Development and preliminary investigation of a semi-autonomous socially assistive robot (SAR) designed to elicit communication, motor skills, emotion, and visual regard (engagement) from young children with complex cerebral palsy: a pilot comparative trial

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INTRODUCTION

Through playful interaction, children develop physical, cognitive, and social skills, thus enhancing their sense of autonomy and achievement of developmental milestones through repeated experiences. [1,2,3] Participating in play is crucial, but children with disabilities or developmental delays cannot always access the same opportunities as typically developing children. Due to limited abilities or environmental interaction, children with complex cerebral palsy often do not develop skills and abilities as well as their peers. [4]

It has been suggested that educational toys may have a greater impact for children with severe disabilities. [4] However, this population is less likely to actively engage themselves, resulting in the need for more frequent and exciting play opportunities. [4] Adapted toys and assistive technologies can be fundamental in enabling children with physical disabilities to play, as well as facilitate learning in those with cognitive disabilities. [5,6]

The term “Socially Assistive Robots” (SAR) has recently entered the literature. These systems are designed to assist the user through social interaction while encouraging learning and rehabilitation by replicating the therapeutic and educational benefits of a clinical caregiver. [7] An effective SAR must understand and interact with its environment, exhibit social behavior, and focus its attention and communication on the user to help achieve desired goals. [8]

This study focuses on the preliminary research toward a fully autonomous SAR as therapeutic augmentation for children with cerebral palsy. This first step will help determine if the SAR elicits a higher level of engagement than a standard therapeutic toy. Further research will include these results to design an engaging autonomous system that responds appropriately to the child in a clinical setting; the final goal is to create an at-home information-relaying SAR to increase the number of therapeutic interactions to promote development.

MATERIALS AND METHODS

SAR development

This study incorporated a with-in subject crossover design comparing a control condition (standard, push-button toy) with an experimental condition (SAR). The SAR developed and used in this study was built on the m3pi hobbyist robotic platform. Movements and sounds are performed by activating the embedded electronics controlling two motors driving the on-board wheels, as determined through a remote control managed by the study investigator. These wireless communications are enabled by the addition of a Wixel 2.4 GHz radio.

The communication among hardware components of the system involves the investigator controlling the SAR using a wireless Xbox controller, which sends commands to the server by use of a dongle, and then wirelessly to the SAR via a serial com port connected to the Wixel radio. The server sends commands for the SAR to perform the next action with the associated behavior; commands include forward, backward, left, right, and varying sounds. While in wizard mode, the SAR receives commands directly from the Xbox wireless controller, and all data is stored to a file to be analyzed later. The entire management system executes external to the SAR, because the actual memory on the m3pi is limited. The system receives inputs from the listed devices, and the information flows up the stack to execute commands and store the appropriate data.

To protect the electronic hardware and provide structural support to the fabric covering, a 3D printed exoskeleton was mounted on top of the m3pi base. The dressed up, multicolored, bright, fluffy “stuffed animal” version of the SAR covers the entire base, allowing the wheels to be completely covered.

Eligibility, recruitment, and consent

This study focuses on children with complex cerebral palsy, a condition prevalent in approximately two out of every 1000 births worldwide. [9] This diagnosis covers a range of non-progressive motor impairment disorders resulting from malformations or injuries during early brain development. [10] The severity of impairment in gross motor skills for each child in this study is placed at a Gross Motor Function Classification System (GMFCS) level of V, which represents severe limitations on posture and self-mobility. [11] Voluntary control of motor movements and the ability to maintain most head and trunk postures are restricted, with no means of independent mobility.

Children between 18 months and 5 years old with complex cerebral palsy were recruited. Each participant had significantly limited motor ability, resulting in minimal ability to physically interact with their environment. Additionally, their ability to communicate was limited to vocalizations or very few word approximations. Fifteen children were enrolled, with 8 eligible participants completing the study for an attrition rate of approximately 45%.

When an interested and eligible research participant contacted the investigators, they were invited to the study site at Assistive Technology Partners (ATP)- a specialized assistive technology facility with comprehensive clinical and research programs focused on the assistive technology needs of people with disabilities- for consenting procedures and eligibility verification. Investigators had separate conversations with each family to determine the ideal location for the study to consistently take place, with the three optional places being ATP's early childhood room, the participant's home, or the participant's school.

Eligibility verification was determined through demographic and health history information, as well as two pre-screening measures of early development. The Receptive-Expressive Emergent Language Test Third Edition (REEL-3) – Expressive Language Subtest was used to inform inclusion/exclusion based on the participant's communication ability. Motor and cognitive subsections from the Assessment, Evaluation, and Programming System for infants and children (AEPS) were used to describe the physical and cognitive skills of each patient.

Intervention

Each enrolled subject was randomized to one of two orders: 1) interacting with the standard toy first or 2) interacting with the SAR first. After three sessions with the first toy type, each child then had three sessions with the second toy type. Each participant completed six individual sessions, each lasting no more than 30 minutes, over a 12 week period. The length of time to complete the experimental visits was to account for scheduling, transportation, and health-related issues that had an impact on attendance.

During the initial experimental visit, ATP's pediatric occupational therapist worked with the parent, legal representative, or treating therapist to identify the ideal seating and positioning options for proper support, alignment, safety, and comfort for the participant to maximize the child's ability to interact. Once established, positioning remained consistent for subsequent visits, unless changes were needed for comfort and/or stability.

Before each of the six experimental visits, the investigator administered a pre-visit checklist to the parent or legal representative to determine the child's health, mood, and level of arousal. During this time, the child was able to become acquainted with their surroundings. The investigator then familiarized the child with the push-button toy or SAR to ensure they were familiar with the toy's operation and would not become startled by its movement or sounds. The toy/SAR was then placed on a supporting surface within the child's visual field, close enough to touch. The child was left to interact on their own, but the investigator remained in the room, mostly out of the child's field of vision, to assure ongoing optimal positioning and control commands for the SAR. Each interaction lasted between ten to fifteen minutes and was video recorded from two front-facing views for later analysis.

With the push-button toy, the child had to initiate touching a large red button to make a firefighter character move up and down a one-foot tall ladder; the movement of the character is accompanied by a mechanical noise from the toy's simple motor system. The SAR moved and emitted sound in response to the therapist's desired actions using a remote-control system, allowing the SAR to respond in a therapeutic manner to the child's actions.

Procedures of measurement

After all experimental visits were completed, the video data was edited, sorted, and analyzed using the Morae usability software suite from Tech Smith Inc. Each video was interpreted using a list of predetermined behaviors exhibited by the child; the selected behaviors were adapted from Every Move Counts, a program focusing on communication development for children with sensory motor impairments. The investigators collaborated with a group of subject-matter experts to define engagement regarding the population for this study. Visual Regard, Vocalization, Gross Motor Movements (Reach), Fine Motor Movements (Grasp), and Emotion were established as significant aspects in determining participant involvement in interaction.

Behavior codes were determined per partial interval recording techniques; videos were divided into 30-second intervals, and each interval was listed as having a specific behaviors or actions if they were present at any point in the interval. The frequency of behaviors and actions were divided by the total number of intervals to determine a percentage of occurrence, which was then related to the percent of overall engagement expressed by the child.

To verify the validity of the behaviors expressed and coded, inter-rater reliability was assessed. Ten of the 48 videos were randomly selected to compare coding values to determine the degree of agreement using Krippendorff's alpha with a reliability cutoff value of $\alpha = 0.80$. This minimum acceptable coefficient value is relied on by social scientists to verify that quantified analysis does not significantly deviate from perfect agreement.

RESULTS

To determine levels of engagement, investigators focused on frequency of Visual Regard, Vocalization, Reach, and Pulling Away. Video analysis showed that a large percentage of grasping movements were done without any focus on the push-button toy or SAR throughout all subjects, while both Positive and Negative Emotion better determined a child's level of comfort with the toy or SAR, not the intensity of overall engagement. Five of the eight subjects- Subjects 1, 2, 3, 6, and 7- had a higher level of overall engagement with the SAR over the push-button toy when considering only Visual Regard, Vocalization, and Gross Motor Movements (Reach and Pulling Away).

Subjects 1 and 2 both had only slightly differing variations in Visual Regard and Gross Motor Movements for both the SAR and push-button toy, so the behavior that determined level of engagement for these subjects became Vocalization. Subject 1 was more vocal with the SAR, with a large number of sounds being made in response to the SAR's bell tones, which would keep the child interested for approximately 10-15 seconds at a time. Alternatively, Subject 2 only had slightly higher Vocalizations, but there was also a slightly higher level of Reach. The final contributor in deciding Subject 2 was more engaged with the SAR was the need for the investigator to initiate engagement with the push-button toy to elicit any type of response from the child.

Subject 3 had similar frequencies of behaviors to Subject 2, and investigator intervention was also needed at the beginning of each push-button toy session. Additionally, Subject 3 had a higher frequency of grasping with the push-button toy; however, during video analysis, this seemed to only be a preference to the smooth surface of the button and not in relation to any movement or noise from the toy itself. Like Subjects 1-3, Subject 6 only had a noticeable difference in frequency of Gross Motor Movements. However, this difference was accompanied by a higher level of Positive Emotion with the SAR and greater Negative Emotion with the push-button toy, and Subject 6's emotions coincided with active engagement during analysis.

Subject 7 could compose verbal commands and presented more like typically developing peers than other subjects. Overall, all positive behaviors for Subject 7 were higher in response to the SAR than the push-button toy, making it clear that the subject was more engaged with the SAR, as shown in Figure 1. This was also apparent throughout the recordings of the video sessions; the initial session with the SAR required investigator and teacher intervention to ensure the child was comfortable, and by the end of the final session with the SAR, the subject asked the SAR, "Are we friends?" Throughout the SAR sessions, it was evident that the subject became increasingly comfortable with the SAR and enjoyed interacting and providing instruction ("Stop!", "Over here!"). Conversely, interaction with the push-button toy was limited to less reaching movements and decreased interest

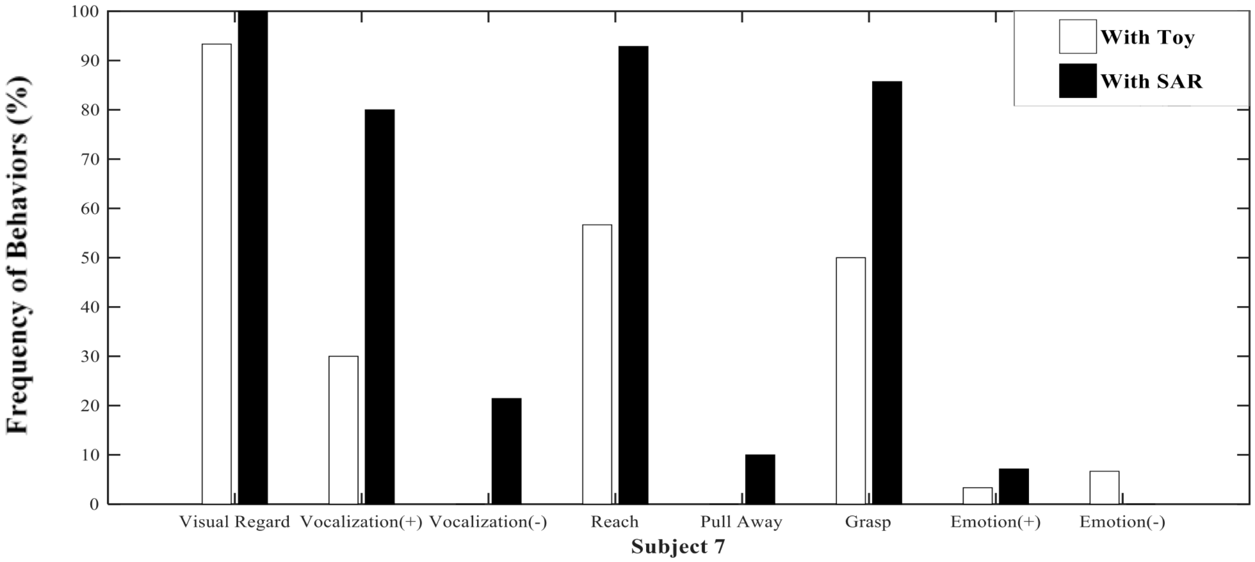

Figure 1. Bar graph with results for Subject 7, showing a higher frequency of behaviors with the SAR over the push-button toy in all behavior areas except Negative Emotion.

("I done now."). Subject 7 provided the clearest example of increased engagement with the SAR.

DISCUSSION

Using a crossover methodology with repeated observations with the push-button toy and SAR addressed both the limited population of potential participants in geographic proximity and the fluctuations in mood and/or level of arousal common in this population. The study appropriately addressed this heterogeneity of participants via its use of a crossover design. Since each subject served as their own control, the impact of heterogeneity on the findings is mitigated although the impact on generalizability remains. Additionally, the repeated observation of a participant increased the precision with which each participant's response was measured. This approach diminished the impact of a child having a "bad day" while also assessing the impact of repeated exposure.

Repeated exposure to the SAR proved to be beneficial in increasing engagement, as most children became more familiar with the SAR over time. The interactive "personality" of the system did influence the overall engagement of each child, providing them with a positive difference in quality of play. If the sessions were to continue, investigators most likely would have seen increased engagement among the remaining three participants as well; these children may have needed additional exposure to become comfortable with the SAR. Overall, introducing the SAR as a source of playful engagement for children with complex cerebral palsy proved that a greater quantity and quality of engagement can be achieved than with a standard push-button toy.

CONCLUSIONS

Children with complex cerebral palsy often experience limitations in their quantity and quality of play as compared to their typically developing peers. Maintaining engagement in this population, especially educational and therapeutic engagement, has been shown to be challenging. Introducing a SAR designed primarily for children with complex cerebral palsy shows promising results. This pilot study provided crucial information: Do these children even respond positively to this type of engagement? The results show that yes, across multiple exposures, children with complex cerebral palsy become more comfortable with the SAR and begin to interact more openly and without interference. Providing quality play to this population is critical in supporting the advancement of crucial developmental milestones and thus increasing overall quality of life.

Expanding on this newfound knowledge will focus on the development of a fully autonomous SAR to be used as an augment to a child's current therapies. Rather than having an investigator control the movements and responses, the SAR will be equipped with vision and auditory systems to obtain data about the movements and noises made by the child as they work towards a therapeutic goal. Current research is being done to design the vision system specifically to recognize the specific, often repetitive movements of children with cerebral palsy. Additional work will incorporate this vision system into a fully functional autonomous SAR, allowing the SAR itself to obtain important information about how the child reacts to certain behaviors and then responding appropriately.

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