (pointing at each of them)" - "You will get to drive the robot. Would you like to press this button to turn on the robot?" - "Great! Are we ready to start? Can you drive the robot right down here (pointing the route) and knock that pile of blocks"?
2 – Inhibition	- "Now how about you help me build the stack of blocks? Can you help me take these blocks from here (pointing where the blocks are) to there (pointing the end of the table)" - "Are you ready? So now we are going to drive the robot and we need to stop here (pointing where the blocks are), so I can put the blocks on the robot". - If the child stops the robot at the correct place (beside the blocks), the researcher places the blocks on the robot and tells the child "Well done! Now let's drop off the blocks at the end here (pointing where the child should stop)"
3b – Laterality	- "Now we have these two piles of blocks (pointing at the piles). Which one would you like to knock over first?" - Let the child choose and then: "Ok!, now you have these three switches (pointing at the switches and ensuring the child is aware of them), go ahead and knock over those blocks"
3b – Sequencing	- "Now can you knock down the pile of blocks that is left?"