Robots Learn to Play: Robots Emerging Role in Pediatric Therapy

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Abstract

There is an estimated 150 million children worldwide living with a disability. For many of these children in the U.S., physical therapy is provided as an intervention mechanism to support the child's academic, developmental, and functional goals from birth and beyond. Typically, for a physical therapy intervention to be adopted, there must be sufficient evidence-based practices showing the efficacy of the given method in use with the target demographic. With the recent advances in robotics, therapeutic intervention protocols using robots is ideally positioned to make an impact in this domain. Unfortunately, there has not yet been sufficient evidence-based research focused on the use of robots in child-based therapy to result in a full systematic review of this area. As such, in this paper we provide a review of the emerging role of robotics in pediatric therapy, with the goal of summarizing the research that could possibly transition into providing evidence on the efficacy of robotic therapeutic interventions for children.

1. Introduction

Many therapeutic interventions for children with physical and/or cognitive impairments focus on improving functional movement skills and cognitive abilities (Park and Howard 2010; Curtis et al. 2011; Roberts, Park, and Howard 2012). Pediatric physical therapy differs from adult therapy in that younger children typically cannot (or may not be willing to) follow direct instructions required of a therapy routine. Thus, clinicians typically incorporate therapy in play to provide an engaging and motivational intervention that may enhance the child's participation in the therapy session. No one will argue about how important play is during childhood. The role of play in the development of children has been extensively studied, and a large body of work exists to discuss the importance and nature of play in children. Piaget's book "Play, dreams, and imitation in childhood" is one of the earlier references showing the importance of play in the learning of cognitive, social, and physical skills (Piaget 1951). This work examined the stages of child development and the role of play in the developmental process. It suggests that play is useful for a variety of reasons, including helping to develop motor skills and spatial abilities.

Due to a number of factors, include costs and the limits on time available for therapists to provide quality one-on-one sessions for physical and occupational therapy (PT/OT) sessions, there has been interest in finding alternative ways to augment physical therapy sessions in-between clinical visits. In recent years, the promotion of robotic platforms as an assistive therapeutic device has been gaining momentum. Since this is an emerging field, it becomes necessary to provide a foundation for understanding the state-of-the art in this domain in order to identify common challenges and limitations, as well as highlight current successes. The purpose of this review is therefore to document the state-of-the-art of robots used in therapeutic play with children. A brief introduction to the significance of play is given, followed by an overview of the literature on therapeutic play involving robots. Several types of robots are discussed, including robots capable of being teleoperated by children with motor impairments for use in manipulation based play, integrating play with a robotic orthosis for improving upper and/or lower extremity functions, and autonomous robot toys for engaging children with pervasive developmental disorders. Some conclusions regarding the work are given at the end of the review, followed by a full list of citations.

2. Play-Based Manipulation for Children with Motor Impairments

There are over 200,000 children with disabilities being served in the U.S. public school system that have an orthopedic impairment, including multiple disabilities (U.S. Dept. of Education 2010). Of these children, many have difficulty performing traditional manipulation tasks, such as those required to perform instrumented activities of daily living. Adapted robotic manipulators that provide therapeutic interventions for children with upper extremity motor impairments typically engage children in physical activity that will aid in increasing their functional skills. However, most robots in this augmentative manipulation domain are not autonomous and are designed to be teleoperated by either the clinician or the child. The following provides an overview of the various augmentative manipulation platforms as applied to pediatric therapy interventions.

2.1 Augmented Manipulation through Robotics

PlayROB (Kronreif et. al. 2005) is a tele-operated 3 DOF Cartesian robot that was designed to allow children with physical disabilities the ability to manipulate LEGO bricks. The robot is controllable using a variety of access methods in order to engage the widest demographics of children with disabilities, including a 5-key input device, a joystick, and a head switch. The system was evaluated in a two-year study involving five to ten children at three Austrian institutions beginning in 2004 (Kronrefik et al. 2007). The authors state that the resulting data provides preliminary evidence that, through robot usage, there is a corresponding increase in children's endurance and concentration, as well as spatial perception. In addition, the robot system provides a training tool for learning how to interact with different accessible input devices.

The Handy Robot (Topping 2002) is a tele-operated 5DOF arm and gripper designed to assist individuals with disabilities in the accomplishment of a variety of daily tasks, such as eating and drinking. Control of the robot is accomplished by a single-switch input device in which a sequential scan of an array of LEDs activates different robot behaviors. Although its primary use has been on assisted manipulation, it was deployed in a single subject study (Handy Artbox) to encourage independent thought, creativity, and help improve motor skills and spatial awareness. The Handy Artbox Robot was used over a one-month period with a single child subject at a special school in Newcastle, Staffordshire in art and drawing play activities. Based on this preliminary case study, the authors concluded that the system could have the potential of being a useful aid for children with severe disabilities.

In (Cook et al. 2002), a 6DOF arm for use in play-related tasks was presented in which individual robot arm joints could be controlled by children through various control interfaces including large push buttons, keyboards, laser pointers, and head-controlled switches. A pilot study (Cook et. al. 2005) was conducted that included twelve children with severe physical disabilities from 6-14 years of age for 12-15 sessions over a period of four weeks. Preliminary results indicated improvement in all children in operational control of the robot, which translated to varying levels of increases in functional skill development that carried over to tasks performed in the classroom environment.

A prototype robotics arm was deployed in (Howell and Hay 1989) during an 18-month pilot project in the Columbus Public School with the intent of fostering cognitive, affective, and psychomotor development in students with severe orthopedic disabilities (Howell 1989). Based on results derived from seven children with severe orthopedic disabilities, issues involving accessibility, software design, and curriculum integration were identified.

Other assistive manipulation robotics projects have primarily focused on deployment and evaluation of the system with respect to task achievement (versus evaluating its effect as a therapy tool). Such systems primary have focused on providing manipulation capability to assist in the classroom environment (Eberhardt, Osborn, and Rahman 2000; Harwin, Ginge, and Jackson 1988; Karlan et. al 1988; Davies 1995). For example, in the POCUS project (Kwee et al. 2002) the MANUS Manipulator was adapted for use as an assistive tool for 7 children and young adults with cerebral palsy, aged from 7 to 29 years. Interfaces such as push buttons, keypads, joysticks, and head-controlled switches were investigated for control. The preliminary results provided showed the feasibility of use in performing various manipulation tasks, but did not focus on outcome measures with respect to therapeutic interventions. In the PLAYBOT project (Tsotsos 1998) the focus was also on assisting children with disabilities in manipulation activities related to play.

The aforementioned research focused on compensating for the physical limitations of the child by augmenting their manipulation capabilities. Some preliminary results have shown the positive use of these systems in therapeutic intervention scenarios, but there is still insufficient evidence to fully validate the efficacy of these platforms in pediatric therapy setting. Given the growing acceptance of similar-type systems for use in stroke-rehabilitation (Lum et al. 2004), it makes sense that researchers should continue pushing forward research in the augmented manipulation domain to support its clinical use for children with physical disabilities.

3. Robotic Orthoses for Children with Motor Impairments

Many children who have neurological disorders, such as cerebral palsy, may not only have difficulties in upper-extremity movements but may have limitations in lower extremity movements as well. Such children may have difficulties in sitting, standing, and walking. Balance problems and/or stiffness in their gait can range from barely noticeable to the need for a wheelchair. As such, robotic exoskeletons, or the utilization of a robotic orthosis, provide another means of therapy for such children. Various orthotics, ranging from robotic arm orthoses (Sukal, Krosschell, and Dewald 2007) to robot-assisted locomotor trainers have been used in this domain. Although robotic arm orthoses endure the same fate as the augmentative manipulation platforms with respect to lack of a sufficient evidence-base, there is a growing body of clinical literature that shows robot-assisted gait training is a feasible and safe treatment method for children with neurological disorders (Borggraefe et al. 2010; Meyer-Heim et al. 2009). In fact, a systematic review that included studies assessing the effectiveness of robot-assisted gait training for children was recently provided in (Diamiano and DeJong 2009). To counter some concerns with respect to findings that state task-specificity and goal-orientedness are crucial aspects in the treatment of children versus passive training for motor learning (Papavasiliou 2009), researchers have begun to investigate the coupling of robotic orthotic systems with scenarios involving play. For example, in (Brütsch et al. 2010) a pilot study with ten patients with different neurological gait disorders showed that virtual reality robot-assisted therapy approaches induced an immediate effect on motor output equivalent to conventional approaches with a human therapist. Another case study showed that using custom rehabilitation games with a robotic ankle orthosis for a child with cerebral palsy was clinically more beneficial than robotic rehabilitation in the absence of the video games (Cioi et al. 2011). Although this research area is still pushing to provide a sufficient evidence-base for using a robotic orthosis in play, this domain is the closest to validating its efficacy through clinical studies. General challenges identified by researchers in this area primarily discuss the need for creating new game designs in order to maintain participant's motivations, as well as the need for further research with a larger number of participants both in the clinical as well as in the home environment.

4. Robotic Engagement for Children with Developmental Disabilities

Recent estimates in the United States show that about one in six, or about 15%, of children aged 3 through 17 years have one or more developmental disabilities (Boyle et al. 2011). Occupational therapy, which is concerned with a child's ability to participate in daily life activities, is used to help improve a child's motor, cognitive, sensory processing, communication, and play skills with the goal of enhancing their development and minimize the potential for developmental delay (Punwar 2000). Recently there has been growing interest in research involving occupational therapy through play between robots and children with developmental disorders, such as Down syndrome, Autism Spectrum Disorders, and Fragile X Syndrome. The majority of this research has focused on children with pervasive development disorders (PDD). While typically developing children possess the ability to imitate others from birth, children with PDD, such as autism, demonstrate significant difficulty in object and motor imitation. Imitation skills are thought to be closely related to early language and social abilities. Studies involving therapeutic play between robots and children with PDD have thus been of particular interest for several reasons. First, based on a clinical evidence-base, it has been shown that children with autism are capable of learning and of altering their behaviors when teaching is provided using clear instructions, repetition and practice, and immediate reinforcement of correct responses. This use of repetition and feedback in teaching has been well-established in a variety of prior and recent clinical studies (Lovaas 1981; Crockett et al. 2007). Robots in their basic incarnation are well suited to provide consistent actions in a repetitive fashion. It has also been shown that children with and without disabilities naturally find robots to be engaging and respond favorably to social interactions with them, even when the child typically does not respond socially with humans. Finally, it has been proposed that passive sensing used in conjunction with robots could help provide metrics of assessment for children with disabilities (Brooks and Howard 2012). Metrics associated with the child's movement parameters, gaze direction, and dialogue during interaction with the robot can provide outcome measures useful to the clinician for diagnosing and determining suitable intervention protocols for children with developmental disabilities.

The following section provides an overview of robotic systems that are designed to engage children in play, whether through passive interaction through their design or through active interaction using imitation -based play.

4.1 Play-Based Interaction with Robots

Cosmobot (Lathan, Brisben, and Safos 2005) is a commercially-available telerehabilitation robot that was designed as in interaction tool to promote educational and therapeutic activities for children with and without disabilities. The current configuration has been used in movement therapy in which a child's wrist and forearm gestures, identified by attached sensors, are correlated to CosmoBot movements in order to engage the child in the intervention protocol. A pilot study was conducted with three children with cerebral palsy, ages 4-11, with upper extremity limitations in (Wood et. al. 2009). Future analysis is on-going to provide quantitative measures of movement and strength improvements as well as objective measures of functional ability.

IROMEC (Interactive Robotic Social Mediators as Companions) is a robot designed to engage three demographics of children – children with autism, children with cognitive disabilities, and children with severe motor impairments in various social and cooperative play scenarios (Patrizia et al. 2009). The IROMEC robotic toy is specifically designed to assist in the development of four types of play: sensory motor play, symbolic play, constructive play, and games with rules. In (Marti and Giusti 2010), field trials of an original prototype were conducted involving 5 children with different disabilities, ranging from 6 to 11 years of age. Based on these preliminary observations a new prototype was built and a pilot study was conducted in two different schools in Italy over a two-month period with four children with different disabilities. Although specific quantitative data analysis is still on-going, anecdotal evidence shows positive results with respect to usability, suitability with respect to learning objectives and user acceptance.

The Aurora project (Dautenhahn and Werry 2004) is an ongoing research effort to aid in the therapy and education of children with autism. The overall goal is to encourage the development of basic communication and social interaction skills. In one associated project, scientists utilized a humanoid robotic doll, named Robota (Billard et al. 2007) in behavioral studies using imitation-based games to engage low-functioning children with autism. Quantitative results from these longitudinal study show that Robota can successfully elicit imitative behaviors in children with autism and qualitative results through video analysis reveals changes in various aspects of social interaction skills. In (Robins et al. 2009), a child-sized robot named KASPAR (Kinesics And Synchronisation in Personal Assistant Robotics) was designed as a social mediator and combined facial expressions and gestures to encourage children with autism to interact with other people. The goal was to provide a mechanism for teaching social interaction skills through the use of joint attention and imitation. Published trials, which have included three children with autism, have shown these children transfer imitation skills learned with the robot to other people.

Roball (Michaud 2005) is spherical-shaped robot with intentional self-propelled movement designed to facilitate interaction with young children. Initial trials were performed to determine how effective Roball was for interacting with young children, with the goal of understanding the potential of such a robot to encourage skill acquisition (motor, language, intellectual, social, etc.) during the child-development process. Eight children between the ages of 12 and 18 months participated in this study. The quantitative results were somewhat inconclusive but are leading to on-going improvements in the design. Anecdotal results describing successful interactions between children with autism and other robot toys having the same underlying objective can be found in (Michaud 2002). In general, it was found that, although many different robot designs had been evaluated over a number of years, children with autism enjoy playing with mobile robotic toys, and respond differently to them than to human educators or non-interactive toys.

One robotic platform that has been developed for therapy and play is Keepon, a robot designed to engage children with developmental disorders in playful interaction that was generally initiated and directed by the child (i.e. without any experimental setting or instruction). Several studies have been performed using the Keepon robot including a two-year study involving 25 children with autism, Asperger's syndrome, Down syndrome, and other developmental disorders from three age groups: 6-12 months, 12-24 months, and over 2 years old (Kozima and Nakagawa 2006). Longitudinal observations provided by the study discussed the emergence of various types of actions that arose in relation to the robot interaction.

Finally, in (Scassellati, Admoni, and Matarić 2012) a review of robotics for use in autism research is presented in which an overview is provided of the common design characteristics found in the field, as well as observations made on the types of evaluation studies performed in therapy-like settings using these robot platforms. An interesting observation is made that, despite productive collaborations between several robotics and clinical groups, the differences found between robotics research and clinical psychology often hinder the development of a common acceptable experimental standard. This is not only a common theme found in robotic-based autism research, but in most research involving robotics and pediatric therapy.

5. Discussion and Conclusions

There are many compelling reasons for utilizing robots in therapeutic play scenarios, ranging from augmenting the capabilities of children with motor impairments to engaging children with pervasive development disorders. Although much of the presented work is encouraging, one of the primary shortcomings in this domain is the limited amount of quantitative results validating the benefits of utilizing robots in pediatric therapy settings. Many papers provide anecdotal evidence that children with disabilities will interact with the robots and, in many cases, achieve a therapeutic benefit. However, very few papers present quantitative results showing clear benefits to children derived from playing with robots. Those few studies that provide preliminary quantitative results are only indicative of these benefits. Additional substantial quantitative evidence, as well as longitudinal studies that demonstrate the effectiveness of robots for therapeutic play is still necessary for validating the efficacy of these systems for pediatric therapy settings.

The overall research presented herein brings up several interesting observations regarding the use of robotics in pediatric therapy. Many of the papers discussed the difficulty of performing studies involving children. Common reasons included distraction from outside stimuli, engaging with the robot outside of the designed protocol, and the wide variances found in children's abilities. Another observation is the stress that many of the researchers placed on robustness and iteration in design. For example, in many of the studies, children played with the robots in unexpected ways – ways that could potentially damage the robot if not designed in a robust fashion. Another factor reiterated by researchers was a stated importance of the inclusion of highly interactive behaviors (such as flashing lights) as a mechanism to provide feedback for prolonging engagement and motivation. It is also interesting to note that most of the robots discussed here that are capable of manipulation were intended to be teleoperated by the child, whereas those that are autonomous did not physical manipulate objects. It appears that one area that has been largely unexplored is the utilization of autonomous robotic playmates capable of engaging children in shared manipulation-based play. It seems natural then that this research thread, along with an increased emphasis on providing quantitative results from child-robot interaction studies, emerges as the next step in the domain of robots for pediatric therapy.

Acknowledgments

This research was partially supported by the National Science Foundation under Grant No. 1208287.

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