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A Multifaceted Device for Discreetly Acquiring Natural Behaviors of Children with Autism

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Peer Review

This work has undergone a double-blind review by a minimum of two faculty members from institutions of higher learning from around the world. The faculty reviewers have expertise in disciplines closely related to those represented by this work. If possible, the work was also reviewed by undergraduates in collaboration with the faculty reviewers.

Abstract

Autism is a multifaceted neurological disorder that affects the four fundamental areas of sensory processing, communication mechanisms, social interaction skills, and whole child/self-esteem. The underlying mechanisms and symptoms of the disorder have been shown to largely vary from patient to patient, and therefore, a durable, effective therapy is best achieved through multifaceted, multidisciplinary approaches that allow a direct assessment of each individual's behavior, both quantitatively and qualitatively. The aim of this project was to simulate, design, manufacture, and assess a device that can help cultivate sensory, social, communication, and motor skills in autistic children while being able to extract data of the child's behavior that could be used by the therapist. Critical components of the toy involve auditory and visual stimulation, as well as interactive mechanisms to promote development. The most important features of the toy are hidden cameras that discreetly monitor the child's reactions in order to provide analytical feedback mechanisms, allowing parents, caregivers, or therapists to monitor and evaluate the child's learning and therapy. The performance of the toy was examined on 17 children with autism at two specialized centers for child with developmental disorders. The results showed that the device was found satisfactory by the majority of children as assessed by their willingness to spend time accomplishing the tasks on the device, as well as by captured videos of their natural reactions throughout. Furthermore, improved performance was observed on the same population of children who were tested multiple times, indicating the potential use of the toy for therapeutic and learning purposes.

Keywords

Autism; Motor skills; Sensory development; Natural behavior; Analytical feedback

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INTRODUCTION

In the United States alone it is estimated that 1 in every 50 children has autism, which translates to about \$3.2 million per person in incremental societal costs over their lifetime (Blumberg & Bramlett, 2013; Ganz, 2007). Children affected by autism exhibit communication difficulties, social challenges, sensory processing problems, and repetitive behaviors (Miles & McCathren, 2005; Wood, Fujii, Renno, & Van Dyke, 2014). Additionally, a lack of motor skills in some autistic children is also linked with social and communication development (MacDonald, Lord, & Ulrich, 2013). Autistic individuals are believed to have a dysfunctional sensory system. Sensory integration is the neurobiological process that refers to the integration and interpretation of sensory stimulation from the environment by the brain, and when sensory input is not integrated or organized properly, it can produce problems with information processing, development, and behavior (Leekam, Nieto, Libby, Wing, & Gould, 2007; O'Neill & Jones, 1997). Sensory integration focuses on the tactile, vestibular, and proprioceptive systems (Dawson, Geraldine & Watling, 2000). These systems begin forming before birth, and their development continues through interaction with both the individual's environment and maturity. The three sensory systems are what allow people to experience, interpret, and appropriately respond to various stimuli present in our environment (Hatch-Rasmussen, 2013).

The tactile system involves nerves under the skin that relay information to the brain regarding light touch, pain, temperature, and pressure. A dysfunction in this system can be seen through withdrawals from touch, refusal to wear certain textured clothing, and avoidance of getting one's

hands dirty. This dysfunction and resulting misinterpretation of touch can lead to self-imposed isolation, general irritability, distractibility, and hyperactivity (Rubenstein & Merzenich, 2003; Wiggins, Robins, Bakeman, & Adamson, 2009). The vestibular system is what allows our perception of the orientation of our bodies and head in relation to the earth; in other words, it is responsible for telling us whether our head is upright or tilted. When this system lacks proper function, it can cause fear of movement activities such as swings or slides, apprehensive movement on uneven or unstable surfaces, or the appearance of clumsiness (Goldberg, Landa, Lasker, Cooper, & Zee, 2000; Kern et al., 2007). The proprioceptive system provides subconscious awareness of body position in addition to dealing with components of muscles, joints, and tendons. Problems with motor skills and motor planning result from a dysfunction of this system. These problems lead to clumsiness, lack of awareness of body position, difficulty manipulating small objects, and a general inability to plan and execute various motor tasks (Hatch-Rasmussen, 2013; Iarocci & McDonald, 2006).

In order to aid in the regulation of their sensory systems, autistic children will engage in perseveration or stereotyped movements. These include lining up toys, spinning wheels, running back and forth in a room without regard to objects underfoot, and repeatedly moving a toy back and forth (Morgan, Wetherby, & Barber, 2008; Pierce & Courchesne, 2001). They also engage in self-stimulation behavioral movements such as rocking back and forth, flapping their hands, and constant spinning. These very self-absorbed behaviors are believed to be the result of the child's sensory processing problems (Case-Smith & Bryan, 1999; Haack, & Haldy, 1998). Dysfunction in these sensory systems causes difficulty

adjusting to new situations, people and other stimuli; this, in turn, leads to frustration, aggression, or withdrawal, and ultimately, isolation and a lack of social and communicational development (Landa, 2007; Lord, Rutter, & Le Couteur, 1994; Mundy, Sigman, Ungerer, & Sherman, 1985).

Autistic children have issues with two types of motor skills, object control and locomotion skills (Vernazza-Martin et al., 2005). Object control skills deal with tasks that involve dexterity, such as catching and throwing a ball, while locomotion movement deals with balance and clumsiness in activities like running and walking (Staples & Reid, 2010). Autistic children exhibit impairment in brain regions that facilitate sensor arousal and motor function. This inhibition in motor function, in turn, leads to further social and communication developmental issues. The presence of struggles with development of motor skills is strongly correlated to more severe problems with social and communication skills (Preidt, 2013; Provost, Lopez, & Heimerl, 2007). In a study at Oregon State University, it was investigated as to whether or not autistic children's motor skills had any relation to their adaptive behavior skills (MacDonald et al., 2013). These skills include overall behavior, communication skills, daily living skills, and adaptive social skills. Their age, severity of their disorder, and non-verbal problem-solving skills were all taken into account for each individual child. The study arrived at the conclusions that the children's level of fine motor skills predicted how well they scored on every section of the adaptive behavior skills assessment, the children's motor skills predicted how well they did with daily living skills, and the children who had weaker fine or gross motor skills had greater difficulties with adaptive behavior skills (MacDonald et al., 2013).

Autistic children's social development issues result in their inability to interact and understand various stimuli that they come across in everyday life, and not being able to make sense of stimuli, thus failing to react to it properly. The social issues that the children face oftentimes can lead to behavioral problems as well (Boonen et al., 2014). The communication issues that these children also face, including interpreting facial and body expressions, and understanding other's feelings, contribute to their social development (Landa, Holman, & Garrett-Mayer, 2007). A study was conducted in which autistic patients were presented with an emotional stimuli, in male and female portraits, however the subjects were unable to properly identify the gender and emotion represented in the portrait. This study found that the primary reason for this disability was the inability of the autistic individuals to properly allocate their attention to crucial elements in the portraits. Therefore, developing an autistic child's social skills is imperative in increasing their ability to interact with society and ultimately determining their capability of becoming independent later on in life (Mathersul, McDonald, & Rushby, 2013).

Various forms of therapy and treatment exist for helping autistic children to improve overall function and reach their potential. These include behavior training and management, medicines to treat related conditions, community support and parent training, and more specialized therapies such as speech, music, animal, occupational, and physical therapy (Bass, Duchowny, & Llabre, 2009; Kaplan & Steele, 2005; Solomon, 2010). Behavioral training and management utilizes positive reinforcement, self-help, and social skills training in order to improve autistic children's behavior and communication. Forms of this type of treatment include Applied Behavioral Analysis (ABA) (Virués-Ortega, 2010).

Occupational therapy is often concerned with the child's sensory processing and modulation. The three main elements to the sensory integration approach of occupational therapy are helping the parents to understand their child's behavior and foster nurturing relationships, helping the parents and teachers to modify the environment so it matches the sensory needs of the child, and helping the child to organize responses to sensory input. Activities that are consistent with the sensory integration approach provided graded tactile, proprioceptive, and vestibular input to the child to influence attention and arousal. This approach is applied to autistic children in order to help remedy behaviors indicative of sensory defensiveness and intolerances because sensory integration is fundamental in a child's ability to engage in play and sustain social interaction (Hatch-Rasmussen, 2013; Schaaf & Miller, 2005).

The most common toys currently on the market designed to help develop social, motor, sensory, and communication skills include the fleur rollercoaster table, sensory ice cubes, and the squeezer. The fleur rollercoaster table is a large toy designed to encourage the interaction of multiple children and has been used for over 20 years. This toy integrates visually stimulating patterns and numerous playable pathways in order to help develop motor skills by encouraging repetitive use (*Anatex Enterprises, Van Nuys, CA*). The sensory ice cubes use LEDs to stimulate children's senses while they are eating and drinking in order to attract their attention and prevent them from becoming restless. These are normally used for those autistic children who particularly have trouble focusing, and need extra sensory development (*The Sensory University, Buford, GA*). The squeezer is a toy consisting of two foam rollers that have a channel between them for children to squeeze through. It is designed

to help autistic children's social, sensory, and locomotive motor skill development. The touch of the foam rollers aids in the tactile sensory system's development, while the ability for this toy to be used in succession by multiple children encourages a more social atmosphere, developing communication and social skills. The locomotive motor skills of the children are developed through the movement required in order to get through the squeezer from one side to the other (*Fun and Function, Merion Station, PA*).

While many of the toys on the market that aid in autistic children's development are very useful and popular, they do lack some characteristics that would be very beneficial. All of the previously mentioned toys, fleur rollercoaster table, sensory ice cubes, and the squeezer, lack an essential feedback system. Therefore, the product that has been developed in the present study contains two video cameras that record both the children's hand movements and facial expressions. These videos provide therapists with proper qualitative and quantitative data in order to track the improvement in the development of motor, sensory, decision making, and skills of the child. In this study, the developed product was used to show improvement in response to stimulation, and development of appropriate reaction to stimuli with the button game; and improvement in fine motor skills, dexterity, and decision making skills through the path game.

MATERIALS AND METHODS

DEVICE

The toy is designed to develop the motor skills of the children, while focusing on allocating attention more accurately and effectively. Through the implementation of path and button activities, as shown in Figure 1, the child with autism is able to complete goal-oriented tasks and receive congratulatory responses. Lights surrounding the panel signify the child's successful completion of the activity. The interactive button activity tracks the number of correct buttons pushed by the child during each session, based on a random sequence of illumination designated by an Arduino Uno

electrical components were powered by a 15,000 mAh power bank, which served as an efficient and long-lasting power source for the low power consuming microcontrollers.

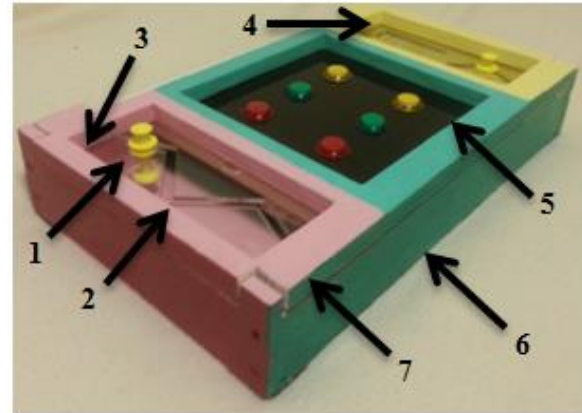


Figure 1- Image of the device: 1. Peg, 2. Path panel, 3. Left camera, 4. Right camera, 5. Button activity, 6. Power bank (underneath), 7. Hinged cover.

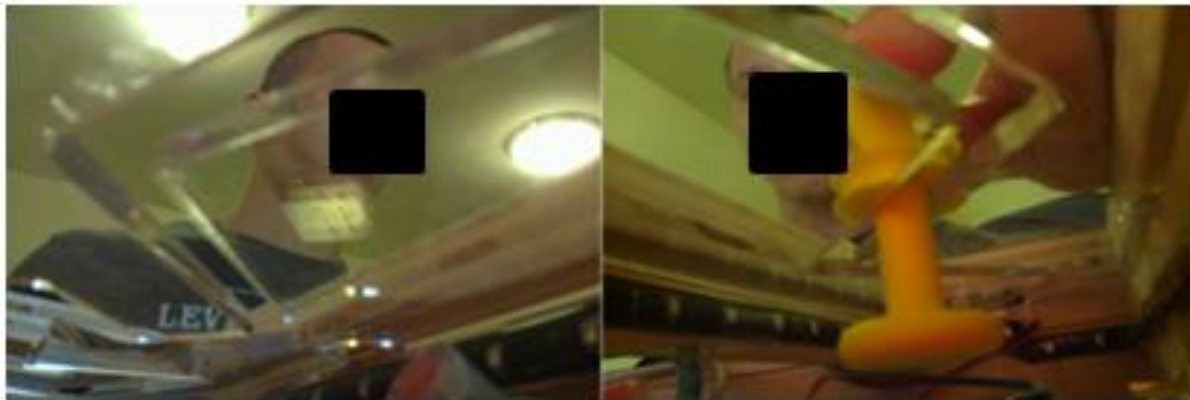


Figure 2- Discreet cameras capture the user's progression, as well as facial behavior during use.

microcontroller. Each panel is completely interchangeable, allowing for varying levels of difficulties to further strengthen cognitive and motor skills. Figure 2 displays the view from the discreet cameras under both side panels, which provide parents and therapists with subjective data of the child playing with the toy. The use of Raspberry Pi camera modules allows for data to be saved on a secure digital memory card, and transferred wirelessly to a network computer. This feedback can then be used to analyze the child's behavior, as well as evaluate their progress after repetition. All

HUMAN SUBJECT TRIALS

In order to achieve real-time, physiological multifaceted feedback from children with autism under various sensory and motor skills-related conditions, the device was tested on children with autism. All test procedures were in compliance with Institutional Review Board (IRB) guidelines and were approved by the IRB committee at Stevens Institute of Technology (CPHS protocol 2014-008). An unbiased pool of children with autism (n=18) was recruited from two autism specialized centers, Garden

Academy (*Maplewood, NJ*) and The Harbor School (*Eatontown, NJ*). The inclusion criteria were comprised of children with development ages between 3 and 17 years of age, with determination of the child's developmental age being decided by their instructor. The children ranged in age from 7-14 years old and, out of the 18 children, only one child was found unwilling to participate in the observational study. Each child was allowed to interact with the toy for exactly 5 minutes, while being video recorded. Although some children wanted to play with the toy for additional time, only the first 5 minutes were recorded and valid in data collection.

DATA COLLECTION

Upon the beginning of each session, one investigator used to the remote control to start the recording discreetly, while all four investigators, as well as the student's instructor observed the child. Qualitative measurements were obtained from multiple cameras, as well as questionnaires that were completed by the child's instructor and field notes by the research team. Specific attention was placed on the type of reactions in each child when trying to manage frustrating situations. The number of paths completed and buttons correctly pressed were recorded for comparison between various case studies in order to evaluate cognitive and physical improvement. During the session, each instructor was required to complete two questionnaires concerning the number of tasks completed, as well as overall satisfaction, interaction, and enjoyment of the child during their time with the toy.

RESULTS AND DISCUSSIONS

Many problems in therapy arise because of the use of standardized measures that are inappropriate due to autistic

children's common nature of being noncompliant and unresponsive to instruction. Therefore, observations on child's behavior in a natural, discreet environment are more appropriate and effective measures in assessing autistic children. This is accomplished by measuring the frequency or duration of specific behaviors or actions during a child's natural play, as compared to tests that require the child to respond to instructions (Case-Smith & Bryan, 1999). The product developed in this study was designed to feel more like an ordinary, everyday toy that the child enjoys interacting with, while at the same time providing quantitative and qualitative feedback to serve therapeutic purposes. The toy was a means of self-therapy, only requiring minor parental involvement, therefore allowing passive observation to occur. Another issue with most of the existing devices for autism therapy is that they are targeting groups of children and not the individual child, which may prove ineffective in assessing the true progress made throughout the therapy of each child (Case-Smith & Bryan, 1999). The toy used in this study, while capable of being used by multiple children in succession, was able to differentiate the actions of individual children through the use of the internal cameras and enable tracking of individual progress.

ORIGINAL TOY DESIGN

Through on-site observation and video analysis, the results indicated in the questionnaires were used to interpret and verify the children's behaviors. The results yielded from the questionnaires are shown in Figures 3-5. The data indicate that the 17 children who participated in the study completed an average of 21 tasks, see Figure 3A, while neither task was greatly preferred over the other, see Figure 3B. Furthermore,

the instructors' analysis of the toy proved to be positive, as indicated by their answers to questions regarding the toy's satisfaction, see Figure 4, and the child's enjoyment, see Figure 5.

For the majority of the subjects, the cameras were able to capture their faces as they interacted with the path activities, which provided ample data to analyze the

child's behavior. Two sample images of the videos are shown in Figure 6 to display the camera angle and raw data. Sample video recordings can also be found as the supplementary materials in the online version of the manuscript. Due to the confidentiality of the study, subjects have been de-identified in the camera images.

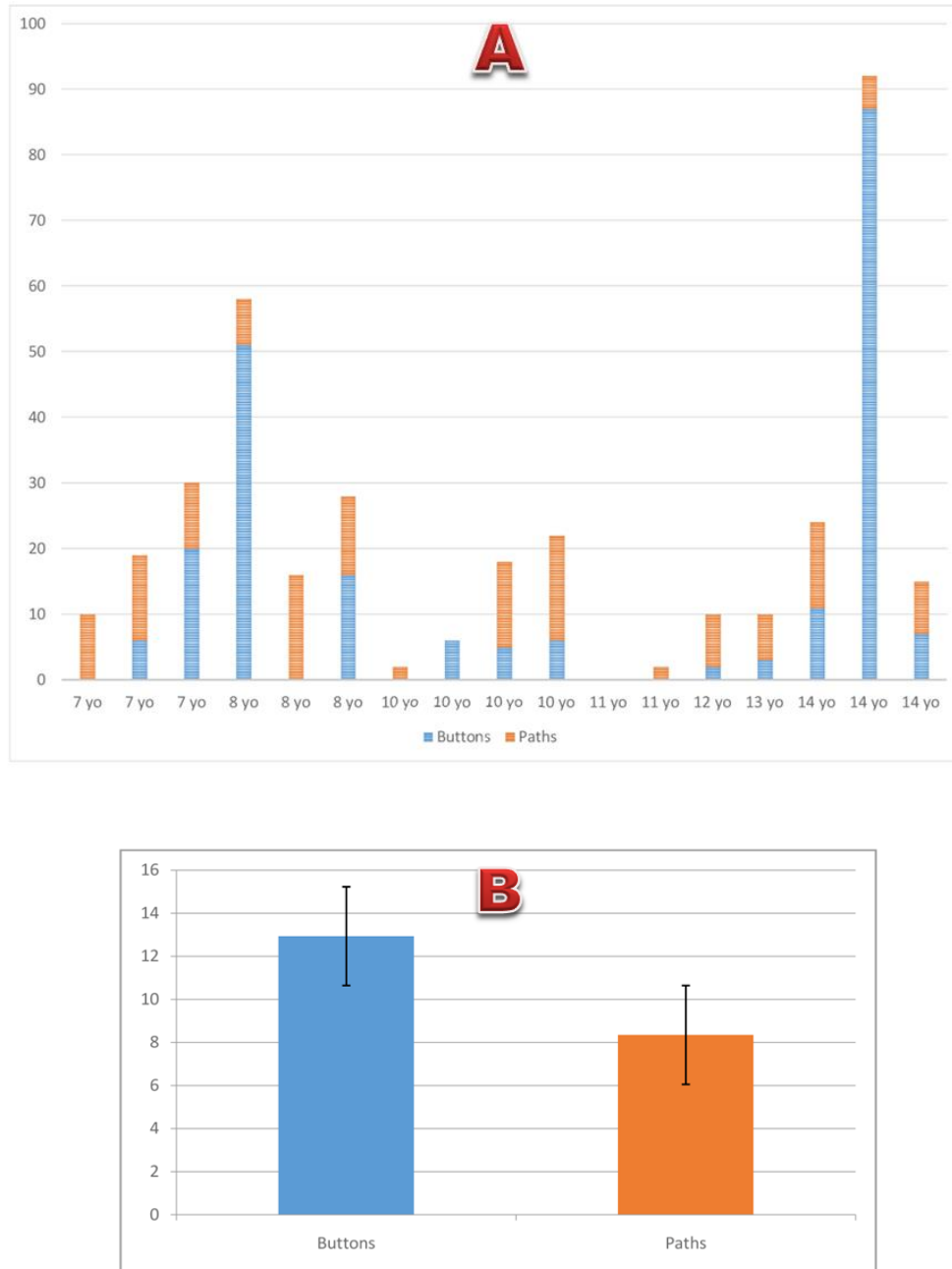


Figure 3- (A) The number of button and path activities completed by each subject, sorted by age. (B) The average number of total activities completed.

Did the toy satisfy the basic needs of the autistic child?

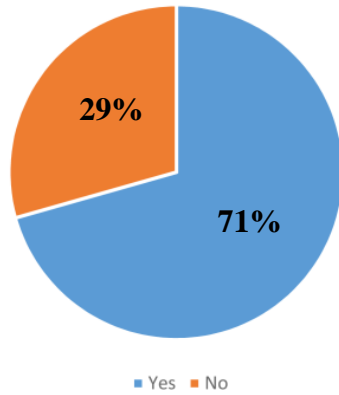


Figure 4- Instructors' response to: "Did the toy satisfy the basic needs of the autistic child?" indicating a 71% satisfactory feedback.

How evident was it that the child enjoyed playing with the toy?

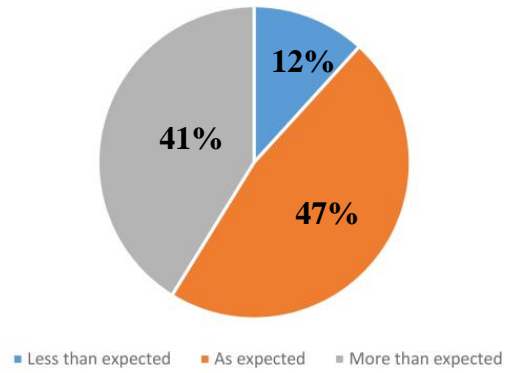


Figure 5- Instructors' response to: "How evident was it that the child enjoyed playing with the toy?" indicating 47% and 41% feedbacks of 'as expected' and 'more than expected', respectively.

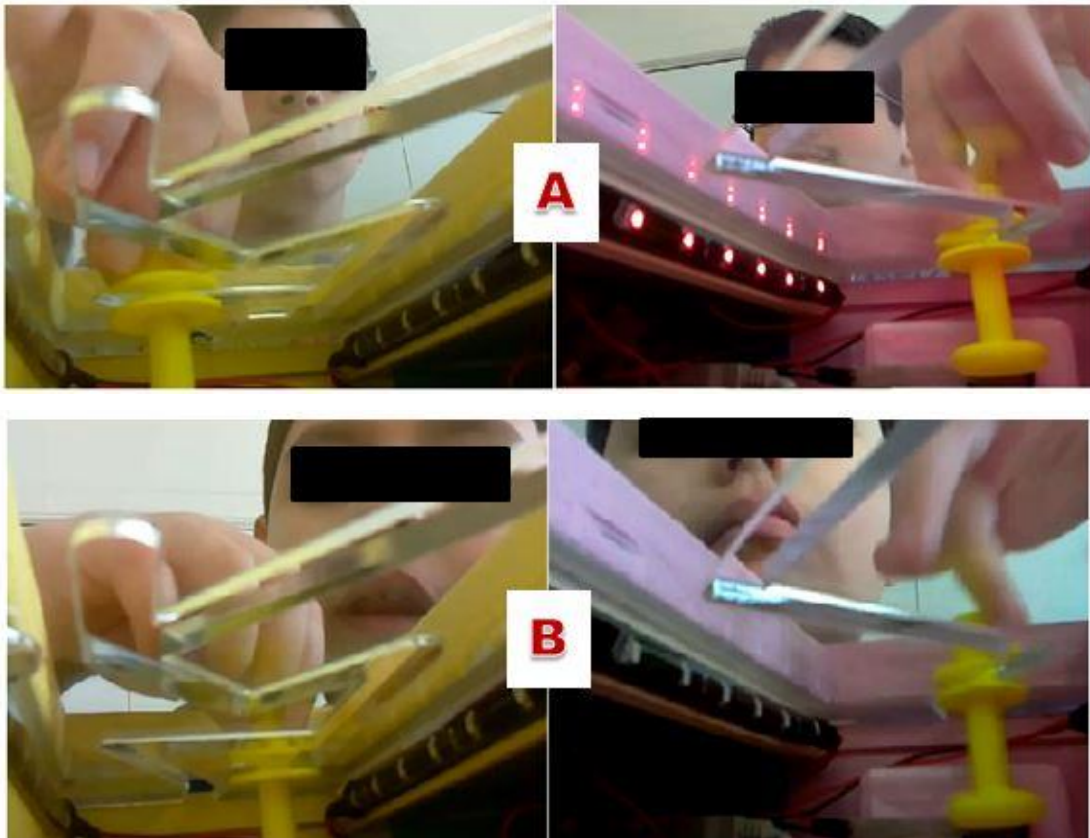


Figure 6- Sample recordings by right and left cameras: (A) Subject 1 (age 10), and (B) Subject 2 (age 8)

Upon testing the toy at the two schools, the majority of the instructors believed that the toy was very helpful for autistic children, and were often amazed by the child's intrigue while interacting with the toy. It is important to note that four children who participated in the study experienced multiple disorders other than autism, resulting in only one instructor of an autistic child indicating that the toy did not satisfy their basic needs.

MODIFIED TOY DESIGN

Overall, there have been few areas of improvement on the toy that have been identified throughout the conduct of the human trials. In particular, the current setup of the button activity panel has the lit up LED button switching to the next random button whenever any of the buttons are pressed, correctly or incorrectly. As a result, some of the children were content with pushing any button, even if the button was not lit up. This can be resolved by making the button change only if the user pushes the lit up button, and by having a congratulatory sound play if the correct button is pushed. This way, the child is encouraged to push only the lit button; and the sound will



Figure 7- Top view of the improved toy design used for second trial. The improved features include: 1. Enhanced path panel 2. Modified button panel 3. New peg

reaffirm this notion to the user. In addition to the button activity, it was observed that many children would repeatedly push the peg into the end of the path to activate the congratulatory noise and lights. This stopped the child from continuing to properly complete the path activities and overcome the obstacles throughout the path. As a result, the future device would be designed so that once one of the sensors is activated, it could not become activated again until the peg is moved to the other side of the path and the other sensor is activated.

After making the necessary changes, primarily consisting of altering and adding noise to the button activity, the toy was evaluated for a second time at Garden Academy (*Maplewood, NJ*) approximately three weeks after the first trial. The goal of this visit was to determine if the children tested the first time had progressed by measuring the total number of tasks they completed. The major changes to the toy design were the button panel, which was reduced from six to four buttons, and the two path panels, which were remade to increase difficulty, see Figure 7. Each child was again allowed to play freely with the toy for five minutes while being video recorded, and the total number of tasks completed was observed and compared to the number of tasks completed during the first visit, see Figure 8. Of the eight children tested during the first visit, only six were able to participate in the second study. Five out of those six exhibited progression based on the total number of tasks they completed within the five minute session. Furthermore, the results indicated that all six children preferred the button activity more than the path activity during the second visit, most likely due to the implementation of noise.

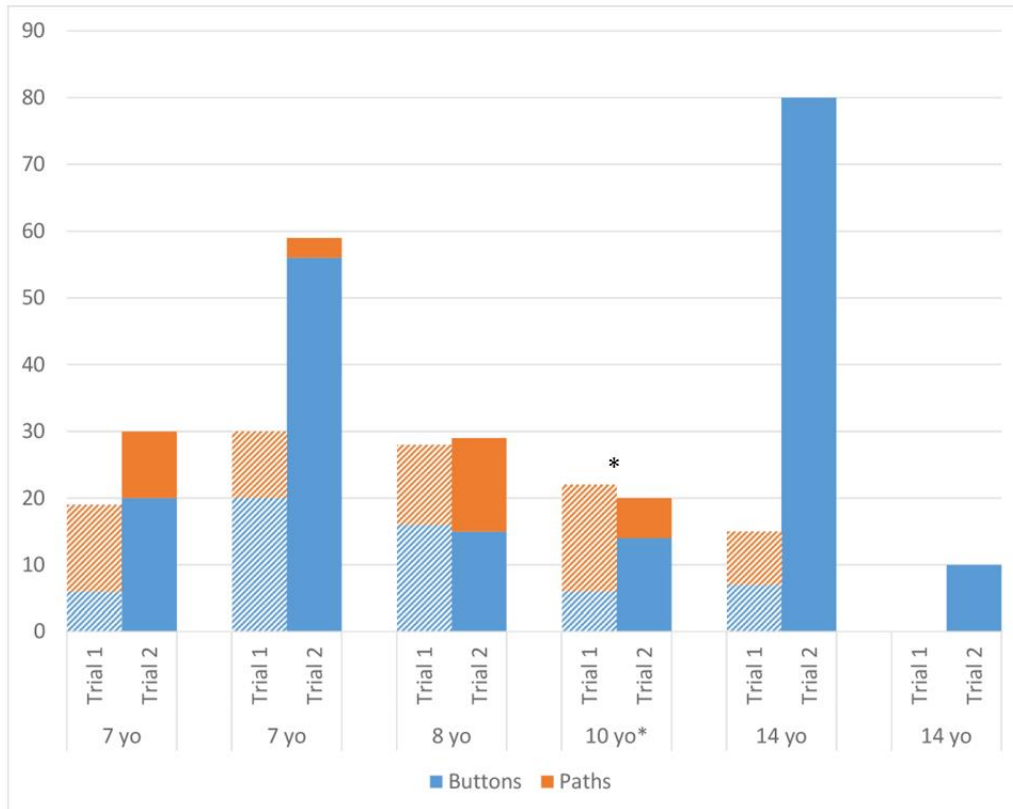


Figure 8- The total number of tasks completed by the same population (n=6) during the first trial and second trial (3 weeks later). Except 1 subject (indicated with *), the rest of the 6 subjects indicated improvements on the second trial.

CONCLUSIONS

The aim of this project was to simulate, design, manufacture, and assess a toy that could help cultivate sensory, social, communication, and motor skills in autistic children. The new toy developed in this study has been equipped with interchangeable panels that allowed for hundreds of variations in order to progress in difficulty with the child's development and preference, thus increasing re-playability. The path panels of the toy can be created in almost any imaginable shape, allowing endless ways for the child to play with the toy, and develop their motor skills accordingly. A form of visual feedback has also been considered in the new toy by incorporating two minuscule Raspberry Pi

cameras, hidden to the child, in order to accurately evaluate the child's natural behavior. The recording of the hand movements and facial expressions of the children throughout the completion of the tasks by the cameras, along with the ability to store video footage, has allowed for progress to be quantitatively measured and tracked; thus giving clearer insight into the development of the child.

The employment of the device at two schools for autism and observing the children's reactions when playing with the toy indicated that the toy fully engaged the children's senses and motor skills. The subjects' reactions to the stimulations provided by the toy were communicated to their caretakers after the study to be used for the therapeutic and social deficiency

improvement purpose. The first-hand observation of use of the toy confirmed that the objectives of the study were achieved. All children attempted to play with both the button and path activities, while neither task caused frustration for the subjects. Many children were persistent in solving the harder paths after realizing the reward from the easier paths, and eventually were able to complete both paths. Overall, the children were easily acclimated to the toy without instructor interference, which allowed for video acquisition of natural reactions. Ongoing and future studies are being conducted in order to further improve the toy, with an ultimate goal of developing a final product that can be incorporated as part of the standard therapeutic schemes in autism specialized centers throughout the United States.

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