Therapeutic Robotics for Children with Disabilities: A Case Study

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Abstract

The advancement of technology is having a profound effect on enhancing the lives of children with disabilities. As advances in biomedical technology allow research breakthroughs to continue at a steady pace, more and more is being discovered about the nature of different disorders in children. At the same time, partly due to the continuing rapid rate of advancement (and societal acceptance) of robotics technology, researchers, educators, and therapists are exploring the idea that robots might be used as an effective therapeutic and educational tool.

Over the past nine years, AnthroTronix has collaborated extensively with therapists, educators, researchers, parents, and children to uncover the therapeutic and educational benefits of including robotics as part of rehabilitation curriculum for children. As a central part of this effort, the company has worked with its colleagues to develop and refine the CosmoBot system, an interactive robotic toolkit designed to enhance therapy, education, and play for children with disabilities.

1. Introduction

AnthroTronix, Inc., a human factors engineering company founded in 1999, specializes in the development of interfaces that enhance human interaction with the technology around them. The company has developed interface technology to address issues in the health (education and rehabilitation), space, and defense industries. AnthroTronix' projects have been funded by a range of institutions, including the National Institutes of Health (NIH), National Science Foundation (NSF), Department of Education (DoEd), NASA, and the US Army.

Since its founding, AnthroTronix has worked with therapists, educators, parents, researchers, and children to develop a suite of alternative technologies to help children with disabilities. These technologies include CosmoBot, an interactive therapy robot, and Mission Control, a simple 4-button alternative computer interface device. Combined with educational software and wearable robotic interaction sensors, this suite, known as Cosmo's Learning Systems, has been used by numerous children with disabilities in research studies and classroom and home settings.

2. Challenges

Throughout our years of working with therapists and educators, we have encountered some who have been reluctant to accepting robotics as a useful tool for facilitating therapy or educational activities. However, as the general public becomes more and more comfortable with technology, robotics is being embraced as an extremely effective medium for communicating with children in ways that human therapists and educators cannot.

3. Background

3.1 Autism Spectrum Disorder

Autism spectrum disorder (ASD) is characterized by impairments in from one to three aspects of behavior: reciprocal social interaction, communication, and restrictive repetitive behavior. Reciprocal social interaction is the core impairment in all variants and degrees of ASD [7], and may, of itself, be responsible for undermining the child's cognitive, social, and communicative development [2, 3, 4]. The social deficits typically persist throughout the individual's life. Basic sources of satisfaction, such as human relationships, fulfilling work, and independence are beyond the majority of individuals with ASD, including many who are otherwise characterized as "high-functioning" with good verbal skills.

Once considered a rare disorder, ASD is now recognized as a condition that occurs with alarming frequency. A study published in 2003 by the Centers for Disease Control and Prevention [5] reported a prevalence of 3.4/1,000 among children aged 3 to 10. It has been estimated that over 40% of persons diagnosed with an ASD do not have mental retardation [6]; effectively meaning that almost half of the population can be considered "high-functioning."

The value of autism-specific, early educational intervention has long been considered incontrovertible [7, 8], particularly when delivered according to a structured, data-based procedure [9]. A number of tightly controlled studies of specific intervention components, with small numbers of subjects, have contributed to a growing body of knowledge about useful approaches and their potential benefits and limitations [10, 11, 12, 13, 14, 15, 16, 17]. At the same time, there is a need for more knowledge about how to relate specific child characteristics to components of a training package.

3.2 Cerebral Palsy, Brain Injury, and Stroke

Of children with physical disabilities, many require ongoing PT/OT to optimize their movement capabilities in order for them to participate in family, school, and recreational activities. The most common neurological disorders of the brain that impact the physical ability of children are cerebral palsy, brain injury, and stroke.

According to CerebralPalsyFacts.com, "About two children out of every thousand born in this country have some type of cerebral palsy. Studies have shown that at least 5,000 infants and toddlers and 1,200 - 1,500 preschoolers are diagnosed with cerebral palsy each year. In all, approximately 500,000 people in this country have some degree of cerebral palsy" [18]. The incidence of brain injury among school-aged children has been estimated by the Center for Disease Control (CDC) as 90 per 100,000, resulting in the addition of 60,000 children with new brain injuries annually [19]. The incidence of stroke in neonatal children (<1 month of age) has been estimated by the CDC as 1 per 4,000 and for children from 2 months to 18 years as 14.5 per 100,000 [20].

Children with cerebral palsy, brain injury, and stroke have similar physical impairments to movement, although the sources or causes of the impairments differ. A common impairment that requires PT and/or OT intervention is that of decreased amplitude and strength of voluntary movement in the upper extremities due to neurological involvement in the brain. These physical impairments can impact the child's educational development by interfering with his/her ability to move about and explore their environment, contribute to decreased social interaction and communication, and inhibit access to and interaction with computer or traditional learning tools (e.g., manipulatives such as building blocks, books, writing tools, etc.).

4. Why Use a Robot?

There are significant advantages to using a robot such as CosmoBot instead of software for children's therapy. These advantages are elaborated below. Such data supports the use of physical robots as adjuncts in therapeutic activities.

1) *The ability of a robot to engage the child:* Children have been shown to exhibit a high degree of interest in an interactive robot [21, 22]. Researchers such as Dr. Cynthia Breazeal at the MIT Media Lab have demonstrated the differences between a robot and an animated character in terms of a person's engagement and perceptions of the robot and character. They found that a physical robot was more engaging and rated more highly on the scales of perceptions than an animated character [23, 24]. There are also researchers who are looking at the advantages of a "socially assistive robot" such as CosmoBot that interacts with the environment, exhibits social behavior, and focuses its attention and communication on the user in order to help the user achieve specific goals [25, 26]. Feedback from therapists during the initial phase of our NIH-funded Gestural Interfaces research study indicated that CosmoBot was effective in enabling children to reach not only their traditional PT/OT goals of strength and coordination for example, but also improved the children's attention to their tasks and allowed them to engage in pretend play - important for cognitive develop [27, 28].
2) *The flexibility and expandability of a robot:* Children's software for "play" is generally limited in content and can only engage a child's attention for a limited time. For example, in a software maze, a child may be able to go from point A to point B a few times before they become familiar with the maze and lose interest. Software has limited options to make that maze more engaging to the child. With a robot in the real world, navigating from point A to point B can be expandable to have different concrete goals (e.g., tagging each person in the room, collecting ingredients for a sandwich, stacking blocks). CosmoBot, for example, allows exploration and is unlimited in the ability to use it for creative play therapy. Al Cook's work with Lego Mindstorms robots for unstructured play [29] is a great example of the advantage of a robot over software. Where Mindstorms falls short is in the ability of the Lego robot (or a remote control toy car) to engage the child in the way that a socially assistive robot can.
3) *Robot as an expandable platform:* Finally, one can envision a robot system such as the CosmoBot system as a platform, analogous to a desktop computer, where new content can be developed to address specific therapy goals and to continually provide motivation for the children to interact with the robot. For example, under our NIH Autism Phase I SBIR grant, we developed Social Activity Modules for children with Autism that make use of the robot's capability to attract and sustain children's attention and interest to foster key reciprocal social behaviors including attending to others, imitation, joint attention, and cooperative play. Our hypothesis is that the Social Activity Modules constituted a novel, engaging, effective mode of delivering social skills training to children with Autism Spectrum Disorder.

5. The CosmoBot System

5.1 User-Centered Design of CosmoBot System

AnthroTronix has incorporated extensive input from a variety of therapists, researchers, educators, parents, and children during the design processes for the current CosmoBot and its two predecessors: JesterBot and CosmoBot version 1 (pictured below in Figure 1). After considering this input, we defined functional requirements that the CosmoBot system should meet in order to be effective. These functional requirements and rationale can be summarized as follows:

- ***Target young children*** – Need for early intervention
- ***Degrees of freedom (DOF)*** – Although we do not know the minimal number of DOF needed for a clinically appropriate robot, based on our previous work [30], we hypothesize that CosmoBot's 9 DOF will be sufficient.
- ***Anthropomorphic*** – Appealing to young children and can somewhat mimic the child
- ***Interface*** – Accessible to children with disabilities (e.g., alternative to fine motor control operation)
- ***Expandable/Programmable*** – Needed for longevity and appeal to children of various ages
- ***Embedded assessment/Data collection capabilities*** – Needed for therapeutic and educational value
- ***Therapy value*** – Can target a variety of PT/OT goals, and ultimately make the therapist's job easier
- ***Educational value*** – Activities target cognitive development

a. b. c. d.

Figure 1. a) JesterBot; CosmoBot: b) version 1, c) version 2, d) version 3

The initial robot, JesterBot, whose name reflects a pun of "gestures" and "robot," was a simplistic robot with limited degrees of freedom (DOF). Its arms were able to move up and down and the robot could navigate a room using two wheels.

The first version of CosmoBot became a bit more complex, including a handheld computer (iPaq) in its chest for onboard processing. CosmoBot version 1 could also perform twice the arm movements as JesterBot in addition to moving its head.

Figure 2. Child controlling JesterBot using wearable wrist sensors

After considerable aesthetic and functional redesign, the current CosmoBot was born. The "softer," friendlier feel of this version seemed to be well received by the children. Functionally, the onboard computer was removed and replaced by a Bluetooth link and an electronics board. Range of motion was also increased in CosmoBot's head.

5.2 System Components

The CosmoBot system as a whole primarily consists of the CosmoBot robot and Cosmo's Learning Systems (i.e., Mission Control and Cosmo's Play and Learn Software), which are pictured below. Cosmo's Learning Systems was launched as a commercial product in 2006 by AT KidSystems (an AnthroTronix subsidiary) targeting children developmentally aged 2-8.

a. b. c.

Figure 3. The CosmoBot system: a) CosmoBot; b) Mission Control; c) Cosmo's Play and Learn software

AnthroTronix has created gestural interface sensors (both wearable and stationary) that children can use to interact with CosmoBot. The array of sensors is shown in Figure 4 below (from left to right): an adapted standard 4-way joystick, wearable leg sensor, wearable arm sensor, wearable head sensor, wrist extension glove, and pronation-supination sensor with arm restraint brace. The head, arm, and leg sensors, for example, employ accelerometer technology to sense a child's gestures. Threshold levels for all of the sensors can be easily modified in a software program.

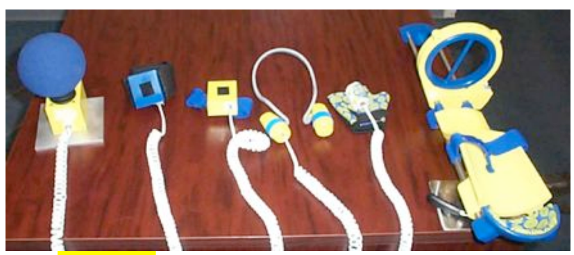

Figure 4. CosmoBot gestural interfaces

6. Pilot Studies with the CosmoBot System

CosmoBot has been involved in six formal research studies, with children with cerebral palsy, autism spectrum disorder (ASD), Down's syndrome, and speech-language delays. The NIH, NSF, and DoEd have funded these studies. The most recent study, funded by the NIH and conducted in 2006 and 2007, explored the efficacy and feasibility of using CosmoBot to improve the social skills of children with ASD.

6.1 NIH Autism Study – Social CosmoBot

6.1.1 Study Description

This "Social CosmoBot" research study was a Phase 1 Small Business Innovation Research (SBIR) study exploring the feasibility of using CosmoBot to address different social skill discrepancies in children on the ASD spectrum. In this first phase, AnthroTronix proposed to develop and test a system integrating a suite of prototype Social Activity Modules and a modified CosmoBot system. The Modules are engaging instructional activities directed at fostering key reciprocal social behaviors that are impaired in children with ASD.

The purpose of integrating the Modules with the robot is to capitalize on CosmoBot's demonstrated capability to attract and sustain children's attention and interest in social activities in which they might not otherwise choose to participate. Modifications to CosmoBot were proposed in order to improve its utility as a tool for instruction and practice in reciprocal social skills; modifications included installation of a camera in CosmoBot's nose, so that manipulating the robot's direction of "gaze" to take in social cues could become part of the explicit activity. Software development was limited to the minimum necessary for running the study, with further development deferred to Phase 2, pending evaluation of the system. We evaluated the modified robot and prototype activities (Modules) with young children diagnosed with an ASD, in order to assess usability and appeal.

The Social CosmoBot study took place at the Neurodevelopmental Center for Young Children (NDCYC) in Crofton, MD, under the supervision of the center's director, Dr. Carole Samango-Sprouse (Ed.D). Table 1 below briefly describes three of the Modules that were tested in the study. Dr. Cheryl Trepagnier, an ASD expert at the Catholic University of America, designed the Modules.

Table 1. Social Activity Modules description (1 example of 6)

Module 2	*Look at that!*
Goals addressed	**Joint attention**
Activity	**Robot attempts to elicit child's attention to target to which he is pointing**
Target Response	Child follows robot's point within 1 sec.
Equipment	Two closed boxes that can open under remote control, each with a remotely controlled toy inside. Therapist launches box opening and toy operation when sees that child is looking where the robot indicates.
Procedure	Therapist waits for child to be looking at robot and inputs key stroke to initiate robot's speech and point.

Figure 5. Module 2 – *Look at That!* focusing on joint attention

Dr. Samango-Sprouse recruited seven children from among clients with an ASD diagnosis. Each child was seen for 8 sessions at the NDCYC. Characteristics of the child participants are listed below in Table 2. Children's scores are reported on the Leiter Brief IQ, an estimate of nonverbal IQ. Since children with ASD are language-impaired, with impairments ranging from minimal to severe, nonverbal IQ is preferable to full-scale IQ tests.

Table 2. Characteristics of children who participated in the feasibility study

Subject Code	**Gender**	**Chron. Age (months) as of 5/1/07**	**Leiter Brief IQ**
SC01*	M	77	123
SC02	M	82	131

SC03	M	59	85
SC04	M	46	NA**
SC05	M	72	83
SC06***	M	73	82
SC07***	F	73	38

*SC01 was very distressed when he arrived for his first session and was withdrawn by his mother.
**Leiter not available; WIPPSI-III performance IQ is 79 ***SC06 and SC07 are fraternal twins.

6.1.2 Research Tools Used

Tools used to track the children's progress through the study included the following:

- Parent Questionnaires
    - 2 total; 1 pre-study, 1 post-study
- 5-Minute Play Observation
    - Performed by Dr. Trepagnier
- Videotaping
- Observation Sheets
    - Completed by Dr. Trepagnier and AnthroTronix staff
- Software Log Files
    - CosmoBot control software recorded when, with which child, and during which module each CosmoBot action (verbal or movement) occurred.

6.1.3 Outcomes

Tables 3 and 4 below summarize each participant's response to intervention. The baseline assessment and intervention approach is reported for each subject and the post data example highlights a specific outcome observed.

Table 3. Highlights of participants' responses to intervention

Subj.	Baseline Assessment	Intervention Approach	Post Data
SC02	ASD. Highly cooperative	Partnered with SC03 Therapist needed to find ways to make the Modules adequately challenging for him	As sessions progressed, improved in cooperating with partner to accomplish Modules
SC03	ASD, with mild cognitive delay	Partnered with SC02 Required moderate support for participation	Improved attention to other's behavior (SC02) and positive affect sharing
SC04	ASD with language delay.	Required moderate support for participation	Showed gains in attending to faces
SC05	ASD with rigidity and atypical sensory behaviors	Partnered with his mother for all 8 sessions Level of support needed for participation declined as sessions progressed	Improved in interpreting nonverbal communication, and showed improved flexibility
SC06	ASD with echolalia. Notable for inattentiveness to instructions despite high level of functioning	Partnered with SC07 (fraternal twin) Required little support to participate in Modules	By last session, successfully produced and interpreted communication via facial expression
SC07	ASD with severe communicative impairment and unusual sensory behaviors (mouthing objects)	Partnered with SC06 (fraternal twin) Required high level of support to participate in Modules.	Mother reported that child complied with a verbal request (for imitation) for the first time. Showed improvement in performance of Modules over the 8 sessions. Also gained skill

			in operating joystick.

Table 4. Summary of qualitative observational data (small "x" indicates some improvement, large "**X**" indicates marked improvement)

Subject	SC02	SC03	SC04	SC05	SC06	SC07
FUNCTIONAL GOALS:						
1. Gain experience in attending to other's face	x	x	x	x	x	x
2. Improve joint attention	N/A	N/A	**X**	N/A	x	x
3. Increase interest in other's activities	N/A	**X**	x	**X**	x	x
4. Demonstrate positive affect sharing	**X**	**X**	x	**X**	**X**	x
5. Gain experience in taking other's perspective	**X**	**X**	x	x	**X**	x
6. Gain experience in communicating via gesture and facial expression	x	x	x	**X**	**X**	x
7. Improve cooperation and attention to verbal instructions	**X**	**X**	**X**	**X**	x	**X**
Parent Questionnaire Social Skills Ratings (Pre-)	35	44	29.5	42	54	0
Parent Questionnaire Social Skills ratings (Post-)	28	48	43	44	60	7
Percent Change	-7%	4%	13.5%	4%	6%	7%

Module 6, "Did we get a lot of points," pictured below in Figure 6, focused on practicing nonverbal communication. This Module consisted of a card game in which one child (in front of CosmoBot's nose camera) was shown either a high or low card. The therapist coached this child as to whether the card was "good" or "bad." The child was then asked to convey to a second child (watching CosmoBot's nose camera video feed)

a. b.

Figure 6. Module 6 – *Did we get a lot of points?* a) nonverbal facial card interpretation; b) nonverbal thumbs-up card interpretation (on video display)

6.1.4 Next Steps

AnthroTronix intends to apply to continue this research study in order to expand on the Phase 1 research. The end goal of this research is to commercialize a suite of ASD-specific activity modules that help children and their therapists to more effectively achieve their therapy goals.

6.2 NIH Gestural Interfaces Study

AnthroTronix engineers have developed innovative new ways for children with impairments (due to cerebral palsy, brain injury, or stroke) to interact, via body gestures, with technology in their environment (e.g., robots, software games). The end goal of this work is to enhance the PT/OT for these children through allowing them to directly manipulate their environment. Development goals are twofold: 1) to create effective and intuitive gestural interfaces for children w/ impairments and 2) to integrate CosmoBot with another therapeutic robotic device, Roamer-Too, to create a new robotic tool that leverages the interaction capabilities of both components.

The gestural interfaces are being designed to work with and expand the capabilities of the CosmoBot system. In addition to developing these physical gestural interface devices, effort is being applied to developing specific content for the CosmoBot system to maximize its utility for PT/OT, specifically focusing on upper extremity movement (UEM) in these young children. These efforts are being conducted as part of an NIH-funded Phase 2 SBIR project entitled "Use of Gestural Interface and Robotics Technology to Facilitate Motor Development and Functional Mobility."

6.2.1 Gestural Interfaces

Figure 7. Child interacting with CosmoBot via wearable sensor at Mt. Washington Pediatric Hospital

In Phase 1 of this project, we performed a technical feasibility study using gestural interface technology and interactive robotics (the CosmoBot system) to facilitate motor development and functional mobility of children with a wide range of physical disabilities. Clinical testing of the CosmoBot system was conducted with six children at the Mount Washington Pediatric Hospital in Cheverly, MD. Outcomes are summarized in Table 5 below.

Table 5. Phase 1 Gestural interfaces study outcomes

Efficacy	Increased / improved UE strength in 4 children	Improved coordination in 3 children	Increased attention to task in 4 children	Improvement in activities of daily living in 3 children
Motivation for Children	Each child engaged in pretend play with CosmoBot (CB) in every session over 4 months	Each child asked for technology during each session	No child claimed boredom or did not want to use CB in therapy	Other therapists in clinic used CB as reward for many children during SLP & OT
Therapist's Ease of Use	Technology robust & easy to use	Technology needed repair once over 4-month period	CB gives therapist ability to keep sessions new & fun during 4 months	Therapist saw high motivation when using CB for each child, leaving more time for therapy & less coaxing child

Table 6. Additional Phase 1 study outcomes

Name	Child A	Child B	Child C	Child D	Child E	Child F
Age	10	5	5	4	6	8
Developmental Age	6 1/2	4	4 1/2	4	6	2 1/2

Diagnosis *all subjects diagnosed w/ CP; entry provides more details & other diagnoses*	L hemi-plegia	s. quadri-plegia	s diplegia & R hemi-plegia	s. quadri-plegia	s. R hemi-plegia	s. diplegia & ADHD
Difficulty focusing attention on therapy tasks?	N	Y	Y	N	Y	Y
FUNCTIONAL GOALS:						
Improve ADLs: tying shoes, fasten belts & buttons	x				x	
Improve ball skills (throwing, catching)	x					
Increase ability to walk farther than 20 steps using walker		x				
Increase ability to independently dress & maintain hygiene			x			
Improve sitting independently				x		
Sit in chair & lift arm over head without falling over				x		
Control joystick on power wheelchair				x		
Improve functional use of upper extremity				x		x
STRENGTH/COORDINATION/RANGE OF MOTION (ROM) GOALS—to increase:						
supination ROM	x			x		
wrist ROM	x			x		x
bilateral coordination	x		x			
shoulder ROM		x	x	x		x
Upper extremity strength		x	x	x	x	x
Elbow ROM				x		x
SENSORS USED: (see Section 10 for details on sensors)						
Supination/pronation brace	x		x			
Wrist extension glove	x		x	x	x	x
Wearable arm sensors		x				x
Wearable leg sensors				x	x	
Joystick		x		x	x	x
Mission Control buttons	x	x	x	x	x	x

The innovation research being undertaken in Phase 2 is to further develop and evaluate the use of gestural interface and interactive robotics to treat young children with motor control and functional mobility impairments due to cerebral palsy, brain injury, or stroke.

6.2.2 CosmoBot and Roamer-Too

Through a partnership with Valiant Technology, Ltd., whose team has developed an easy-to-program robotic platform called the Roamer-Too, AnthroTronix is working to create a new CosmoBot product that combines CosmoBot and Roamer-Too (see Figure 8), implementing the Roamer-Too platform as CosmoBot's base. Initial clinical testing of the prototype system began in the fall of 2008. This CosmoBot is also being used in our formal study with children with physical impairments at the Mayo Clinic in Rochester, MN.

Figure 8. CosmoBot version 3 (with integrated Roamer-Too base)

7. Conclusions

Clinical research studies using the CosmoBot system repeatedly demonstrate the effectiveness of both using a robot (in general) and leveraging the CosmoBot character with children with disabilities. Phase 1 of our NIH Autism study demonstrated that (1) children found the robot motivating and engaging, (2) children participated in the instructional activities, and (3) they demonstrated acquisition of the skills being taught. Results from the initial phase of our NIH Gestural Interfaces study (see Table 5 above) also suggest that CosmoBot is effective, both as (1) a therapeutic intervention tool for targeting goals of increased strength, coordination, and range of motion, with the ultimate goal of improving function, and (2) a motivation for children to participate in therapy. Further research is currently underway (NIH Gestural Interfaces, Phase 2) to systematically and objectively evaluate these metrics in a controlled manner, over a considerable amount of time.

However, further development will be needed to mold CosmoBot into a commercial version available to therapists everywhere. And while we look forward, the field of interactive robotics continues to grow and robotics technology continues to improve and become more available. Basic human-robot interaction is now easier and less expensive to achieve than ever before, with objective data collection included in the package! It is therefore ever so critical that the disabilities community expand its leverage of the incredible therapeutic potential of robots like CosmoBot.

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