Using a Robotic Teleoperation System for Haptic Exploration

by

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ABSTRACT

The properties of an object, such as size, shape or texture, can determine how the object can be used as a tool. Children learn how to use objects as tools throughout their childhood, this allows them to meet task demands in an adaptive manner. In order for individuals to determine which objects can be used as tools for different tasks, they must perform exploratory actions that include reaching, grasping or lifting to perceive an object's properties. When individuals are not able to perform exploratory actions due to physical disabilities they may not be able to explore or perceive object properties and may not be able to make judgments about tools. Haptic robots controlled through a teleoperation system allow a person to move and manipulate objects at a distance and could be a means through which people with physical disabilities can explore object properties using a joystick-like device. Two studies were conducted to determine if a haptic robotic system allowed adults, typically developing children and an adult with disabilities to recognize object properties in order to use the objects as tools. The studies also compared how object manipulation differed when participants used the robotic system compared to when they used their hands. A Function Judgment Task based on Kalagher (2015) and Klatzky, Lederman, & Manikinen (2005), was replicated where participants made judgments about tool use in two conditions: 1) using their hands and 2) using a teleoperation system with haptic feedback. Participants were able to perform exploratory actions with the system and with their hands that provided them with haptic information to make accurate judgments about tool use. Results showed that the overall the performance of adults without disabilities, typically developing children and the adult with disabilities was similar or improved when they used the robotic teleoperation system compared to when they used their hands.

PREFACE

This thesis is an original work by Lina Maria Becerra Puyo. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Health Research Ethics Board, Project Name “Using Robotic Teleoperation Systems: Function Judgement Task”, No. MS1_Pro00071222, March 30, 2017.

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CHAPTER 1: INTRODUCTION

Haptic exploration occurs when individuals manipulate objects and use their sense of touch to determine the material and physical characteristics of the objects (Lederman & Klatzy, 2009). Children perform haptic exploration during playful activities (Fenson & Schell, 1985) where they experience sensory exchange between themselves and the environment and gain information about physical characteristics of their surroundings (Gibson E. , 1988). Adults use haptic information to perform everyday tasks, such as buttoning a shirt while getting dressed or changing gears while driving, without needing additional visual information (Klatzky & Lederman, 2003). Haptic exploration is present from birth and continues to have an important role throughout childhood (Gibson E. , 1988; Bushnell & Baxt, 1999; Klatzky, Lederman, & Manikinen, 2005) and adulthood (Kleinmen & Brodzinsky, 1978; Klatzky & Lederman, 2003).

In order to perform haptic exploration, individuals use specialized movement patterns of the hands to extract information about specific object properties. These movement patterns are called exploratory procedures (Lederman & Klatzky, 1987; Klatzky, Lederman, & Manikinen, 2005). When individuals use exploratory procedures they perceive object properties which in turn provide clues as to how to use objects as tools (Klatzky, Lederman, & Manikinen, 2005; Lockman, 2000; Kalagher, 2015). For example, the rigidity of a stick defines if it can be used as a tool to stir a mixture. In order to determine if a stick is rigid enough to be used as a tool, adults and children will most likely use the exploratory procedure of applying pressure to the stick (Klatzky, Lederman, & Manikinen, 2005; Kalagher, 2015).

Because haptic exploration is dependent on characterized exploratory procedures (EPs) of the hands (Lederman & Klatzky, 1993; Lederman & Klatzky, 1987), it may not be possible for individuals who are unable perform the required hand movements. When physical disabilities limit children's ability to play and perform haptic exploration, they may miss out on opportunities to interact with the world around them and learn the skills required for tool use -skills that are necessary later in adulthood (Fenson & Schell, 1985; Lockman, 2000; Missiuna & Pollock, 1991). Children with motor impairments may grow into adults that have not had enough opportunities to practice the skills required for tool use through haptic exploration. Additionally, adults with motor impairments may still not have access to sensory information (i.e. compliance, texture or weight of objects) required for tool use (Withagen, Kappers, & Vervloed, 2010; Haggard & Longo, 2010), further limiting their ability to make judgments about objects that can be used as tool.

Assistive robots may allow new actions to become available to individuals with disabilities. Switch controlled robots have been shown to provide children with a means to manipulate objects and toys (Rios, Adams, Magill Evans, & Cook, 2016). Likewise, robotic arms, often mounted on wheelchairs, allow adults with disabilities to participate in daily activities and have access to the physical environment (Allin, Eckel, Markham, & Brewer, 2010). However, in the past, the robotic interfaces used by children and adults with physical disabilities have not given them the haptic sensory feedback of the object manipulated (Rios, Adams, Magill Evans, & Cook, 2016; Adams, et al., 2017; Allin, Eckel, Markham, & Brewer, 2010).

Robots controlled through a teleoperation system allow a person to move sense and manipulate objects at a distance (Cui, Tosunologlu, Roberts, Moore, & Repperger, 2003). The robots may also be a means through which individuals can acquire information about object properties through their haptic sensory system. The addition of haptic feedback to robots might allow individuals to perform EPs and acquire information about an object's properties in the environment in order to determine how to use objects as tools. This study explored if a robotic teleoperation system allowed participants to perform haptic exploration, and, how haptic exploration with the system resembled or differed from haptic exploration using the hands.

Two studies were performed. In study 1, participants were adults and children without disabilities. Study 1 replicated a Function Judgment Task used in previous studies (Kalagher, 2015; Klatzky, Lederman, & Manikinen, 2005) Results from both age groups provided information about how haptic exploration and the exploratory procedures may be similar or different when they use their hands compared to when they use a robotic system.

Study 2 was and exploratory case study conducted with an adult with physical disabilities to understand how motor impairments may influence participant's tool judgment when using hands and when using the robotic teleoperation system. The participant performed a modified version of the same Function Judgment Task that was performed by participants in Study 1 (Kalagher, 2015; Klatzky, Lederman, & Manikinen, 2005). The results from Study 2 were compared to the results from Study 1 in order to explore how performance may be different when a participant with motor impairments and alternative experience with haptic exploration performs that task compared to when adults without disabilities perform the task. Results provided information about modifications that the system may require for future development so it can be used by adults and children with physical disabilities and calls for future research aimed at understanding how robotic teleoperations systems can influence haptic exploration in this population. These two studies will provide the foundation for future research exploring the use of robotics for haptic exploration with individuals with physical disabilities.

RESEARCH QUESTIONS

The two studies in this thesis aimed to determine 1) if a robotic teleoperation system with haptic feedback allows participants to recognize the properties of objects in order to use them as tools and 2) if haptic exploration using a robotic teleoperation system with haptic feedback resembles haptic exploration using the hands. The following questions were proposed for both studies:

1. Can participants indicate if spoons with varied bowl sizes can transport a piece of candy, and if sticks of varied rigidity can mix a substance, through haptic exploration using their hands?
2. Do participants vary their exploratory procedures as a function of task (Mixing or Transport) when judging whether a tool is appropriate to complete the task through haptic exploration using their hands?
3. Do participants indicate if spoons with varied bowl sizes can transport a piece of candy, and if sticks of varied rigidity can mix a substance similarly to when they use a robotic teleoperation system compared to when they use their hands?
4. Do participants vary their exploratory procedures as a function of task (Mixing or Transport) when they use a robotic teleoperation system compared to when they use their hands?

CHAPTER 2: LITERATURE REVIEW

This literature review focuses on three important areas relevant to the proposed research: 1) Characteristics of haptic exploration 2) Robotic systems used by children with disabilities to play and explore objects 3) Robotic systems used by adults to manipulate objects, 4) Teleoperation systems that provide haptic feedback and 5) Confidence Measures.

Characteristics of Haptic Exploration

The following section explores how haptic exploration is developed and can influence tool use during childhood and adulthood. A description of the exploratory procedures and their role in haptic exploration is also presented.

Development of Haptic Exploration

Typically developing children perform intentional exploratory manipulation in order to investigate the sensory perceptual feedback of objects; this may include object properties such as hardness, size or shape (Gibson E. , 1988). When typically developing children perform exploratory manipulation they are able to interact with their environment, which in turn allows them to learn and create predictions about the world around them (Gori, et al., 2012)

Children are naturally interested in exploring their environment and therefore seek out sensory experiences (Parham & Fazio, 2008; Klatzky, Lederman, & Manikinen, 2005). Exploratory behavior occurs in infancy and early childhood when information about the physical and social aspects of the environment is acquired through interactions with objects (Fenson & Schell, 1985), during play activities (Fenson & Schell, 1985) or in novel situations (Parham & Fazio, 2008; Fenson & Schell, 1985).

Exploration allows children to acquire and process information about objects. Gibson (1988) links haptic exploration to: perception, action and cognition. Through perception, children acquire information about objects and the environment. However, in order for children to perceive object properties through haptic exploration they must perform actions. Actions are used for examining textures, shapes or locations by holding, carrying, reaching, lifting or manipulating objects and allow active adjustments in the haptic sensory systems. As children develop actions, they also become better at gathering information, which in turn allows them to more easily explore object properties. Cognition comes into play when children acquire knowledge as a result of object exploration. As children acquire knowledge, exploratory activities are used to a greater advantage to discover the properties of objects more efficiently. Therefore, perception, action and cognition must interact in order for haptic exploration to take place (Gibson E. , 1988).

Because haptic exploration depends greatly on action (Hatwell, 2003; Gibson E. , 1988; Kalagher & Jones, 2011; Lederman & Klatzky, 1987), it may be difficult for children with physical disabilities to extract object features and properties through this perceptual system. The strong relationship between haptic exploration and the development of motor skills (Klatzky, Lederman, & Manikinen, 2005; Gibson E. , 1988) suggests that when children are not able to reach, grasp or manipulate objects due to physical disabilities they may also have difficulties extracting object properties such as texture, size or shape through the haptic sensory system. Therefore, in order for children with physical disabilities to explore the physical properties of objects through the haptic exploration they need to be able to perform some sort of object manipulation: assistive robots could enable children to perform such actions on objects.

Tool Use

In tool use, the task is to detect affordances of objects and of relations that exist between them (for example a key goes into the keyhole in the door) based on information that is perceptible (visual or haptic) (Lockman, 2000; Osiurak & Badets, 2016). Affordances are the action possibilities that objects can offer individuals in a certain situation (Gibson E. , 1988; Gibson J. , 1977). According to the manipulation based approach to tool use and affordance, the ability to identify affordances and determine how objects can be used as tools is based on the action capabilities of an individual (Osiurak & Badets, 2016).

Klatzky, Lederman, & Manikinen (2005) confirmed the role of haptic exploration in determining tool function. They asked 4 year old children and adults to make decisions about the appropriateness of a tool to perform a functional task, i.e., spoons of varied sizes to carry a piece of candy and sticks of varying rigidity to mix either sugar or gravel. Children and adults were visually presented with the tools and allowed to handle them. They found that participants used perceptual exploration sensitive to the task goals. When the task was constrained to size they used vision, however when the task was constrained to rigidity they used haptic exploration. Results showed that participants were able to perform perceptual analysis to judge if a tool was appropriate through visual or haptic exploration, without needing to carry out the actual task. For example, participants could determine the stick's utility for the task just by perceiving the rigidity through the haptic exploration before needing to actually stir the mixture with the stick.

A later study performed by Kalagher (2015) replicated the study by Klatzky, Lederman, & Manikinen (2005) with children 3 to 5 year old children and adults, however in their study the view of the tools was occluded and the participants were constrained to only use haptic exploration to judge the tool's utility. This study found that an age difference exists in the amount of exploration and accuracy in responses. The 3 year olds explored objects less and were less accurate in their responses than the older children and adults. The results of the 4 year olds in the study were the same as those of the Klatzky, Lederman, & Manikinen (2005) study. Five year olds demonstrated adult-like exploration and were very accurate in their responses. This suggests that in the absence of vision children as young as four and five years old are able to determine tool use reliably solely through haptic exploration.

Exploratory Procedures

An exploratory procedure (EP) is a movement pattern of the hand that has certain characteristics aimed at extracting specific information about object properties (Lederman & Klatzky, 1987). Studies have confirmed that adults use EPs during haptic exploration and are highly efficient at extracting properties of objects and using that information for object recognition (Lederman & Klatzky, 1987; Lederman & Klatzky, 1993; Lederman & Klatzky, 1990).

Lederman and Klatzky (1987) were the first to describe the EPs used by adults to extract knowledge about objects. They used a match-to-sample task, where adults were blindfolded and asked to match objects on a particular dimension (e.g., shape or texture). Hand movements during exploration were classified. It was found that the EP's performed by participants were related to desired object knowledge that was required for the match. A description of the EP's according to Lederman & Klatzky (1993) can be found in **Error! Reference source not found.**.

Table 2-1 EPs and description based on Lederman & Klatzky (1993)

EP	**Description**	**Desired Object Property**
Lateral Motion	Repetitive and lateral rubbing motion	Texture
Pressure	Pressure applied to the object's surface	Hardness
Enclosure	Molding of the palm and/or finger(s) to the contours of an object	Shape and volume
Static Contact	Stationary contact on a surface without molding	Temperature

Unsupported Holding	Lifting an object away from a supporting surface, used to extract information about weight	Weight
Contour Following	Dynamic edge following used to obtain precise spatial details concerning an object's shape	Shape
Other EPs	Used for extraction of information pertaining to the motion of an object part and function determined by the object's structure	

Studies have also tried to compare children's EPs with those presented by adults. In their study about tool use Klatzky, Lederman, & Manikinen (2005) determined that when 4 year olds were asked to make perceptual comparisons about objects (e.g., which object is harder) they used appropriate adult-like EPs. Children lifted objects to judge weight, pressed objects to compare hardness and used Enclosure to judge size. The authors suggest that children perform the same EP's when performing the same perceptual comparisons because haptic exploration plays a role in motor planning by directing the manipulation of familiar objects in the absence of vision.

Likewise, in her subsequent study Kalagher (2015) found that the EPs used by children between 3 and 5 varied with age. All age groups demonstrated the same movement patterns (Lateral Motion, Contour Following and Enclosure for size and Pressure for rigidity), however, younger children employed them in a smaller proportion on each individual trial. Older children spent more time exploring the tools using the optimal EP. The authors also concluded that the more appropriate exploration children performed, the better their performance on the task.

Previous experience with objects will have an effect on an individual's ability to identify objects (Klatzky & Lederman, 2003). Identifying common everyday objects is part of a general perceptual task called pattern recognition. In this process, the sensory system breaks down incoming stimulation into features that access memory for known categories of patterns. Memory determines the category to which the stimuli are assigned and the best match is made. Therefore, in order for people to interact with and manipulate objects without looking at them, they must first know what the object is (Klatzky & Lederman, 2003). Likewise, when children are exposed to objects and allowed to perform haptic exploration, the previous experience with the objects will guide future haptic exploration and influence the kinds of EPs they perform when they are presented with different objects (Kalagher, 2013). Therefore, it may be important that before participants use a robotic teleoperation system to determine tool use, they first be allowed to practice haptic exploration using the system.

Robotic Systems for Children to Explore and Play

No studies about robots with haptic feedback being used by children with physical disabilities to explore their environment were found (Jafari, Adams, & Tavakoli, 2016). However, studies have found that non-haptic robotic systems can facilitate object and toy manipulation, allowing children to explore the world around them and participate in playful activities. A literature review by Van den Heuvel, Lexis, Gelderblom, Jansens, & Witte (2015) concluded that three main groups of technology for play could be distinguished: robots, virtual reality systems and computer systems. The review found that robots were especially used for playful activities (play for play's sake) when compared to virtual reality and computer systems which were used for therapeutic activities. The authors concluded that because robotic systems have great potential to support play in children, but still lack commercial availability, they are a meaningful focus for development and improvement.

A study by Cook, Howery, Gu, & Meng (2000) evaluated how children with physical disabilities used a robotic arm to interact with objects for exploration and play. The play activity used for this study was focused around a tub of dry macaroni to provide visual and auditory sensory information while allowing children to learn about the consequences of actions over objects. Children were asked to use switches to control the robot arm to dig up the macaroni and dump it out in order to discover objects buried in the macaroni. Although this technology did not provide haptic feedback, the robotic arm was found to be a flexible approach for children to interact with the environment because it allowed children to manipulate objects in order to explore the macaroni's physical properties through vision.

In another study, playfulness was evaluated when children with cerebral palsy who had difficulty performing gross and fine motor movements with upper and lower extremities used a switch-controlled robot to play (Rios, Adams, Magill Evans, & Cook, 2016). This study found that children's playfulness increased when children had access to the robot that allowed toy manipulation when compared to when children's mothers moved the toys around for them. The study also found that the kind of play in which children participated when using the robot was primarily functional play (Rios, Adams, Magill Evans, & Cook, 2016).Functional play refers to a type of exploratory play in which children move toys around, bang them against each other or stack them for the purpose of having sensorimotor experiences. Therefore, the robots not only provided opportunities for play, but the children were motivated and interested in using them to explore objects in the environment.

In order for children to use robotic systems for play and exploratory activities, the robotic system should be able to provide feedback to the child about his/her actions in the environment. Cook, Adams, & Encarnacao (2010) reviewed the use of robots for assistive play from the perspectives of rehabilitation engineering and robot design in order to define a set of desirable characteristics for robotic systems for children. One of the characteristics defined by these authors referred to the need for appropriate communication between the user and the robot. In order for the system to give the user a sense of effective control over the system and environment the system must provide appropriate feedback. The authors mentioned visual and auditory feedback to the user about the robot state or sensory information perceived by the robot (Cook, Adams, & Encarnacao, 2010). However, haptic feedback may be an equivalent or superior alternative to visual and auditory feedback to provide communication to the user about sensory information perceived by the robot. Although the authors concluded that children could use robots to demonstrate integrated manipulative, communicative and cognitive skills through play, they determined that further development in the area of assistive robots was needed to address the limitations of current robotic systems (Cook, Adams, & Encarnacao, 2010). Haptic feedback may address some limitations of robotic systems therefore improving children's experience when manipulating and exploring objects with the robots.

The robotic systems used for the studies mentioned above did not provide any haptic feedback to children; however, children used robots as tools to push, drag and manipulate objects and toys to play and learn about object properties. In these studies, they learned how object properties related to the robot through vision and cause and effect experiences. For example, children could observe how a robot could push small toys but not a wooden wall. Likewise, they could learn how a robot's gripper can hook onto certain parts of a toy and drag it to specific locations. If children observed that a robot could dig through macaroni but not through a table, they could learn about object properties. A haptic teleoperation system would not only allow children to observe how object properties can relate to each other but also allow them to feel these properties (e.g. weight, texture, rigidity and size).

Robotic Systems for Adults to Manipulate Objects and Interact with their Environment

A review looking at trends in the development of manipulation devices found that robotic manipulation devices allow people with disabilities to participate in occupations and enhance feelings of personal well-being and confidence when performing activities (Allin, Eckel, Markham, & Brewer, 2010). The review also found that in the field of prosthetics, sensory feedback has been shown to further improve user's confidence when manipulating objects, however, in the field of externally mounted manipulation devices providing sensory feedback has not been researched (Allin, Eckel, Markham, & Brewer, 2010). A more recent review also determined that little research has explored the functionality of haptic systems to be used for everyday manipulation tasks (Jafari, Adams, & Tavakoli, 2016).

Research has shown promising results for systems with haptic feedback to be used for rehabilitation therapy. A review by Carignan & Krebs (2006) found that people have been able to use teleoperation systems with haptic feedback to manipulate and receive force feedback from robots to perform a variety of therapeutic activities. This includes occupational therapy sessions online using a force-feedback joystick connected to an orthopedic splint. In these sessions, clients were able to participate in a variety of online therapy games where the system physically assisted or resisted the user under the supervision of an occupational therapist (Reinkensmeyer, Pang, Nessler & Painter, 2002 as cited in Carignan & Krebs, 2006). The authors concluded that although advances in software and hardware development for teleoperation systems with haptic feedback are still a challenge, this technology is becoming increasingly more plausible in home and clinical settings (Carignan & Krebs, 2006).

A teleoperation system with haptic feedback intended to be used to augment movement was tested in an object sorting task by adults without disabilities and one adult with disabilities (Sakamaki, et al., 2017). The haptic feedback used in this study provided virtual fixtures that restricted participants' movements to facilitate performance in a task that required participants to move tokens from the center of the environment to a target on either side of the environment. Tasks performed with these virtual fixtures were accomplished faster and with fewer deviations than those performed without virtual fixtures. For the participant with disabilities, the study demonstrated the importance of adapting the system to individual's unique motions in order to improve assistance when using a teleoperation system. Overall, it was proposed that a teleoperation system with haptic feedback could be beneficial for people who have physical disabilities and with further development, could be used to help children with physical disabilities perform playful tasks.

Teleoperation Systems that Provide Haptic Feedback for Manipulation of Objects

A robotic teleoperation system can be used to give user haptic information. A teleoperation system consists of a user-side robot that controls an environment- side robot from a distance (see **Error! Reference source not found.**). The environment side robot reflects back to the user-side robot the forces generated as its end effector interacts with the environment (Wildenbeest, Abbink, Boessenkool, Heemskerk, & Koning, 2013). The forces generated by the environment side robot can portray haptic sensory information such as weight, texture or hardness of objects. These forces are reproduced through what is called haptic feedback (Grunwald, 2008).

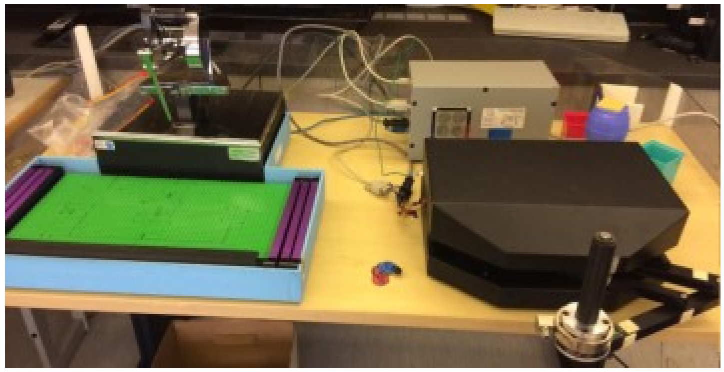


Figure 2.1Teleoperation System**:** Environment-Side Robot is on the left, and User-Side Robot is on the right

When using teleoperation systems that provide haptic feedback, the user must rely on the information arising from the deformation of their muscles (stretching or contracting) and vibrations induced by friction between the environment-side robot and the object (Gentaz, 2003). The deformation of muscles gives the sensations of position or movement (Gentaz, 2003) while the vibrations are related to texture (Chen, Ge, Tang, Zhang, & Chen, 2015). In haptic perception when using the hands, cutaneous information is combined with information from the proprioceptive receptors that results from the mechanical deformation produced by exploratory movements of the shoulder-hand system (Gentaz, 2003). When using robotic systems, the cutaneous information is no longer available; therefore, haptic exploration through a robotic teleoperation system may differ to haptic exploration using the hands.

Teleoperation systems can enable the EPs described by Lederman & Klatzky (1987) required to extract object properties through haptics; however, the procedures need to be modified. The teleoperation system proposed for this research moves in a 2-dimensional plane (horizontal plane: left, right, forward and backwards). Table 2-2 shows how the EPs discussed above in **Error! Reference source not found.** need to be adapted when using a teleoperation system.

Table 2-2: EPs with a Teleoperation System

EPs	Teleoperation System EPs	Dimension
Lateral Motion	Repetitive and lateral rubbing with the end effector of the environment-side robot can be used to extract information about texture.	Texture
Pressure	Pressure applied to the object's surface using the end effector of the environment-side robot could be used to extract information about hardness.	Hardness
Static Contact	Not possible with the available robotic interface	Temperature
Unsupported Holding	Tugging on the object using Lateral Motions can be used to extract information about weight.	Weight
Enclosure:	Not possible with the available robotic interface	Shape and volume
Contour Following	Following the internal or external edge of objects with the end effector of the robot could be used to extract information about shape.	Shape

A study performed by Becerra, Ruiz, Capel, & Adams (2017) looked at how 5 and 6 year old typically developing children and adults without disabilities could use a low tech effector to simulate the feel of performing haptic exploration using a robotic teleoperation system. Participants were blindfolded and asked to "feel" objects using the effector held at different anatomical sites (e.g., hand, elbow, foot, and head). Children and adults performed haptic exploration in order to perform perceptual comparisons of pairs of objects that varied on given attributes (size, shape, hardness, and roughness). Results from this study showed that although some haptic information was lost through the effector, specifically information related to texture, overall participants were able to perform perceptual comparisons when they used the effector with the different anatomical sites. The study also demonstrated that although the EPs that participants could perform with the effector were limited (i.e. participants could not perform Enclosure) they were able to compensate for this limitation by using alternative EPs such as Contour Following and Lateral Motion. Overall, the authors concluded that using an effector could potentially be useful for children with physical disabilities to perform haptic exploration.

Confidence Measures

Participant's confidence when determining object properties using the robotic teleoperation system may provide information related to their understanding of the task as well as the system. If participants are less confident using the system compared to when they use their hands, it may indicate that they feel the robotic system is limiting their ability to extract information about objects.

According to De Neys, Cromheeke, & Osman (2011), if adults are aware that their response is not fully correct when solving a problem, their decision confidence is affected. These authors believe that a way to assess individual's belief that they have made an error when solving a problem is to examine their confidence. That is, if individuals detect that they are wrong when answering a question, they will not be fully confident in their judgments (De Neys, Cromheeke, & Osman, 2011).

Koriat & Ackerman (2010) suggested that children's confidence judgments are based on the ease with which they retrieve or select an answer. In one of the experiments presented in their paper, the authors found that confidence judgements were accurate in discriminating between correct and incorrect answers. This confidence-accuracy correlation was also found to increase with age. They indicated that the confidence–accuracy correlation was significantly higher for fifth graders (mean age 11.1) than for second graders (mean age 7.9) and third graders (mean age 9.0), who did not differ from each other.

CHAPTER 3: GENERAL METHODS

Ethics approval for this study was obtained from the Ethics Review Board of the University of Alberta. Additional information about ethics such as consent forms and assent scripts can be found in Appendix A-E.

Overview

Two studies were performed based on the Function Judgment Task, as in Klatzky, Lederman, & Manikinen (2005) and Kalagher (2015). Study 1 replicated the Function Judgement Task with the same groups of participants as in Klatzky, Lederman, & Manikinen (2005) and Kalagher (2015): adults without disabilities and 5 year old typically developing children. Study 2 replicated the Function Judgment Task with an adult with physical disabilities. Participants in both studies were exposed to the task in two conditions: 1) performing the task by hand (no tech condition) and 2) performing the task with a teleoperation system with haptic feedback (haptic feedback condition).

Materials

Teleoperation System

The teleoperation system consisted of a participant-controlled "interface" robot that controlled the movement of an environment robot that completed the task in the environment (see Figure3.1). The robots were two 6-DOF (3-DOF rotational and 3-DOF translational) desktop controllers with haptic feedback (Phantom Premium 1.5A from Geomagic, Cary, NC).

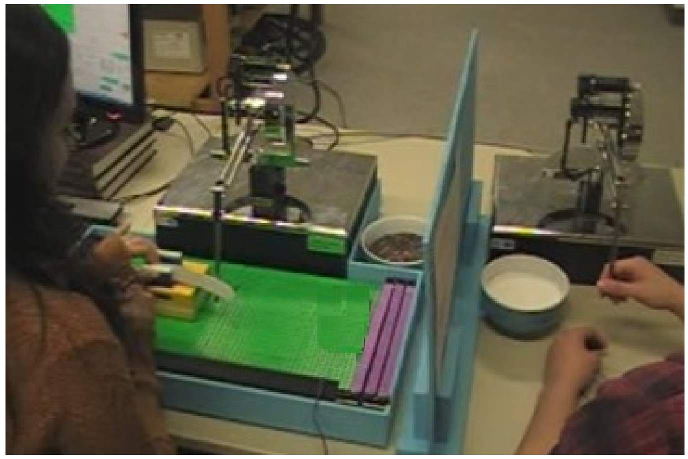


Figure3.1 Teleoperation System used for the Function Judgment Task

Tools

The Function Judgement Task consisted of two subtasks: Mixing and Transport. Two target objects and three tools were needed for each sub task:

- For the Mixing Subtask the target objects were a container filled with sugar and a container filled with gravel. The tools were five sticks with different levels of rigidity. Sticks were constructed of plastics with varying degrees of rigidity and balsa wood for the most rigid stick.
- For the Transport Subtask, the target objects were a round candy of approximately 4 cm diameter and a round candy of approximately 8 cm diameter. The tools consisted of 5 measuring spoons with circular bowls with different diameters; 2cm, 3cm, 4cm, 6cm and 8cm.

CHAPTER 4: STUDY 1, ADULTS AND CHILDREN WITHOUT DISABILITIES

4.1 Method

Design

A cross over study design was used where participants performed the task in two conditions: no tech (with the hands) and haptic (with the robotic system). The order in which the conditions were presented to participants was counterbalanced, so that half of the participants performed the task in the no tech condition first, and the other half performed the task in the haptic feedback condition first.

Sample Size and Sample Methods

Adults without physical disabilities

A convenience sample of 24 adults participated in the study. This number was determined based on the study performed by Kalagher (2015). Kalagher (2015) assessed twenty-five adults in the same Function Judgment Task and was able to find significant differences in the participants' responses when object properties varied. Twenty-four participants were recruited in this study order to counterbalance participant's first condition. Participants in this study needed to complete the screening task to ensure that they were able to understand instructions and provide a "yes" or "no" response (the screening task will be described in the procedures section). Adults were recruited from the University of Alberta through posters and word of mouth. Recruitment strategies were directed at undergraduate and graduate students. No incentive was offered. Inclusion criteria included adults with no physical or cognitive disabilities. Exclusion criteria included adults who had experience using teleoperation systems or that had uncorrected vision or hearing impairments.

Typically developing children

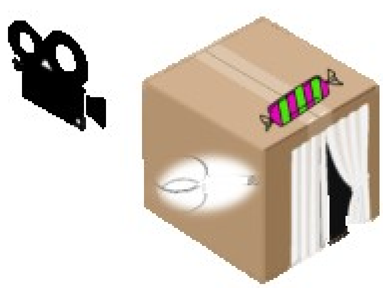
A convenience sample of ten 5 year old children was recruited. Klatzky, Lederman, & Manikinen (2005) performed a study using similar methods and tasks without a robot and attained significant results with 10 children (five 4 year olds and five 5 year olds). Recruitment strategies included email blasts to University of Alberta students and faculty, newsletters and posters. A parent of each participant was present during the entire session and they were asked to make sure their child felt safe and comfortable, but not to prompt the child.

Children with no diagnosis of cognitive or physical disorder were recruited. Previous studies found that children over the age of 4 years are able to make appropriate tool selections based on haptic exploration to complete tasks and perform appropriate EPs to extract object properties (Klatzky, Lederman, & Manikinen, 2005). By age 5 children are able to understand the basic skills needed to manipulate a switch controlled robot (Poletz, Encarnacao, Adams, & Cook, 2010; Encarnacao, et al., 2014) which has similar cognitive demands to the robots proposed for this study (i.e. cause and effect, inhibition, laterality and sequencing). Children in this study needed to complete the screening task to ensure that they were able to understand instructions and provide a "yes" or "no" response (described in the procedures section). Exclusion criteria included children who had uncorrected visual or hearing impairments or that had used a teleoperation system or participated in similar studies in the past.

Environment

The following table describes the two environments that were used during each condition.

Table 4-1 No Tech and Haptic Feedback Environment Description

No Tech Environment	*Haptic Feedback Environment*
A box with openings on opposite sides was used. One opening was covered so that participants placed their hands inside without being able to see the objects that were inside (Figure 4.1) The other opening allowed the researcher to put the different tools inside.	An interface robot and an environment robot were used (Figure 4.2) A panel was used to block the participant's view of the environment during the tasks.
A camera was placed facing the inside of the box to capture the participant's EPs.	A camera was placed on the environment side of the teleoperation system facing the end effector of the robot.
 Figure 4.1 No Tech Environment	 Figure 4.2 Haptic Feedback Environment

Procedures

Screening Task

In order to determine if participants met inclusion criteria they completed four trials that aimed to elicit either "yes" or "no" responses. These trials were based on the warm up trials developed by Kalagher (2015) and established if participants were able to follow instructions and respond to “yes” or “no” questions.

In the first two trials, the participant was told that the researcher’s friend wants a drink of water. For these trials, the researcher showed the participant a spoon and a cardboard ring and asked if the friend can drink water out of each of the objects. The participant answered either “yes” or “no” for each trial.

In the next two trials, the participant was told that the researcher’s friend would like to color a picture. The researcher showed the participant either a rectangular piece of plastic or a crayon. If the participant was able to answer “yes” or “no” correctly, they continued on to perform the tasks proposed for this research. If they were not able to answer all questions, they could not participate in the study. All participants answered the four questions correctly, and participated in the study.

Practice Phase

All participants were given the opportunity to freely explore the tools from the Transport Subtask and the Mixing Subtask using the haptic feedback condition. Adults practiced using the system before performing the task for the first time regardless of their assigned condition, whereas children practiced using the system right before doing the task in the haptic feedback condition. Children participated in the practice phase right before they performed the task in the haptic condition in order for them to more easily recall the robot’s functions and sensory feedback.

This phase was designed to allow participants to learn what objects felt like through the system using both haptic and visual information. It was expected that once participants knew what objects felt like, they would be able to recognize the object through memory (Kalagher, 2013; Klatzky & Lederman, 2003). This phase was also designed to show participants how perform manipulation with the system and how much force to apply on to the interface. As presented in Chapter 2, recognition requires previous knowledge of an object (Klatzky & Lederman, 2003). Adding the practice phase in this study was different from the previous studies (Klatzky, Lederman, & Manikinen, 2005; Kalagher, 2015), however it was needed since the current study was designed to determine if objects can be recognized through the robotic teleoperation system, not if they can be identified without previous knowledge of them.

Participants were given three out of five of the tools for each subtask and shown how they could use the system to "feel the objects". Participants were allowed to ask questions and use the system freely to explore the objects for a maximum of 5 minutes.

Function Judgment Task

Participants performed both subtasks (Mixing and Transport) of the Function Judgement Task, first in their randomly assigned condition (no tech, or haptic feedback) and then a second time in the other condition. The Mixing Subtask always preceded the Transport Subtask, as in Kalagher (2015). The order in which the target objects and the tools were presented within each subtask was randomized. The procedures for each subtask are presented in Table 4-2 and Table 4-3. Unless participants indicated that they needed a break, the tasks were performed one after the other.

A five point rating scale, based on De Neys, Lubin, & Houde (2014), was printed on a sheet of paper to be used as a confidence scale. Five smileys were used to represent different levels of the scale that range from "really not sure" to "totally sure" (see Figure 4.3: Five point Confidence Scale)

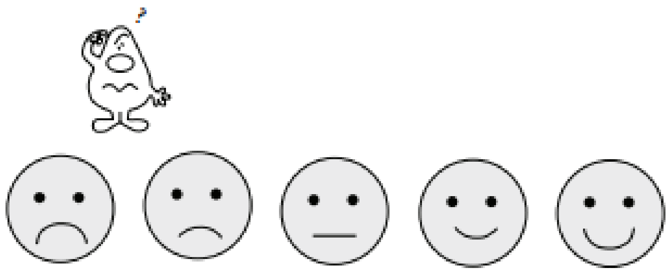


Figure 4.3: Five point Confidence Scale

Before starting the study, the participants were familiarized with the scale; the researcher presented the scale, explained each point and asked the participant to re-explain the scale to determine understanding. The confidence scale was included in this study to determine if participants were able to recognize the limitations imposed by the robotic teleoperation system or their understanding of the task.

Table 4-2 Mixing Subtask Procedures

No Tech Condition	**Haptic Feedback Condition**
The order in which the containers and tools were presented was randomized before the participant's arrival.	
I placed either the container filled with gravel or the container filled with sugar in front of the participant on top of the box.	I placed either the container filled with gravel or the container filled with sugar in front of the participant on top of the interface robot.
While pointing at the target object, I told the participant that her friend wanted to make a cake (for the sugar) or a mud pie (for the gravel), and that she needed help finding a stick to mix the sugar (or gravel).	

I placed a stick, one at a time inside the box. Participants put their hands through the curtain and felt the stick.	I placed a stick, one at a time, on the environment side. The participant held the interface robot. I moved the environment robot's effector until it was touching the stick. I then informed the participant that the robot was touching the stick. The participant moved the robot freely to examine the rigidity of the stick.
Afterwards they were asked, "Do you think your friend can use this?" and provided a "Yes" or "No" response.	
Next, they were asked to say how confident they felt about their answer by selecting a point on a scale (Figure 4.3).	

Table 4-3 Transport Subtask Procedures

No Tech Condition	**Haptic Feedback Condition**
I placed either the large candy or small candy in front of the participant on top of the box.	I placed the candy on top of the interface robot.
While pointing at the target object, I told the participant that his friend wanted to fill a bowl with candy and needs a spoon to carry it in.	

I placed a spoon, one at a time, inside the box and ask the participant to feel it using their hands.	I placed the spoons, one at a time, on the environment side and asked the participant to feel it using the robot. The end effector was placed in the center of the spoon. Participants used the interface robot to feel the different sides of the spoon.
The participants felt the spoons for a maximum of 10 seconds. Afterwards they were asked, “Do you think your friend can use this?” and provided a “Yes” or “No” response.	
Next, they were asked to determine how confident they felt about their answer by selecting a point on the scale (Figure 4.3).	

Data Collection

The current study had three dependent variables: frequency of “yes” responses, types of EPs and confidence. Data collection methods for each dependent variable were as follows. The data analysis that was performed to answer each research question is presented in the results section.

4.1 Frequency of “yes” responses for each target object and tool

The purpose of the function judgement task was to determine if participants were able to make judgements about how well objects would function as tools according to the object properties they could detect. Participants were asked, “Do you think your friend can use this?” and provided a “Yes” or “No” response after they were presented with each tool. All participants were able to indicate “yes” or “no” using verbal responses. The participants’ answers were recorded on a scoring sheet. This data was initially recorded in Excel then transferred to Graph Pad in order to perform statistical analysis.

4.2 Types of EP's and the frequency with which they occurred

The EP coding was done from video recordings based on the methods used by Kalagher (2015). Whenever a participant produced any of the EPs found by Lederman & Klatzky (1987) they were recorded in a scoring sheet

A research assistant watched each video segment with each tool completely once, noted the start and end times of each trial and then watched the segment again. While watching the segment for the second time the coder registered the number of times the participant performed each EP. The coder also documented any other types of manipulation that could be considered exploratory. An EP was only counted once as long as the participant continued performing it without stopping or switching to a different EP. For example, if the participant ran the robot effector along the stick several times without stopping, it was counted as 1 Lateral Motion, however if the participant performed Lateral Motion, then switched to Pressure and returned to Lateral Motion, it was counted as 2 Lateral Motions and 1 Pressure.

I watched and coded 30% of the videos coded by the research assistant in order to determine inter-rater reliability. The coding was compared point by point. Agreement on the type and frequency of the EPs was high (90%).

4.3 Level of Confidence for each "yes/no" answer

Confidence in response was collected using the 5-point confidence scale described above after each "yes/no" answer was given. The confidence scale presented some difficulty for children who struggled understanding the concept of "confidence" or "how sure are you". Because of this difficulty, the question was changed to "Do you think this question was easy or difficult?" Children then selected the smiley that corresponded to their answer (the saddest smiley represented "very difficult," and the happiest smiley represented "very easy"). The level indicated by the adults and children was recorded on a score sheet.

4.2 Results

Each section addresses one of the research questions and ends with a summary of key results. When data were found to be normally distributed, a paired t test was conducted for comparisons between two groups. For comparison between three or more groups, a repeated measures one-way ANOVA with the Greenhouse-Geisser correction was conducted. Non-parametric tests were run when it was found that the data was not normally distributed: for comparisons between two groups the Wilcoxon matched-pairs test was conducted, and for comparisons between three or more groups, Friedman's Test was conducted. The data for frequency of "yes" responses and EPs was measured on an interval scale while the data for confidence was measured on an ordinal scale. Preliminary analysis testing for order effects revealed that there was no significant effect for the order in which participants performed the haptic and no tech conditions, (p values > 0.1290), therefore the data were collapsed across each condition.

Haptic Exploration with Hands

The first research question was, *"Can participants indicate if spoons with varied bowl sizes can transport a piece of candy, and if sticks of varied rigidity can mix a substance, through haptic exploration using their hands?"*

Figure 4-4 and 4-5 show the mean frequency and standard deviation of "yes" responses obtained from adults and children in the no tech condition.

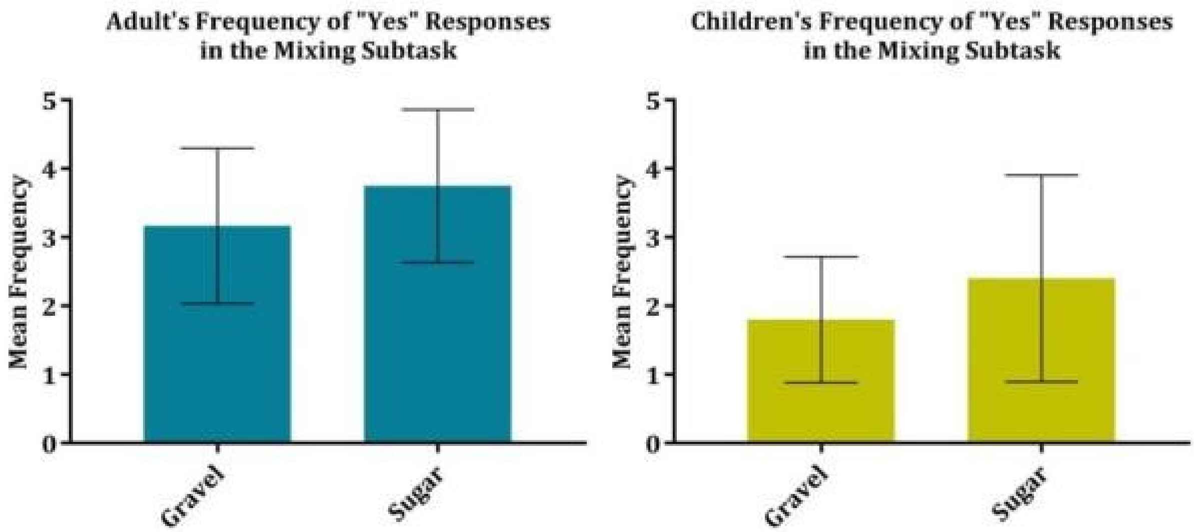


Figure 4.4 Participant's Mean Frequency of "Yes" Responses in the No Tech Condition for the Mixing Subtask by Target Objects

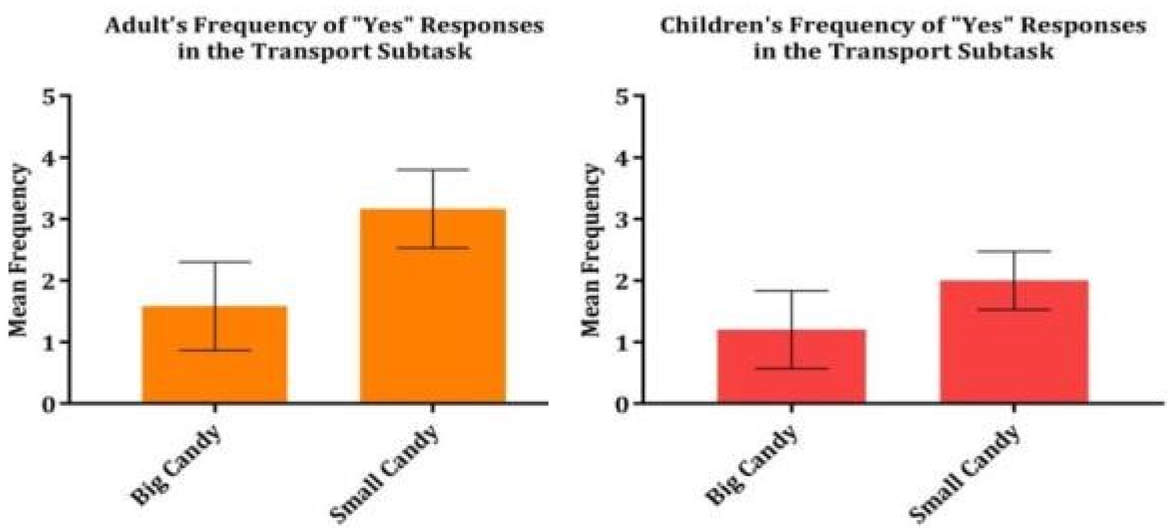


Figure 4.5 Participant's Mean Frequency of "Yes" Responses in the No Tech Condition for the Transport Subtask by Target Objects

The following results were found regarding variation of verbal response as a function of target object:

- For adults, significant differences were found between target objects for the Mixing Subtask, W=93.00, p=0.0064, where adults answered "yes" more frequently to the sugar target object

(M=4.00, SD=1.022) than the gravel target object (M=3.167, SD=1.129). For the Transport Subtask, W=300, p<0.0001, adults answered "yes" more frequently to the small candy target (M=3.254, SD=0.7133) than the big candy target (M=1.583, SD=0.6370).

- For children, significant differences were found between target objects for the Mixing Subtask, t=3.135, p=0.0106, where children answered "yes" more frequently to the sugar target (M=3.091, SD=1.446) than the gravel target (M=1.909, SD=0.9439). For the Transport Subtask, t=2.449, p=0.0106, they answered "yes" more frequently to the small candy target (M=2, SD=0.4714) than the big candy target (M=1.2, SD=0.6325).

Figure 4.6, Figure 4.7, Figure 4.8 and Figure 4.9 display the proportion of "yes" responses for each tool. The *x*-axis in each panel represents the tools ordered by increasing rigidity (Figure 4.6 and Figure 4.7) or size (Figure 4.8 and Figure 4.9).

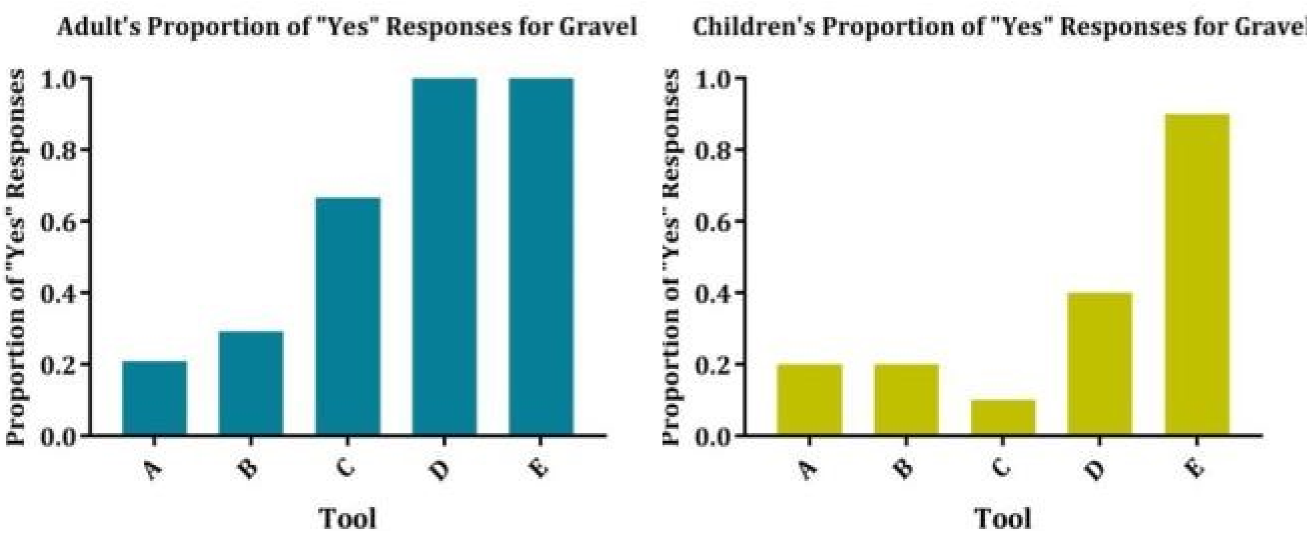


Figure 4.6 Proportion of "Yes" Responses for Gravel in the No Tech Condition by Tool Rigidity

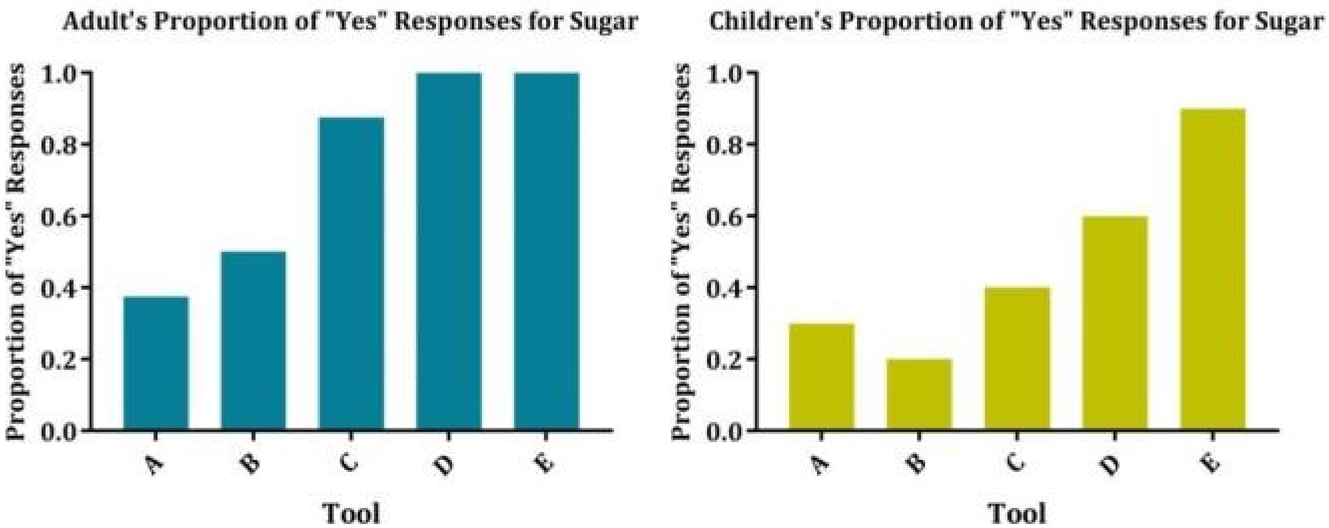


Figure 4.7 Proportion of "Yes" Responses for Sugar in the No Tech Condition by Tool Rigidity

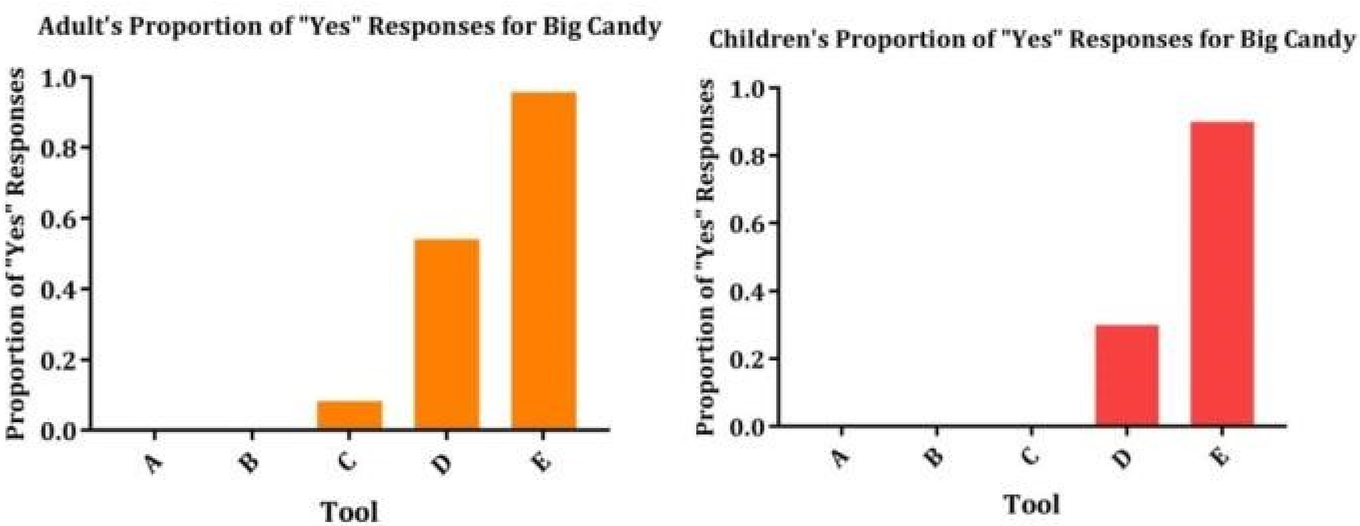


Figure 4.8 Proportion of "Yes" Responses for Big Candy in the No Tech Condition by Tool Size

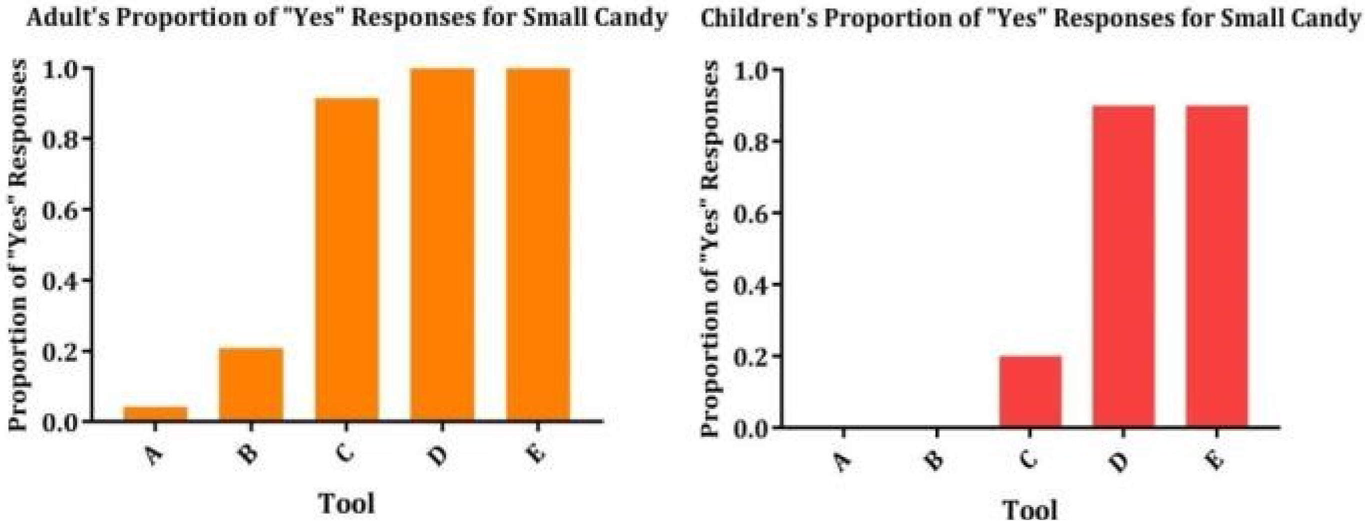


Figure 4.9 Proportion of "Yes" Responses for Small Candy in the No Tech Condition by Tool Size

Significant differences were found for all target objects and both age groups between tools, all p values<0.0028 (see **Table 4-4**), indicating that the proportion of "yes" responses varied between tools. Dunn's multiple comparison test was then conducted for each target object and results were as follows:

- For gravel, adults answered "yes" significantly more frequently to tools D and E, than to tools A and B. Children answered "yes" significantly more frequently to tool E, than tools A, B and C.
- For sugar, adults answered "yes" significantly more frequently to tools D and E, than A. Children answered "yes" significantly more frequently to tool E than B.
- For the big candy, adults answered "yes" significantly more frequently to tool E than A, B and C, and they also answered "yes" significantly more frequently to tool D than A and B. Children answered "yes" significantly more frequently to tool E than tools A, B and C.

- For the small candy, adults answered "yes" significantly more frequently to tools C, D and E than tools A and B. Children answered yes significantly more frequently to tools E and D than A and B.

Table 4-4 Results comparing differences between tools in the No Tech Condition

	Adults		Children	
	Friedman Test	Dunn's Multiple Comparison Test (Adjusted P value)	Friedman Test	Dunn's Multiple Comparison Test
Gravel	$p<0.0001$, Friedman statistic = 59.42	A vs. D, p=0.0001 A vs. E, p=0.0001 B vs. D, p=0.0010 B vs. E, p=0.0010	p=0.0003, Friedman statistic = 59.42	A vs. E, p=0.0468 B vs E, p=0.0468 C vs. E, p=0.0146
Sugar	$p<0.0001$ Friedman statistic = 47.14	A vs. D, p=0.0062 A vs .E, p=0.0062	p=0.0028, Friedman statistic = 16.17	B vs. E, p=0.0468
Big Candy	$p<0.0001$ Friedman statistic = 70.03	A vs. D, p=0.0301 A vs. E, p=0.0001	<0.0001, Friedman statistic = 29.14	A vs. E, p=0.0146 B vs. E, p=0.0146 C vs. E, p=0.0146
Small Candy	$p<0.0001$ Friedman statistic = 77.97	A vs. C, $p<0.0001$ A vs. D, $p<0.0001$ A vs. E, $p<0.0001$ B vs. C, p=0.0010 B vs. D, p=0.0001 B vs. E, p=0.0001	$p<0.0001$, Friedman statistic = 29.66	A vs. D, p=0.0146 A vs. E, p=0.0146 B vs. D, p=0.0146 B vs. E, p=0.0146

Summary

- ✓ Significant differences were found indicating that both age groups answered "yes" more frequently to the sugar target object for the Mixing Subtask and the small candy target object for the Transport Subtask.
- ✓ Significant differences were found between tools for all of the target objects and both age groups indicating that participants answered "yes" more frequently to more rigid or larger tools, but this increase was not consistent across the full range of tool rigidity and size.

EPs in the No Tech Condition

The second research question was, *"Do participants vary their EPs as a function of task (Mixing or Transport) when judging whether a tool is appropriate to complete the task through haptic exploration using their hands?"*

An EP that was not noted in the Klatzky, Lederman & Mankinen (2005) and Kalagher (2015) Function Judgment Task studies was observed and coded in the no tech condition in the current study. This EP was previously described by Lederman & Klatzky (1987) in a matching task. The EP was called Function Test, and when participants performed it, they executed movements related to the object and the task goal. The movements of interest in the current study were pretending to use the stick to stir something in the "air" or pretending to carry an imagined object with the spoon.

Figure 4.10 and 4.11 present median and the interquartile ranges with which EPs were performed during each of the subtasks.

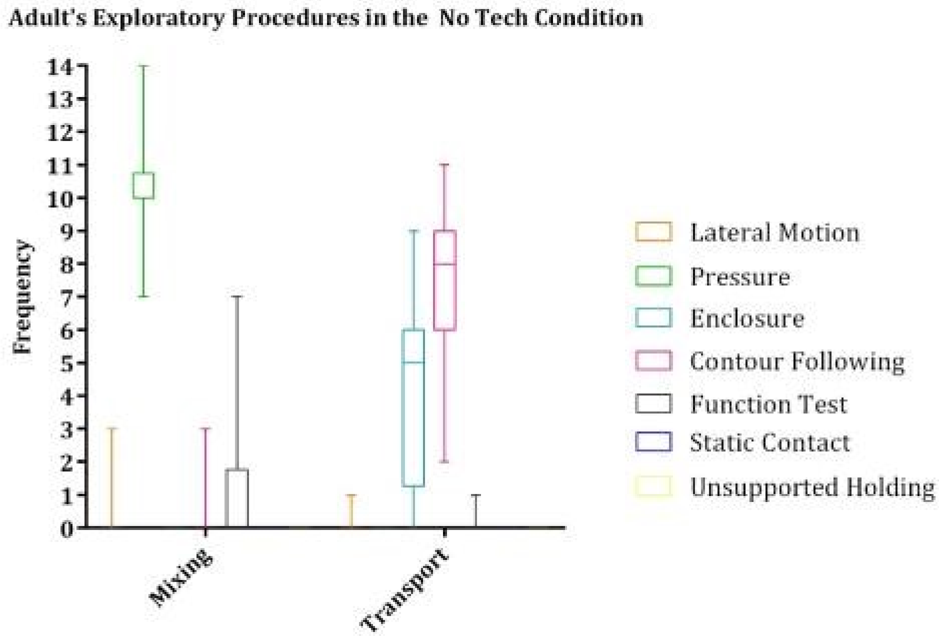


Figure 4.10 EPs in the no tech condition

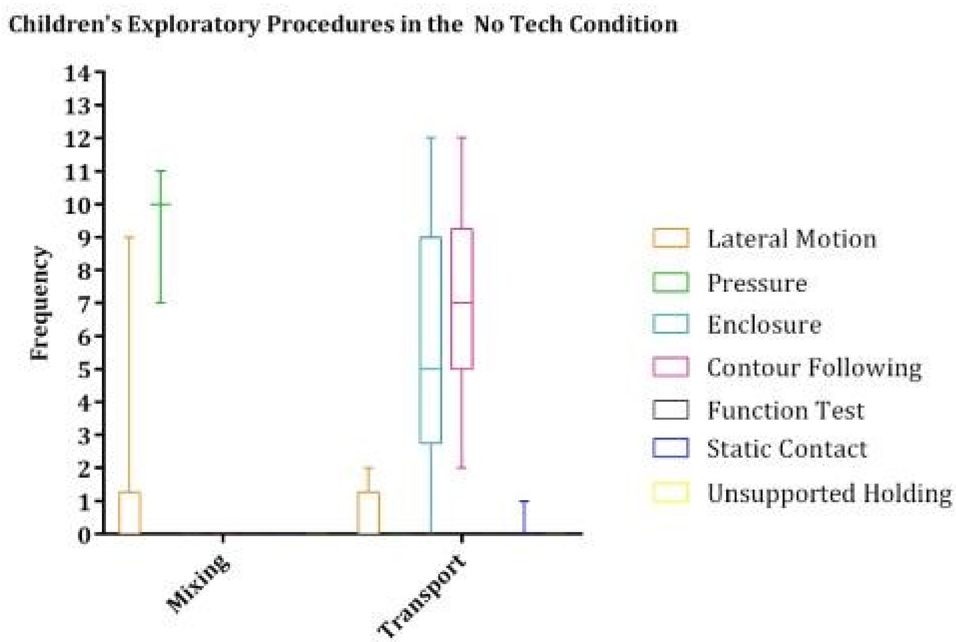


Figure 4.11 EPs in the no tech condition

In the Mixing Subtask, both age groups performed Pressure more frequently than any other EP (around ten times per trial, see Figure 4-10 and 4-11). In addition, adults performed Function Test more frequently than the remaining EPs (i.e. excluding Pressure), however children did not perform Function Test. In the Transport Subtask both age groups performed Contour Following and Enclosure more frequently than the other EPs. Pressure was only performed in the Mixing Subtask, while Contour Following and Enclosure were performed only in the Transport Subtask. The figures show that although other EPs were performed during the Mixing and Transport Sbutask only a very small number of participants performed them.

Summary

- ✓ The Function Test EP was observed and coded for adults, even though it had not been considered in previous studies that used the Function Judgement Task.
- ✓ Both age groups varied their EPs according to subtask as follows:
    - Pressure was performed more frequently in the Mixing Subtask than the Transport Subtask by both age groups.
    - Function Test was performed more frequently in the Mixing Subtask than the Transport Subtask only by adults.
    - Contour Following and Enclosure were performed more frequently in the Transport Subtask than the Mixing Subtask by both age groups.

Comparison of Haptic Exploration between Conditions: No Tech and Haptic

The third research question was, *"Do participants indicate if spoons with varied bowl sizes can transport a piece of candy, and if sticks of varied rigidity can mix a substance similarly to when they use a robotic teleoperation system compared to when they use their hands?"*

Figure 4-12, Figure 4-13, Figure 4.14 and Figure 4.15 show the mean frequency and standard deviation of adult's and children's "yes" responses in the no tech and haptic condition for each subtask.

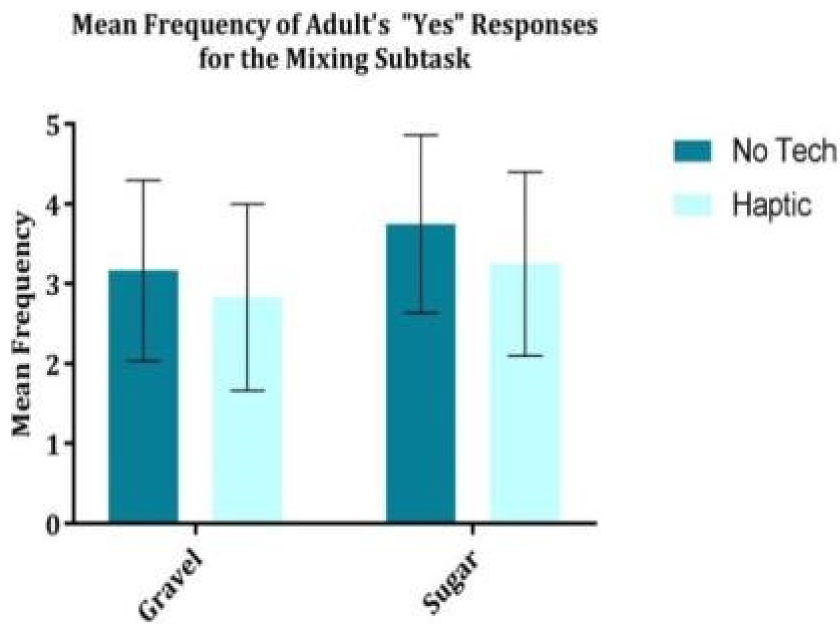


Figure 4.12 Adult's Responses in the No Tech and Haptic Conditions for the Mixing Subtask by Target Objects

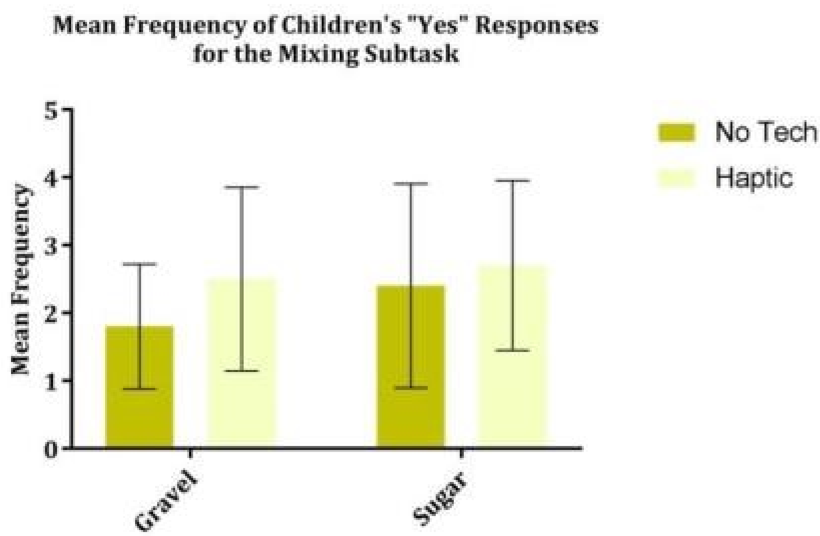


Figure 4.13 Children's Responses in the No Tech and Haptic Conditions for the Mixing Subtask by Target Objects

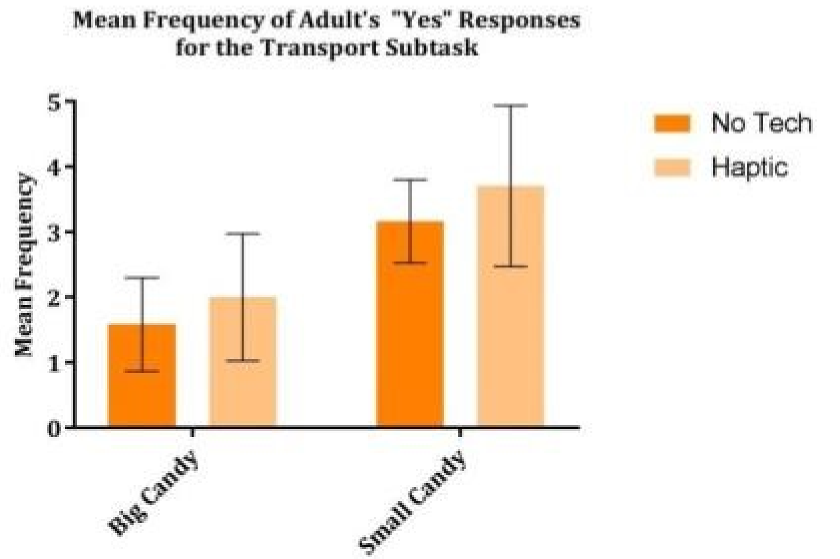


Figure 4.14 Adult's Responses in the No Tech and Haptic Conditions for the Transport Subtask by Target Objects

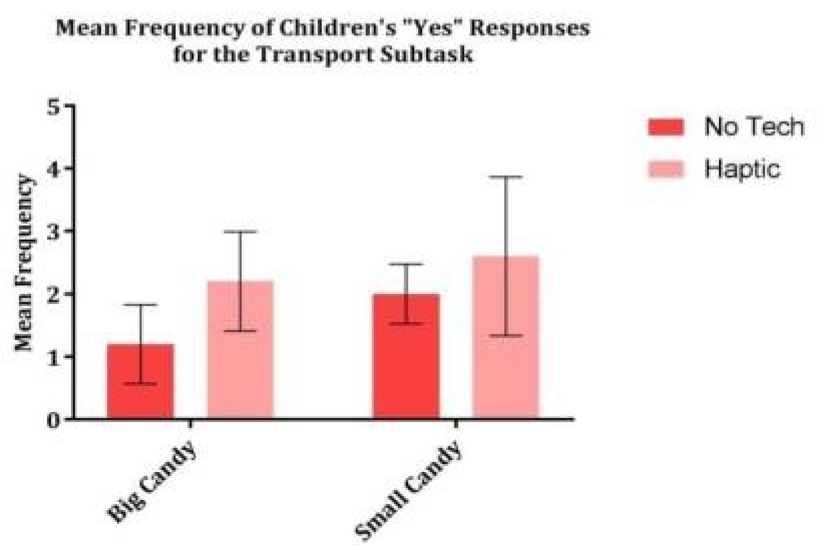


Figure 4.15 Children's Responses in the NoTech and Haptic Conditions for the Transport Subtask by Target Object

In order to determine if the frequency of "yes" responses varied between the two conditions (no tech and haptic) paired t tests or Wilcoxon matched-pairs tests were conducted (depending on whether or not data were normally distributed) for each target object and age group. Significant differences were found between the no tech and haptic condition for the big candy target object for adults, t=2.498, p=0.0201, and children, t=4.743, p=0.0011, where both age group answered "yes" more frequently in the haptic condition (adults M=2.125, SD=0.8999; children M=2.200, SD=0.7888) than the no tech condition (adults M=1.583, SD=0.7173; children M=1.200, SD=0.6325). No other significant differences were found.

Additionally, the same tests as in Haptic Exploration with Hands were performed. The following results were found regarding if participants varied their verbal responses as a function of target object in the haptic condition:

- For adults, results show that there was no significant difference between target objects for the Mixing Subtask. For the Transport Subtask, a significant difference was found, W=260, p<0.0001, where adults answered "yes" more frequently to the small candy target (M=3.708, SD=1.233), than the big candy target (M=2.125, SD=0.8999).
- For children, no significant differences were found between target objects in the haptic condition.

Figure 4.16, Figure 4.17, Figure 4.18 and Figure 4.19 show graphs presenting the proportion of "yes" responses for adults and for children for the tools.

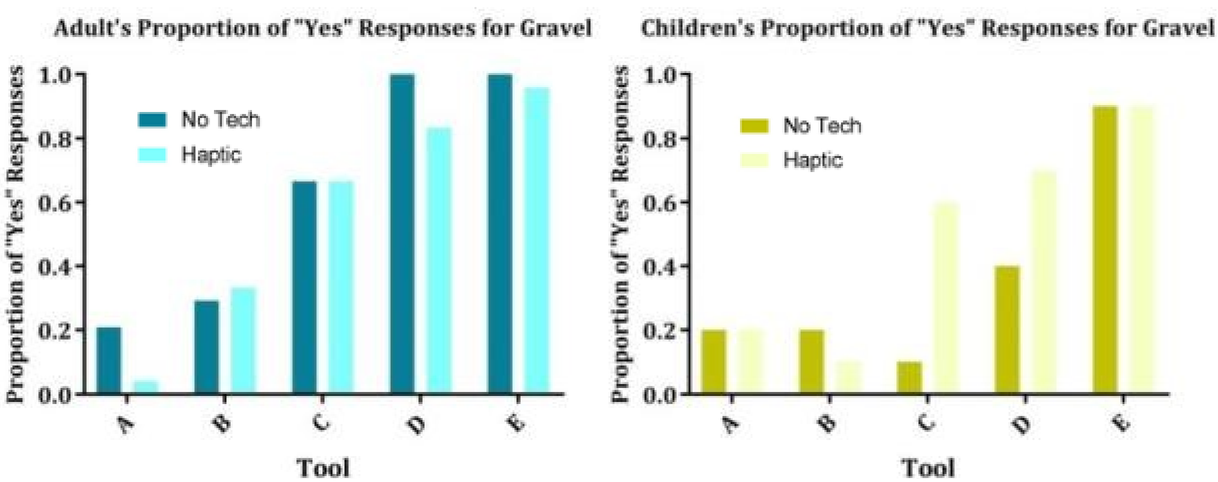


Figure 4.16 Proportion of Participant's Responses for Gravel in the No Tech and Haptic Condition by Tool Rigidity

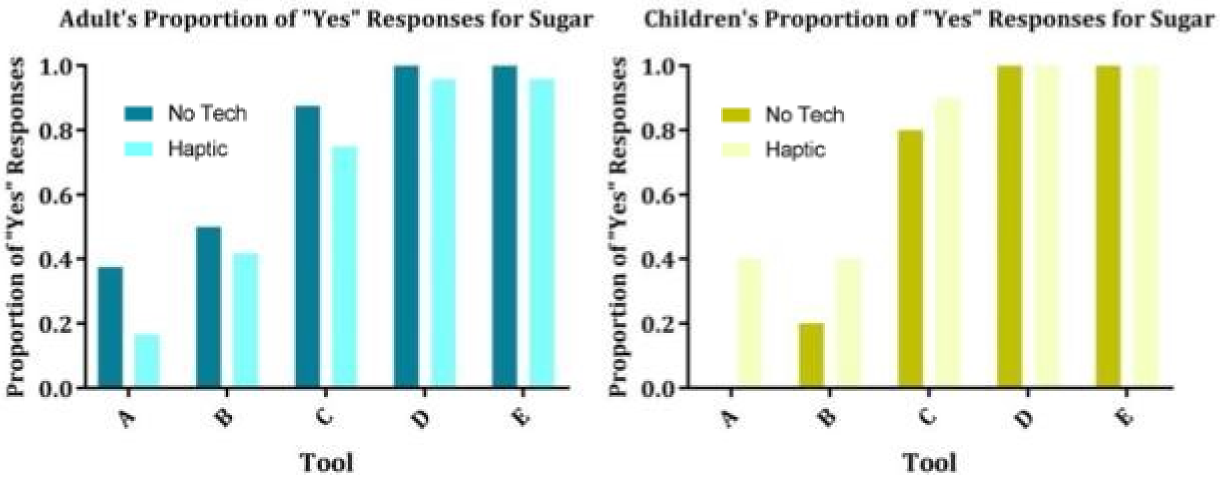


Figure 4.17 Proportion of Participant's Responses for Sugar in the No Tech and Haptic Condition by Tool Rigidity

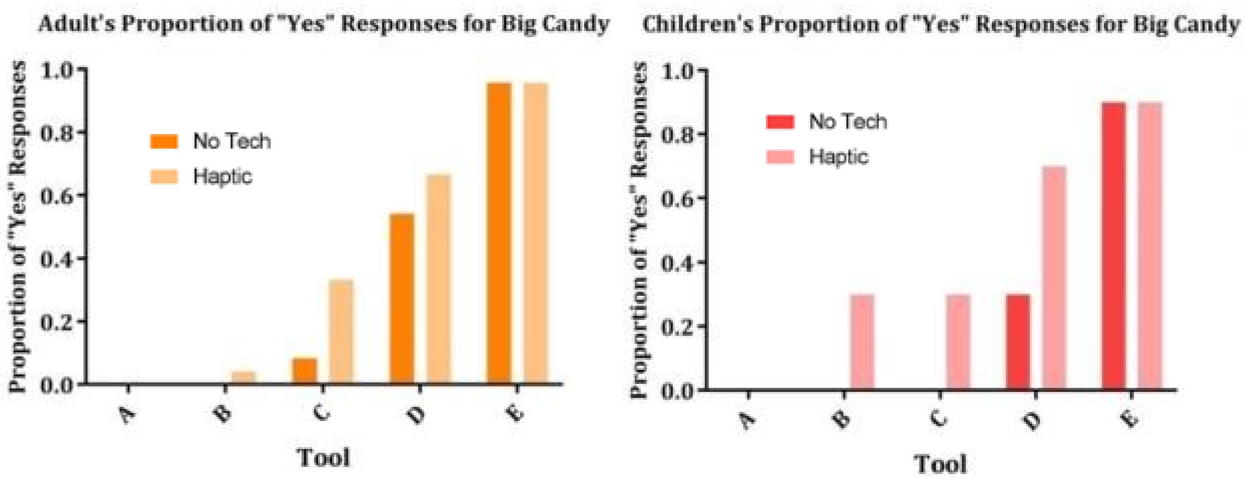


Figure 4.18 Proportion of Participant's Responses for the Big Candy in the No Tech and Haptic Condition by Tool Size

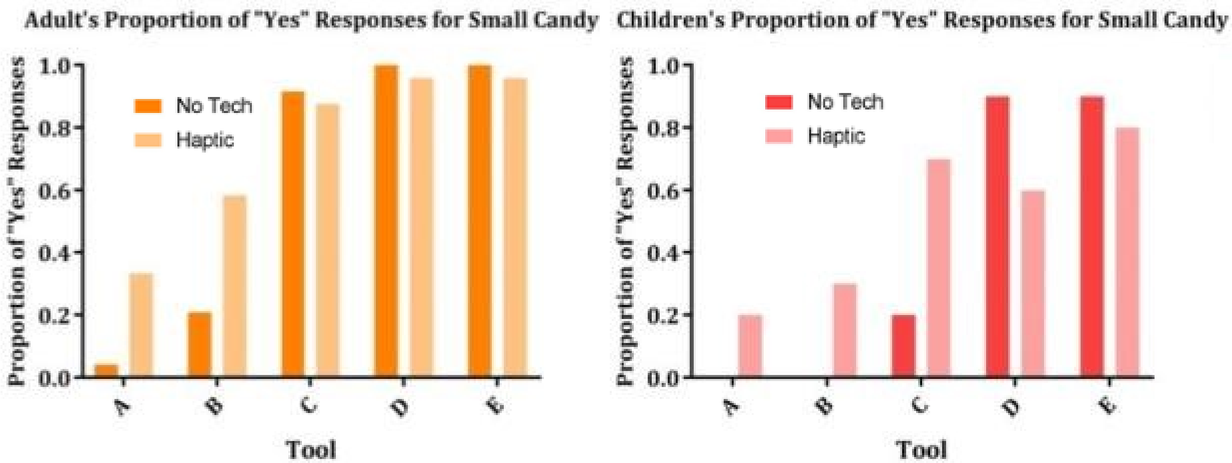


Figure 4.19 Proportion of Participant's Responses for the Small Candy in the No Tech and Haptic Condition by Tool Size

Significant differences were found for all target objects and both age groups between tools, all p values<0.0026 (see Table 4-5), indicating that "yes" responses differed between tools in the haptic condition. Dunn's multiple comparison test was then conducted for each target object in the haptic condition and results were as follows:

- For gravel, adults answered "yes" significantly more frequently to tools C, D and E, than A, and to tool E than B. Children answered "yes" significantly more frequently to tool E than B.
- For sugar, adults answered "yes" significantly more frequently to tools D and E, than tools A and B, and to tool C than tool A. No significant differences were found between tools for children.
- For the big candy, adults answered "yes" significantly more frequently to tools D and E than A, B, and they also answered "yes" significantly more frequently to tool E than to tool C. Children answered "yes" significantly more frequently to tool E than tool to tool A.
- For the small candy, adults answered "yes" significantly more frequently to tools C, D and E than tool A. Children answered yes significantly more frequently to tools E than A.

Table 4-5 Results comparing differences between tools in the No Tech Condition

	Adults		Children	
	Friedman Test	Dunn's Multiple Comparison Test (Adjusted p value)	Friedman Test	Dunn's Multiple Comparison Test (Adjusted p value)
Gravel	p<0.0001, Friedman statistic = 56.07	A vs. C, p=0.0062 A vs. D, p=0.0001 A vs. E, p<0.0001 B vs. E, p=0.0062	p=0.0005, Friedman statistic = 20	B vs E, p=0.0458
Sugar	p<0.0001 Friedman statistic = 47.14	A vs. C, p=0.0341 A vs. D,E, p=0.0003 B vs D, E, p=0.0341	p=0.0004, Friedman statistic = 20.63	NA
Big Candy	p<0.0001 Friedman statistic = 70.03	A vs. D, p=0.0026 A vs. E, p<0.0001 B vs. D, p=0.0062 B vs. E, p<0.0001 C vs. E, p=0.0062	P=0.0011, Friedman statistic = 18.29	A vs. E, p=0.0146
Small Candy	p<0.0001 Friedman statistic = 77.97	A vs. C, p=0.0301 A vs. D,E, p=0.0062	p=0.0026, Friedman statistic = 16.32	A vs. E, p=0.0468

The mean level of confidence selected by adults for each target object are shown in Figure 4.20 and Figure 4.21. It was difficult to obtain a reliable measure of children's confidence, therefore results for children are not reported in this study. Issues about measuring children's confidence will be covered in the discussion section.

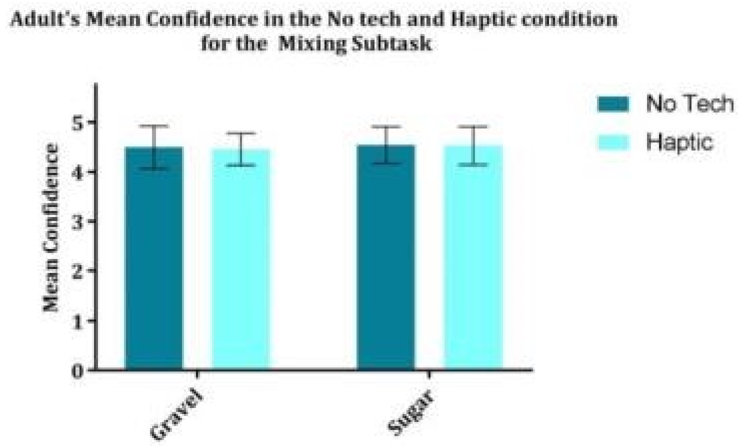


Figure 4.20 Adult's Mean Confidence in the No Tech and Haptic Conditions for the Mixing Subtask

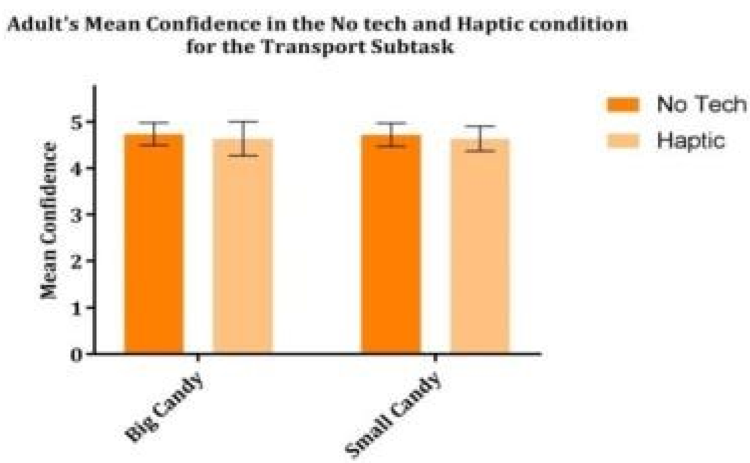


Figure 4.21 Adult's Mean Confidence in the No Tech and Haptic Conditions for the Transport Subtask

In order to determine if adult's mean confidence in each subtask and each condition varied, Friedman's test was performed and a significant difference was found between groups, $p<0.0001$. Sidak's multiple comparison test revealed that adults were more confident in the Transport Subtask than the Mixing Subtask in both conditions (see table 4-6) No significant differences were found in confidence between conditions.

Table 4-6 Results Comparing Confidence

Dunn's Multiple Comparison Test		
	Rank sum diff	Adjusted P value
No Tech Mixing vs. No Tech Transport	-37.00	p=0.0207
Haptic Mixing vs. Haptic Transport	-48	p=0.0009

Summary

- ✓ To recap, the results of the target and tools tests in the haptic condition were as follows:
    - o Adults and children did not vary their "yes" responses for the targets in the Mixing Subtask. For the Transport Subtask, adults answered "yes" significantly more frequently to the small candy target object than the big candy target object, however children did not vary their responses.
    - o Significant differences were found between tools for all of the target objects (with the exception of sugar for children), indicating that participants answered "yes" more frequently to more rigid or larger tools, however the increase was not consistent across all levels.
- ✓ The significant differences between conditions (no tech and haptic) were as follows:
    - o For the Mixing Subtask, no difference was found for the gravel or sugar target objects between conditions for both age groups.
    - o For the Transport Subtask, adults and children answered "yes" more frequently in the haptic condition than the no tech condition for the big candy target object.
- ✓ Adults' confidence did not vary between conditions (no tech and haptic), however their confidence was higher for the Transport Subtask than the Mixing Subtask in both conditions.

Comparison of EPs between Conditions: No Tech and Haptic

The fourth research question was, *"Do participants vary their EPs as a function of task (Mixing or Transport) when they use a robotic teleoperation system compared to when they use their hands?"*

An additional EP that had not previously been mentioned in the literature was observed in the haptic condition. It consisted of participants tapping a point of the tool with the robot's effector and then moving in a straight line until they tapped the opposing point of the object; it seemed that participants were doing this to determine the distance between the two points. This movement was coded only when participants were intentionally trying to move to the direct opposite point across the full diameter of the object. For purposes of this thesis, this EP was called "Tapping".

Figures 4-23 and 4-24 present the median and the interquartile ranges with which EPs were performed by adults and children for each subtask during the haptic and no tech conditions.

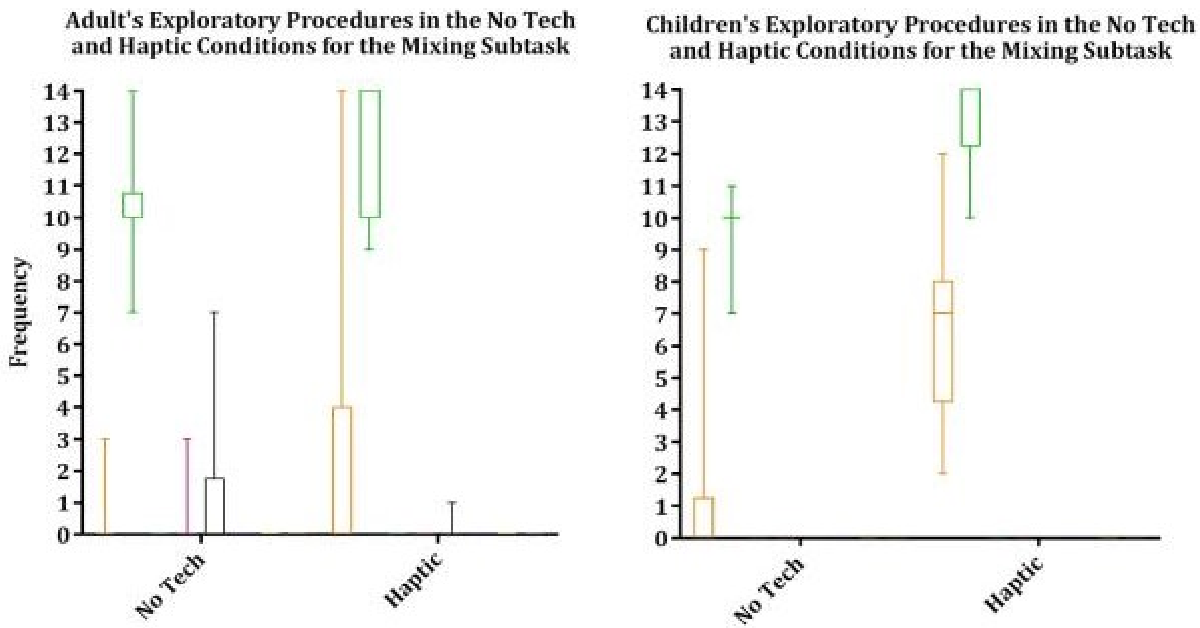


Figure 4.22 EPs in the no tech and haptic condition for the Mixing Subtask

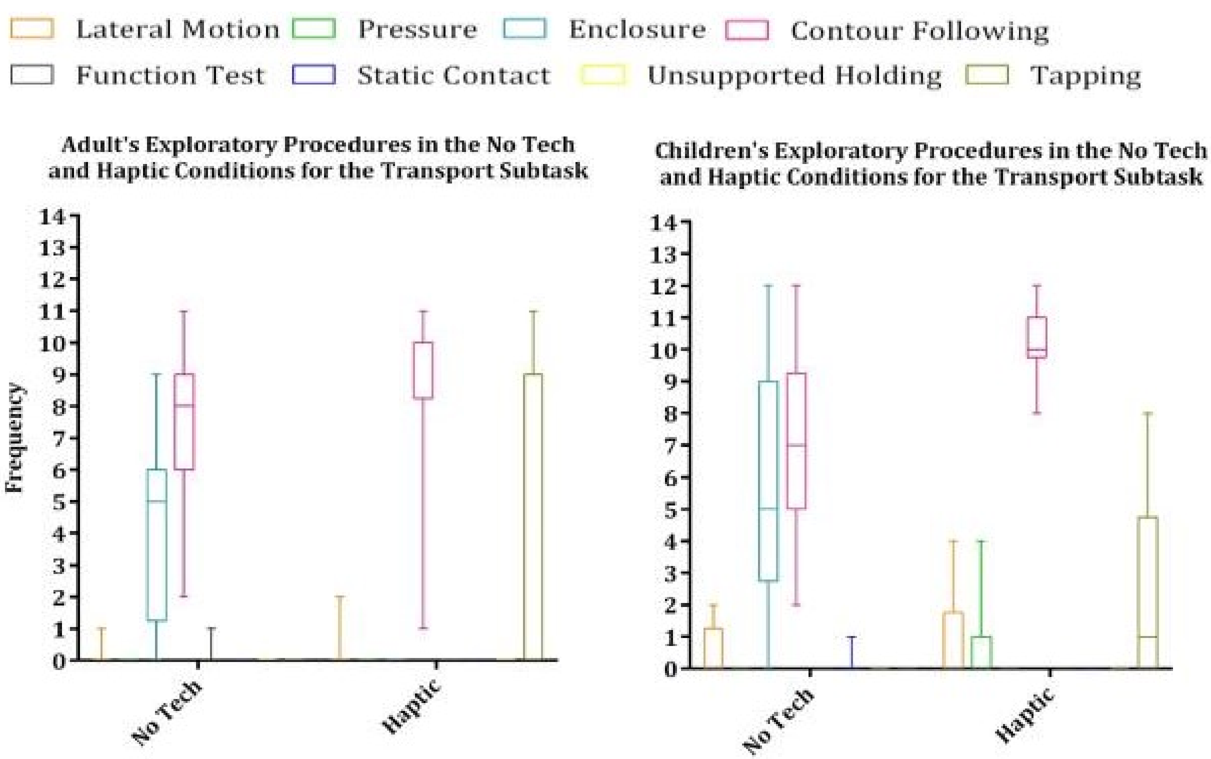


Figure 4.23 EPs in the no tech and haptic condition for the Transport Subtask

To determine if there was a difference between conditions Wilcoxon matched-pairs tests were conducted for the EPs that were coded for each subtask.

- Adults in the Mixing Subtask: Lateral Motion was performed significantly more frequently in the haptic condition ($M=2.708$, $SD=4.319$) than the no tech condition ($M=0.333$, $SD=0.8165$), $W=70$, $p=0.0012$. Pressure was performed more frequently in the haptic condition ($M=11.54$, $SD=1.933$) than the no tech condition ($M=10.29$, $SD=1.233$), $W=98$, $p=0.0091$. Function Test was performed more frequently in the no tech condition ($M=1.042$, $SD=1.805$) than the haptic condition ($M=0.4167$, $SD=0.2041$), $W=-50$, $P=0.0098$. No other significant differences were found.
- Children in the Mixing Subtask: Lateral Motion was performed significantly more frequently in the haptic condition ($M=6.5$, $SD=2.991$) than the no tech condition ($M=1.2$, $SD=2.84$), $W=49$, $p=0.0098$. Children also performed pressure significantly more frequently in the haptic condition ($M=13.10$, $SD=1.663$) than the no tech condition ($M=9.8$, $SD=1.033$), $W=36$, $P=0.0078$. No other significant differences were found.
- Adults in the Transport Subtask: Enclosure was performed more frequently in the no tech condition ($M=4.333$, $SD=3.046$) than the haptic condition ($M=0$), $W=-190$, $p<0.0001$. Contour Following was performed more frequently in the haptic condition ($M=8.542$, $SD=2.828$) than the no tech condition ($M=7.5$, $SD=2.377$), $W=91$, $p=0.0901$. Tapping was performed more frequently in the haptic condition ($M=3.958$, $SD=4.696$) than the no tech condition ($M=0$), $W=66$, $p=0.001$. No other significant differences were found.
- Children in the Transport Subtask: Enclosure was performed more frequently in the no tech condition ($M=5.6$, $SD=3.777$) than the haptic condition ($M=0$), $W=-45$, $p=0.0039$. Contour Following was performed more frequently in the haptic condition ($M=10.10$, $SD=1.101$) than

the no tech condition ($M=7.2$, $SD=2.936$), $W=30$, $p=0.0391$. Tapping was performed more frequently in the haptic condition ($M=2.3$, $SD=3.020$) than the no tech condition ($M=0$), $W=21$, $p=0.0313$.

Summary

- ✓ A new EP (Tapping) that had not previously been mentioned in literature was observed in the haptic condition.
- ✓ In the Mixing Subtask, both age groups performed more Lateral Motion and Pressure EPs in the haptic condition than the no tech condition.
- ✓ In the Transport Subtask, both age groups performed more Tapping in the haptic condition than in no tech condition and more Enclosure in the no tech condition than the haptic condition. Children performed more Contour Following in the haptic condition than the no tech condition.

4.3 Discussion

Haptic Exploration with Hands

Can participants indicate if spoons with varied bowl sizes can transport a piece of candy, and if sticks of varied rigidity can mix a substance, through haptic exploration using their hands?

Results in the current study indicate that when the participants used their hands to perform haptic exploration they were able to judge which sticks were rigid enough to stir the sugar and gravel, and which spoons were large enough to transport the candies. Results from the current study were the same as the results in the Kalagher (2015) and Klatzky, Lederman, & Manikinen (2005) studies, indicating that participants did make judgements based on the tool's properties.

The frequency of "yes" responses in each subtask indicated whether participants considered that a tool was adequate for the task as a function of tool size or rigidity. It was found in previous studies (Kalagher, 2015; Klatzky, Lederman, & Manikinen, 2005) that participants could indicate if the tools function to complete the tasks because: 1) for the Mixing Subtask, “yes” responses were more frequent with the sugar target object than the gravel target object and increased as the tools become more rigid and 2) for the Transport Subtask, “yes” responses were more frequent for the small candy target object than the big candy target object and increased as the tools become larger. Both of the conditions described by Kalagher (2015) and Klatzky, Lederman, & Manikinen (2005) were met by participants in the current study.

The difference in the frequency of “yes” responses between target objects was greater for the Transport Subtask than for the Mixing Subtask. This was true for both adults and children. Kalagher (2015) found similar results to the current study, but Klatzky, Lederman, & Manikinen, (2005) only found a significant difference between target objects for the Transport Subtask and not for the Mixing Subtask when they performed the task with children. For the Transport Subtask there is a correct and incorrect answer for each tool, where either the candy fits in the spoon or it does not. So, for participants it must have been more obvious that the big candy would have a smaller range of tools that would work to transport it than the small candy. However, for the Mixing Subtask the the tool’s function could be more subjective and contingent on each participant’s experience. How vigorously participants imagined mixing the gravel or sugar could reflect on their judgment of whether the tool would function to complete the task.

Comparing participants’ frequency of “yes” responses between target objects provided overall information about participant’s understanding of the task demands. Results from the current study confirmed that participants understood that the gravel target object required more rigid tools than the sugar target object, and the big candy target object required larger spoons than the small candy target object, therefore a wider variety of tools would function to complete the task with the sugar and small candy target objects. However, data obtained about target objects alone cannot confirm that participants were in fact understanding the feasibility of each tool, only by analyzing participants' "yes" responses by tools is it possible to confirm that participant's knowledge acquired through haptic exploration about the perceptual properties of the tools influenced their judgment and if their responses were sensitive to the the constraints on each tool's function.

Visual analysis of all target objects and age groups (Figure 4.6, Figure 4.7, Figure 4.8 and Figure 4.9) and statistical rsults indicated that as tools became more rigid for the Mixing Subtask and larger for the Transport Subtask, the frequency of "yes" responses increased.These results were expected according to Kalagher (2015) and Klatzky, Lederman, & Manikinen, (2005). The results confirm that participants were making judgments based on the information they were acquiring through haptic exploration with their hands and their responses were sensitive to the tool's properties. Also, for each target object, for a certain tool in the set the frequency of "yes" responses increased drastically. The tool with the drastic increase of "yes" responses usually corresponded to the least rigid or smallest tool that participants considered would function to complete each subtask succesfully, therefore all the tools that were more rigid or larger would receive "yes" answers.

Visual analysis indicates that adults answered "yes" more frequently than children to less rigid or smaller tools. These results were similar to those found by Kalagher (2015) where adults also answered "yes" more frequently than children for the sugar and gravel target objects, however they differ from the Kalagher (2015) study, where adults answered "yes" less frequently than children for the small candy target object. It appears that in the current study, children were overall more conservative with their answers. As mentioned previously, the Mixing Subtask answers may be more subjective and reflective of each participant's experience. Adults may have had experience showing that with more effort it would be possible to mix the sugar and gravel with less rigid tools. In the Kalagher (2015) study it is possible that the shape of the big candy, which was a long stick candy, influenced adult's and children's judgment and could explain why results differ from the current study.

EPs in the No Tech Condition

Do participants vary their EPs as a function of task (mixing or transportation) when judging whether a tool is appropriate to complete the task through haptic exploration using their hands?

Results from the current study indicate that participants performed the optimum EPs for each Subtask, confirming that they did in fact vary their EPs as a function of subtask when they used their hands. Based on Klatzky, Lederman, & Manikinen (2005) and Kalagher (2015) rigidity was determined to be the relevant perceptual dimension for the Mixing Subtask, therefore it was expected that participants would execute more of the Pressure EP. In the transport task, size was determined to be the relevant perceptual dimension, therefore, it was expected that participants would execute the Contour Following EP.

The Function Test EP was first named and described by Lederman & Klatzky (1987). According to these authors the Function Test EP is concerned with extracting information related to function pertaining to an object's structure. In the current study Function Test was performed primarily by adults during the Mixing Subtask when they used their hands for haptic exploration, where they would pretend to mix a substance in the air using the sticks. Children, on the other hand, did not use the Function Test EP for either of the subtasks. The Function Test EP was also not coded or observed in the studies that the current study is based on (Klatzky, Lederman, & Manikinen, 2005; Kalagher, 2015). It is possible that because there are more optimum EP's to extract information about tool rigidity or tool size, participants in the previous studies did not need to perform the Function Test EP. Also, it is important to note that Function Test was observed in the current study primarily before or after adults performed the Pressure EP in the Mixing Subtask, it was never observed in the absence of Pressure. This shows that although Function Test may be used to extract information about an objects' functions, it is not the optimum EP to determine tools' rigidity.

Other EPs were performed by participants during the Mixing and Transport Subtask, however analysis of ranges in Figure 4.10 and 4.11 indicated that these other EPs were never performed in the absense of Pressure for the Mixing Subtask or Contour Following for the Transport Subtask. During the Transport Subtask, the mean frequency for Enclosure was high, however some participants performed the entire Transport Subtask without executing the Enclosure EP at all. When participants did execute Enclosure it was usually when they were presented with the smallest and largest tools, however when they were presented with the middle-sized tools, Contour Following was almost always the primary EP executed. This observation could indicate that Enclosure may provide more general information about an object's size which may be sufficient information for the two tools with extreme sizes, however Contour Following may be necessary to perceive more sensitive information about size.

In the current study, when 5 year old children used their hands they demonstrated adult-like EPs. Children where able to use haptic exploration to extract perceptual information related to each subtask's demands in order to assess each tool's function. This supports previous research that found that 5 year old children have an appropriate repertoire of EPs across the two properties that were tested (rigidity and size) (Kalagher, 2015).

Comparison of Haptic Exploration between Conditions: No Tech and Haptic

Do participants indicate if spoons with varied bowl sizes can transport a piece of candy, and if sticks of varied rigidity can mix a substance similarly to when they use a robotic teleoperation system compared to when they use their hands?

Results from participants in the current study indicate that when they used the robotic teleoperation system they were able to indicate if spoons and sticks of different sizes and rigidity could complete each subtask. Results also showed that adults did not consider the robotic teleoperation system to pose an additional challenge to haptic exploration for the current tasks compared to when they used their hands.

In the haptic condition, adults' and children's "yes" responses between target objects were not significantly different from each other, with the exception of adults for the Transport Subtask. As stated previously in this chapter, the frequency of "yes" responses compared between target objects is relevant to participant's understanding of the task demands. It is possible that when participants used the robotic teleoperation system they needed to focus on the novelty of extracting information about the tool's properties through the system and may not have considered the task demands for each target object as thorougly as when they used their hands. When responses were compared between tools it is actually possible to determine if responses are sensitive to the constraints on each tool's function. Participants' responses did seem to be sensitive to tool's functions. Visual analysis of results in the haptic condition (see Figure 4.16, Figure 4.17, Figure 4.18 and Figure 4.19) indicate that as tools became more rigid and larger "yes" frequency increased for both age groups. Overall, although the participants understanding of task demands was not optimum, it appears that the robotic teleoperation system did allow them to extract information about object properties and make appropriate judgments about the tools.

When objects are felt through the robotic teleoperation system the haptic feedback that is received about rigidity may be slightly distorted depending on the amount of force that is applied to the interface. When too much force is applied, the sticks may feel less rigid than they really are. Likewise, when too little force is applied, the sticks may feel more rigid than they really are. This is especially problematic for sticks that are close in rigidity because they may feel equally rigid when too much or not enough force is applied. This could explain why fewer significant differences were found between tools overall and no differences were found for the tool for the sugar target when children performed the task in the haptic condition. They may have had difficulty differentiating the sticks that were close in rigidity, resulting in less variability in their responses.

When it came to determining size using the robotic teleoperation system, the spoons may have felt slightly bigger than they really were regardless of the force that was applied to the interface due to programing limitations (there is some flex in the effector so that it goes past the position where it should stop). The distortion regarding size increased when too much force was applied at the interface. The size distortion probably affected participants' responses when both adults and children answered "yes" more frequently in the haptic condition than the no tech condition for the big candy (Figure 4.18). The flex in the system might not have affected participant's answers between conditions for the small candy because it fit in a wider range of tools than the big candy did.

It was determined that confidence was not a reliable measure for children. It seemed that it was difficult for children to understand the question about how sure they were of their answer. The question oftentimes had to be changed to "do you think this was easy or hard" and some children answered things like "10000%" or "infinity" even when children were not accurate in their responses about tools. Previous studies have shown that 5 year old children have difficulty recognizing when they make mistakes during cognitive demanding tasks with robots, but these skills do improve in 6 and 7 year old children (Adams, Alvarez, Becerra, Gomez, & Castellanos, In Press). Also, understanding personal confidence when answering a question requires a level of metacognition, which is still developing in 5 year olds (Schneider, 2008; Paulus, Tsales, Proust, & Sodian, 2014; Hiller & Weber, 2013).

For adults without disabilities, confidence was compared between the no tech and haptic conditions and no difference was found. This indicates that adults felt just as confident when they performed haptic exploration to judge a tool's function with the robotic teleoperation system as they did when they used their hands. This result was not expected for adults without disabilities, since they had previous experience performing haptic exploration with their hands and the robot was a novel way to explore object properties. Results from adults without disabilities may suggest that participants do not recognize a greater challenge using the robotic teleoperation system for haptic exploration. Also, these results may indicate that participants consider that the feedback that they receive from the system to be as reliable as the feedback they receive when they use their hands during the Function Judgement Task.

For adults without disabilities a significant difference in confidence was actually found between subtasks (Mixing and Transport) in the no tech and haptic conditions. When participants performed the Transport Subtask they felt more confident about their answers than when they performed the Mixing Subtask. This may further support the idea mentioned previously that the demands for the Transport Subtask were clearer for participants than the Mixing Subtask (i.e. there is a clear correct and incorrect answer for the Transport Subtask but not for the Mixing Subtask).

Comparison of EPs between Conditions: No Tech and Haptic

Do participants vary their EPs as a function of task (mixing or transportation) when they use a robotic teleoperation system compared to when they use their hands?

As in the no tech condition, for the most part participants performed the optimum EPs for each subtask more frequently than any other EP in the haptic condition (where the optimum EPs were defined by Klatzky, Lederman, & Manikinen (2005) and Kalagher (2015), as described above in Chapter 2), confirming that they did vary their EPs as a function of task. Adults without disabilities and children performed Pressure most frequently for the Mixing Subtask. Adults without disabilities and children performed Contour Following most frequently.

The Tapping EP was observed only in the haptic condition. When participants used their hands to perform haptic exploration, the Tapping EP was not necessary because they were able to use Enclosure or Contour Following, which are appropriate EPs to determine size. However, when participants used the robotic system, they were no longer able to execute the Enclosure EP. The Tapping EP seemed to allow participants to acquire information about the distance between two points on an object and then use this information to determine the object's size. In the current study, Tapping was only observed during the Transport Subtask when participants needed to measure the size of a circular spoon. The Tapping EP was used to identify the approximate diameter of the spoon. It is possible that the Tapping EP has not been previously described because as far as we know, few studies have looked at how participants perform EPs when using a haptic robotic system with a pointer like effector to determine tool use.

Tapping not only allowed participants to make accurate function judgments for the spoons, but it may have been as efficient as Contour Following. When participants performed Contour Following they needed to move the effector around the complete circumference of the spoon, however when they executed Tapping they needed to only move the effector across the spoon between two opposite points. In addition, participants tended to apply sustained force to the interface when they performed Contour Following, which could distort the perception of the size of the spoons. However, when participants performed Tapping they appeared to use less force, therefore creating less distortion and likely were able to make more accurate function judgments.

The total amount of all EPs performed by participants was greater in the haptic condition than the no tech condition for both adults without disabilities and children. In particular, adults without disabilities and children performed more Lateral Motion and Pressure EPs for the Mixing Subtask in the haptic condition when compared to when they used their hands. This could be due to participants needing to perform the EPs multiple times in order to extract the required information. By performing more EPs, people are able to obtain better information about object properties (Kalagher, 2015); therefore, by repeating the EPs multiple times, participants may have been able to compensate for the robotic teleoperation system's limitations (i.e. rigidity distortions caused by applying too much or too little force on the effector).

In the Transport Subtask, adults and children performed more Enclosure EPs when they used their hands than in the haptic condition and more Tapping and Contour Following EPs in the haptic condition compared to when they used their hands. This was expected given that Enclosure is not possible when using the robotic teleoperation system and Tapping seems to be an efficient alternative to acquire information about the spoons' size. It is interesting to note however, that although Tapping replaced Enclosure, it was still second in frequency to Contour Following. Also, the range observed in Figure 4-23 and 4-24 suggests that it was possible for participants to get by without using Tapping but not without using Contour Following.

CHAPTER 5: STUDY 2, ADULT WITH DISABILITIES

5.1 Methods

Design

An exploratory case study was conducted where one participant performed a modified version of the Function Judgment Task based on Kalagher (2015) and Klatzky, Lederman and Manikinen (2005). The participant performed the task in two conditions: no tech and haptic.

Sample Size and Sample Methods

Adult with Disabilities

An exploratory case study was performed with one participant with physical disability. Inclusion criteria included an adult with physical disabilities that affected his/her ability to freely manipulate objects with hands. Adults needed to be able to grasp the robot's end effector and have sufficient range of motion to control the effector in a 12 cm x 12 cm workspace. Adults needed to be able to follow two-step instructions and have no cognitive disabilities. The screening task was aimed to ensure that participants were able to understand instructions and provide a "yes" or "no" response (the screening task will be described in the procedures section). Exclusion criteria included adults who had uncorrected visual or hearing impairments.

A 40-year-old woman with cerebral palsy categorized as spastic quadriplegic was recruited. She was right handed with limited range of motion in upper limbs and classified in MACS IV where she could manipulate a limited selection of objects but required continuous assistance and adapted equipment. She was unable to voluntarily grasp objects; however, she was able to hold on to them once they were placed in her hand. She uses a communication device to communicate, however she was able to indicate a verbal "yes" or "no". She attended college and there was no evidence of cognitive impairments. The participant's mother was present throughout the entire session.

Environment

The same set up and task materials from Study 1 were used as much as possible. Table 5-1 describes the two environments that were used during each condition for the adult with disabilities.

Table 5-1 Environment used with the participant with Disabilities

No Tech Environment	*Haptic Feedback Environment*
The participant was blindfolded while exploring the tools. Her wheelchair was placed against a flat surface where tools could be placed in a comfortable workspace.	An interface robot and an environment robot were used as in Study 1. A panel was used to block the participant's view of the environment during the tasks. The participant used a lateral grasp of the robot end effector between her ring and middle finger. A rubber band was placed on the distal part of her fingers in order for her to more easily hold on to the robot's effector.
A camera was placed in front of the participant with a view of her hands.	A camera was placed on the environment side of the teleoperation system facing the end effector of the robot.

Procedures

Screening Task

The procedures for Study 2 were the same as Study 1 for the screening task

Practice

As in Study 1, the adult with disabilities was given the opportunity to freely explore the tools from the Transport Subtask and the Mixing Subtask using the haptic feedback feature. When the adult with disabilities started performing the Function Judgment Task with her hands, her mother suggested that she be given the opportunity to stir the gravel and the sugar using her finger in order to acquire information about the demands of each target object in the Mixing Subtask. Her mother explained that the participant had probably never stirred gravel or sugar. The participant indicated through nonverbal communication that she wished to explore the target objects, and she was assisted to place her finger in the gravel and the sugar target objects to explore them.

Function Judgment Task

The procedures used in the Function Judgment Task were the same as in Study 1. The participant performed both subtasks (Mixing and Transport) of the Function Judgement Task, first in the haptic condition then in the no tech condition.

The participant also used the five point rating scale, based on De Neys, Lubin, & Houde (2014), as participants in Study 1. She used a verbal response to indicate her selection as I pointed at the different smileys (see Figure 4.3: Five point Confidence Scale).

Data Collection

The same three dependent variables as in Study 1 were measured: frequency of "yes" responses, types of EPs and confidence. Data collection methods were also the same as in Study 1, however, only descriptive statistics were used for analysis.

5.2 Results

Haptic Exploration with Hands

For this participant, research question one was, *"Can the participant indicate if spoons with varied bowl sizes can transport a piece of candy, and if sticks of varied rigidity can mix a substance, through haptic exploration using her hands?"*

Figure 5-1 and Figure 5-2 show the frequency with which the participant with disabilities responded "yes" to each target object. In order to compare the adult with disabilities' results and the adults without disabilities' results, black lines are placed over or on the bars to represent adults without disabilities' mean frequency of "yes" responses. Visual analysis shows that, for the Mixing Subtask, the participant with disabilities answered "yes" more frequently to the sugar target and, for the Transport Subtask, she answered "yes" more frequently for the small candy target object.

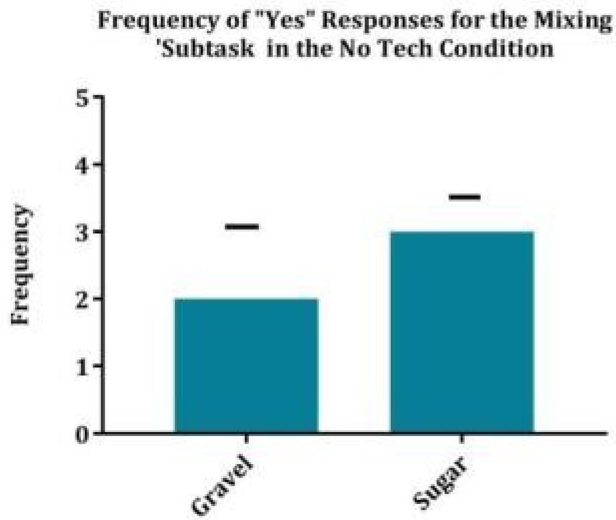


Figure 5-1 The Participant with Disabilities' Frequency of "Yes" Responses for the Mixing Subtask in the No Tech Condition by Target Objects. The black lines placed over the bar represent adults without disabilities' mean frequency of "yes"

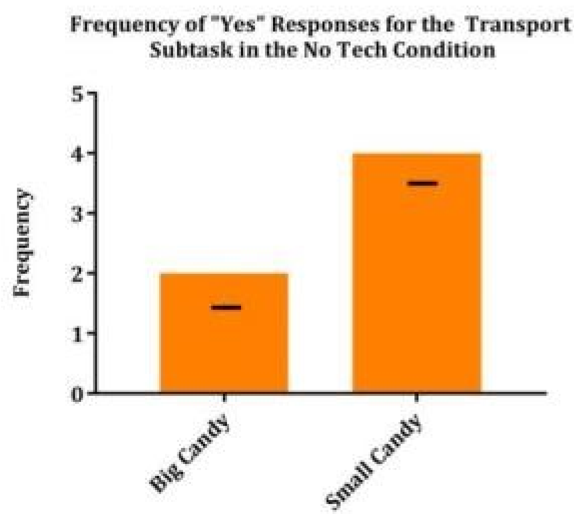


Figure 5-2 The Participant with Disabilities' Frequency of "Yes" Responses for the Transport Subtask in the No Tech Condition by Target Objects. The black lines placed over the bar represent adults without disabilities' mean frequency of "yes" responses

Table 5-2 presents the adult with disabilities' answers for each tool when she performed the task with each target object in the no tech condition. Visual analysis of the shaded area (participant's "yes" answers) shows no clear pattern.

Table 5-2 Participant with disabilities' answers for each Tool in the No Tech Condition

Responses Given for Each Tool and Target Object in No Tech Condition					
	A	**B**	**C**	**D**	**E**
Gravel	No	No	No	Yes	Yes
Sugar	Yes	Yes	Yes	No	No
Big Candy	No	No	Yes	Yes	No
Small Candy	No	Yes	Yes	Yes	Yes

EPs in the No Tech Condition

Research question two was, *Does the participant vary her EPs as a function of task (Mixing or Transport) when judging whether a tool is appropriate to complete the task through haptic exploration using her hands?*

Figure 5-3 shows the frequency with which the participant with disabilities performed each EP in the no tech condition for the Mixing and Transport Subtask.

For the Mixing Subtask, the participant with disabilities only performed Pressure. For the Transport Subtask, the participant with disabilities performed mostly Static Contact. She did this by placing her closed fist over the spoons, or holding on to the side of the spoon's cup that was placed in her hand. She also performed Static Contact when she placed one finger in the smallest spoon and Lateral Motion by running her finger along a certain side of the spoon. Enclosure was performed when the participant was able to hold the entire spoon in her hand.

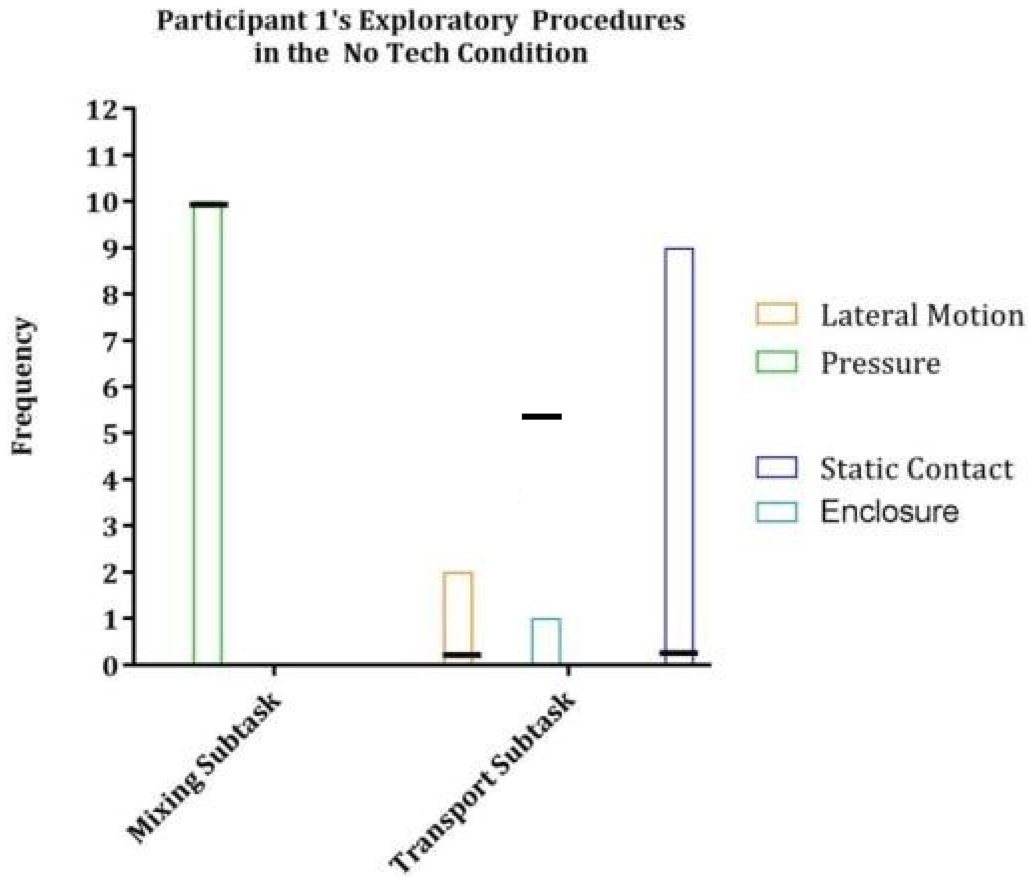


Figure 5-3 The Participant with Disabilities' EPs in the No Tech Condition for each Subtask.
The black lines over the bars represent adults without disabilities' median frequency of each EP.

Comparison of Haptic Exploration between Conditions: No Tech and Haptic

Research question three was, *"Does the participant indicate if spoons with varied bowl sizes can transport a piece of candy, and sticks of varied rigidity mix a substance similarly to when she uses a robotic teleoperation system compared to when she uses her hands?"*

Figure 5-4 and 5-5 show the participant with disabilities' frequency of "yes" responses for each target object in the Mixing and Transport tasks, respectively.

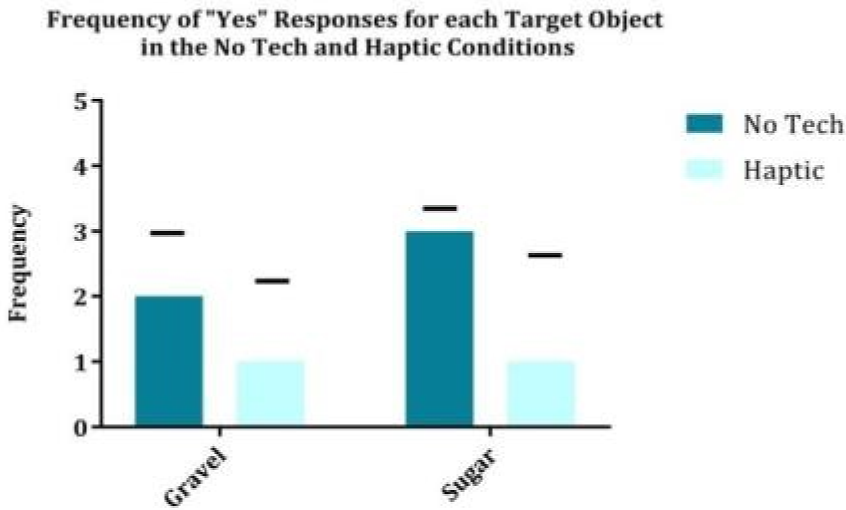


Figure 5-4 Frequency of "yes" responses for the Mixing Subtask in the No Tech and Haptic Conditions by Target Object. The black lines over the bars represent adults without disabilities' mean frequency of "yes" responses

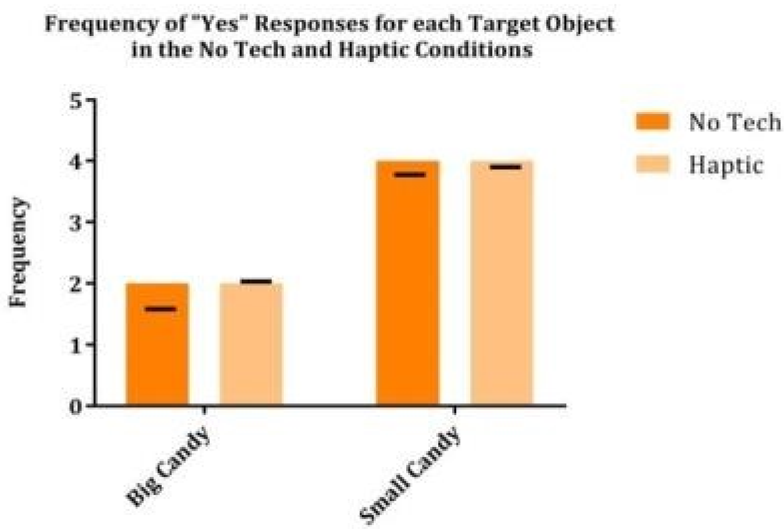


Figure 5-5 Frequency of "yes" responses for the Transport Subtask in the No Tech and Haptic Conditions by Target Object. The black lines over the bars represent adults without disabilities' mean frequency of "yes" responses

Table 5-3 presents the participant with disabilities' answers for each tool when she performed the task with each target object in the haptic condition.

Table 5-3 Participant with disabilities' answers for each Tool in the Haptic Condition

Responses Given for Each Tool and Target Object in Haptic Condition					
	A	**B**	**C**	**D**	**E**
Gravel	No	No	No	No	Yes
Sugar	No	No	No	No	Yes
Big Candy	No	No	No	Yes	Yes
Small Candy	No	Yes	Yes	Yes	Yes

Figure 5-6 and 5-7 show the participant with disabilities' mean confidence for each target object.

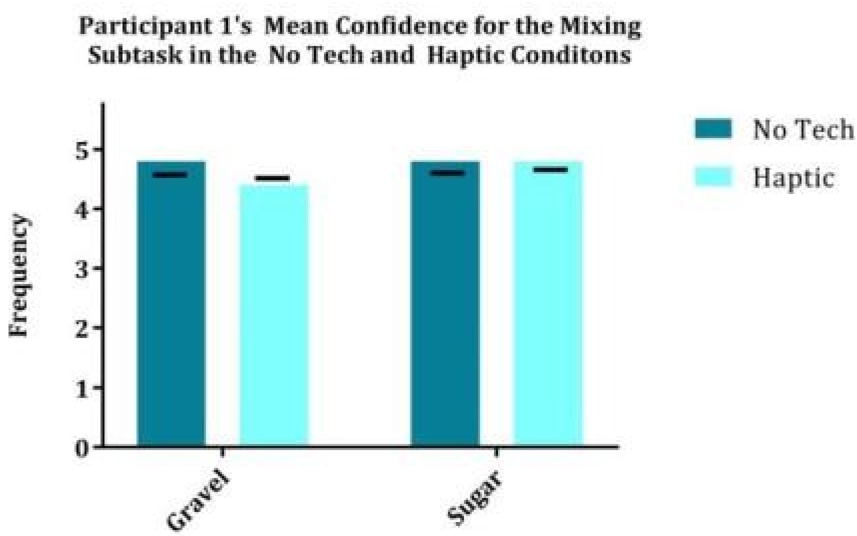


Figure 5-6 The Participant with Disabilities' Confidence for the Mixing Subtask in the No Tech and Haptic Conditions. The black dashes represent adults without disabilities' mean confidence

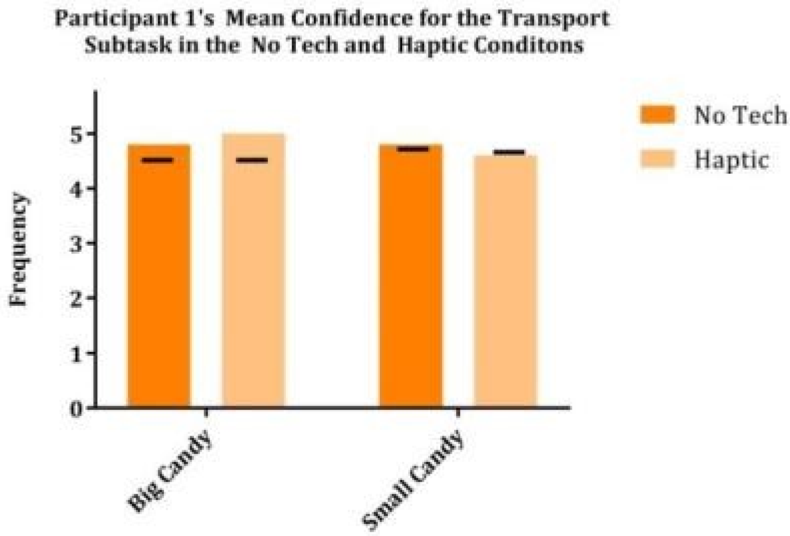


Figure 5-7 The Participant with Disabilities' Confidence for the Transport Subtask in the No Tech and Haptic Conditions. The black dashes represent adults without disabilities' mean confidence

Comparison of EPs between Conditions: No Tech and Haptic

The fourth research question was, *"Does the participant vary her EPs as a function of task (Mixing or Transport) when she uses a robotic teleoperation system compared to when she uses her hands?"*

Figure 5-8 shows the frequency with which the participant with disabilities performed each EP in the haptic condition for the mixing and Transport Subtask.

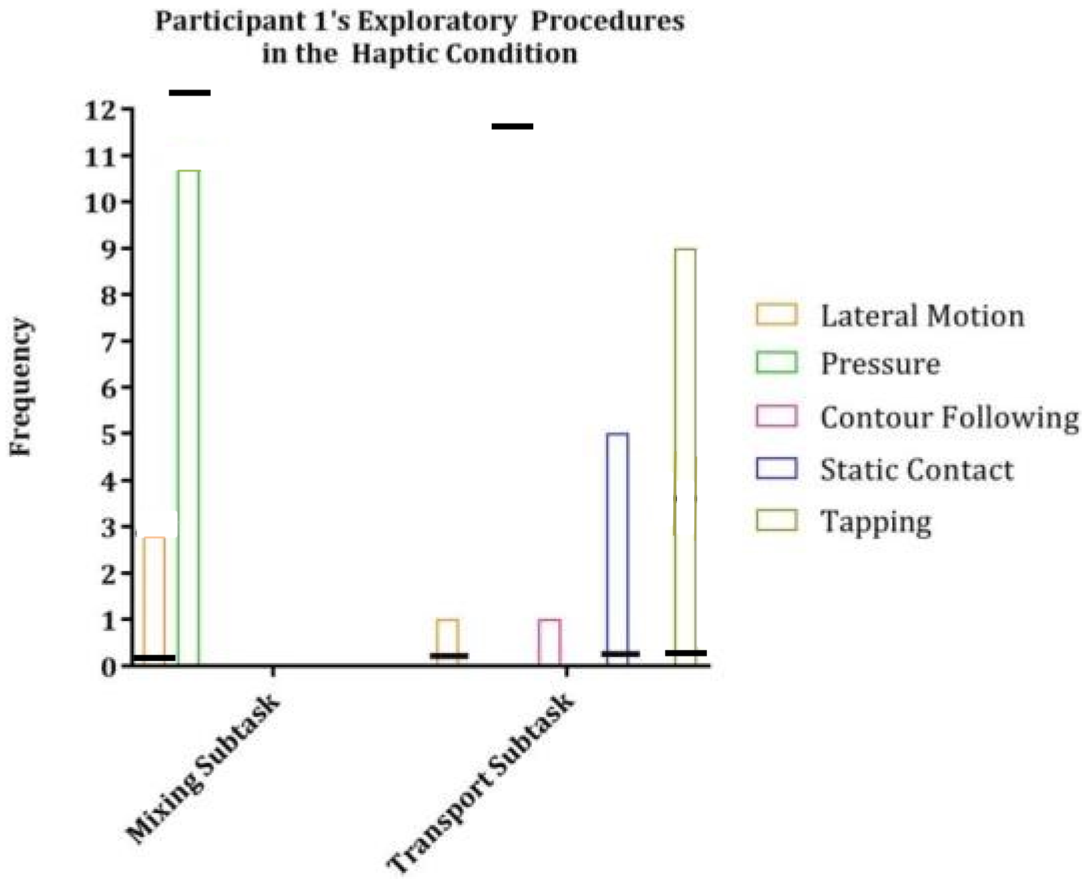


Figure 5-8 the participant with disabilities' EPs in the Haptic Condition for each Subtask. The black lines placed over the bar represent adults without disabilities' median frequency of each EP.

5.3 Discussion

Haptic Exploration with Hands

"Can the participant indicate if spoons with varied bowl sizes can transport a piece of candy, and if sticks of varied rigidity can mix a substance, through haptic exploration using her hands?"

Results from the adult with disabilities indicated that she understood each subtask's demands (i.e. the sugar and small candy target objects could be stirred and transported with a wider variety of tools than the gravel and big candy target objects, see Figures 5-1 and 5-2). However, when looking at her responses for tools, it did not appear that her responses were sensitive to tool's properties (i.e. no clear pattern indicating that “yes” responses were more frequent as tools became more rigid or larger, see Table 5-2). Therefore, it was not possible to confirm that the participant was acquiring knowledge through haptic exploration about the perceptual properties of the tools when she used her hands or if the knowledge she was acquiring was influencing her judgment about tool function. The participant probably required more information about each tool’s properties (rigidity or size) in order to make better judgments about each tool.

The participant with disabilities needed an opportunity to explore the target objects before making judgments about the tools. This additional step was added during her session because without the opportunity to explore the target objects, the participant might not have been able to determine how rigid sticks needed to be to stir the sugar and gravel. As was mentioned in the literature review, typically developing children will oftentimes experience haptic exploration through everyday playful activities (Parham & Fazio, 2008; Fenson & Schell, 1985), however when children have physical disabilities their play oftentimes is reduced and therefore miss out on opportunities for exploration (Pfeifer, Pacciulio, Santos, Santos, & Stagnitti, 2011; Fenson & Schell, 1985). The event described above further supports the idea that people with physical disabilities may oftentimes not have the opportunities to perform haptic exploration and therefore miss opportunities to learn about the world around them. In the participant’s case, she never had a chance to practice stirring gravel or sugar and therefore had difficulty determining how rigid sticks needed to be without first exploring and learning about the target objects.

For the Transport Subtask, although possibly useful, it was not so imperative for the participant with disabilities to explore the target objects beforehand. In fact, it was not possible for her to perform haptic exploration on the large candy target object because it required a large spherical grip that was difficult for her to do. Information about size can be acquired through visual exploration, unlike information about the sugar and gravel's thickness that could only be acquired through previous haptic exploration (Klatzky, Lederman, & Manikinen, 2005).

EPs in the No Tech Condition

Research question two was, *Does the participant vary her EPs as a function of task (Mixing or Transport) when judging whether a tool is appropriate to complete the task through haptic exploration using her hands?*

The adult with disabilities performed only the Pressure EP for the Mixing Subtask (see Figure 5-3), which is consistent with findings from adults without disabilities and children from Study 1, as well as previous studies (Klatzky, Lederman, & Manikinen, 2005; Kalagher, 2015). However, the participant did not perform the expected optimum EPs for the Transport Subtask (i.e. Contour Following or Enclosure) to determine size, when compared to adults without disabilities, children and previous studies (Klatzky, Lederman, & Manikinen, 2005; Kalagher, 2015). The participant performed static contact most frequently for the Transport Subtask. By doing so on one side of the spoon, it may have been possible for the participant to acquire information about size by feeling the spoon's curvature on that specific spot and could explain why she was able to identify the spoons that would function to transport the small candy (Figure 5-1). However, it does appear that the participant had difficulty identifying which tool would function to complete the task with the big candy, perhaps because she could not perform the optimum EP.

Comparison of Haptic Exploration between Conditions: No Tech and Haptic

Research question three was*, "Does the participant indicate if spoons with varied bowl sizes can transport a piece of candy, and sticks of varied rigidity mix a substance similarly to when she uses a robotic teleoperation system compared to when she uses her hands?"*

In the haptic condition, the adult with disabilities demonstrated similar results between target objects and tools to those found for adults without disabilities in Study 1, (i.e. no difference between the sugar and gravel targets, see Figure 5-4, and more "yes" responses for the small candy target than the big candy target, see Figure 5-5). The difficulty telling the difference for the gravel and sugar in the Mixing Subtask could be attributed to the participant having less experience with haptic exploration, due to her physical impairments. The information about size required for transporting candies could be determined through visual exploration, unlike information about the gravel and sugar's thickness that could only be determined through previous haptic exploration.

The participant with disabilities answered "yes" more frequently as tools became more rigid or larger for both subtasks in the haptic condition (Table 5-3), these results differ from when the participant used her hands where no clear pattern was found for her responses (Table 5-2). Although the participant with disabilities was able to execute some EPs when she used her hands, the information she was receiving was not sufficient for her to make accurate function judgments based on the object's properties that she could detect. When new actions become available, it is possible to learn about object's properties through haptic exploration (Gibson E. , 1988). The robotic teleoperation system allowed new actions to become available to the participant, which could explain why her performance improved when she used the robotic teleoperation system.

Visual analysis of the participant's confidence indicated that there were no differences in her responses between conditions. These results are consisted with findings from adults without disabilities in Study 1. Her results were expected given that the participant with disabilities likely had little experience performing haptic exploration with her hands as well as with the robotic teleoperation system

Comparison of EPs between Conditions: No Tech and Haptic

The fourth research question was, *"Does the participant vary her EPs as a function of task (Mixing or Transport) when she uses a robotic teleoperation system compared to when she uses her hands?"*

The participant with disabilities did vary her EPs as a function of task in the haptic condition. For the Mixing Subtask, the participant performed Pressure most frequently as in the no tech condition, which is consistent with adults from Study 1. However, for the transport subtask the adult with disabilities performed Tapping most frequently. This result differs from findings from the no tech condition, where she performed static contact most frequently, and differs from results of Study 1, where adults without disabilities performed contour following most frequently. For the participant with disabilities it was much easier to perform gross motor movements in her shoulder and elbow than fine motor movements with her fingers, therefore she could easily move the interface back and forth or side to side. It is possible that, for the Transport Subtask, the participant with disabilities did not execute Contour Following because the movement required for Tapping was easier for her to perform. Tapping only required her to move back and forth between two points on the spoon, unlike Contour Following, which required more complex movements of the shoulder hand system. The Tapping EP seemed to allow the participant to acquire information about size accurately and successfully complete the task.

When the participant with disabilities performed the task with her hands, she required more assistance than when she used the robotic system. When she used her hands for the Mixing Subtask, each stick needed to be pressed to the participant's hand while she explored the tool and then removed once she finished. With the robot system, after the end effector was placed between her fingers, the participant was able to explore more independently by initiating and ending exploration of multiple tools and whenever she felt necessary. Also, the robotic teleoperation system placed fewer motor demands on the participant allowing her to perform some EPs with fewer movements than when she used her hands.

CHAPTER 6: GENERAL DISCUSSION, IMPLICATIONS AND CONCLUSION

It seems that using a robotic teleoperation system posed minimal limitations to haptic exploration to participants without disabilities and the participant with disabilities in these tasks. In study 1, adults without disabilities and children were able to identify the tools that would function to complete both subtasks when they used the robot similar to when they used their hands. Meanwhile, study 2 was an exploratory study that demonstrated how using a robotic teleoperation system improved exploration for the adult with disabilities. The adult with disabilities seemed to be able to identify tools based on their properties more accurately when she used the robotic teleoperation system than when she used her hands for haptic exploration. However, further research is necessary with a larger sample size and a wider range of participants (i.e. different types of motor impairments and levels of functioning affecting their ability to manipulate objects) to understand how the haptic robotic teleoperation systems can influence haptic exploration in this population.

Overall, adults without disabilities, the adult with disabilities and children performed the optimum EP to determine tool’s rigidity and size when they used their hands and when they used the robotic teleoperation system. In the current study, participants were unable to visually explore the tools to determine their function and were restricted to only using haptic exploration. Participants were given implicit perceptual goals that required haptic exploration. These perceptual goals seemed to direct the type of manual and robotic manipulation performed by adults and children which resulted in participants performing the optimum EP for each given subtask more frequently than any other EP in both conditions. This confirms previous studies’ findings that haptic exploration plays a role in motor planning, serving to direct manipulation of objects when there is no vision (Klatzky & Lederman, 1999; Lederman & Klatzky, 1997; Klatzky, Lederman, & Manikinen, 2005).

Limitations

This study had several limitations. Only one adult with disabilities was recruited and no children with disabilities. With this sample, it is not possible to generalize about how other people with disabilities will perform with a haptic robotic system. In addition, with no data for children with physical disabilities it is not possible to understand how children's performance may be effected when haptic exploration is still developing. Also, the methods used to collect data about confidence was not appropriate for 5 year old children. Perhaps using alternative questions may have yielded more useful data to determine if children felt that their exploration was limited when they used the haptic robotic system.

Another limitation was that the haptic robotic teleoperation system that was used for the current study does not provide exact feedback about object properties. As was mentioned in the previous sections, the flex in the robot's end effector made sticks feel less rigid and spoons feel larger than they really were, thus influencing participants' performance on the tasks. There is a tradeoff in "transparency" (i.e. having the exact feeling at the user-side and environment-side robots), and safety. The gain could be set higher, to make the system more transparent, but the robot could go unstable if high forces are applied at the user-side robot. A safe, but non-optimal gain was chosen.

Participants used the haptic robotic system for the first time during these trials, however haptic exploration develops through multiple experiences that occur naturally in childhood. It is possible that if participants were given the opportunity to practice using the haptic robotic system for a variety of tasks and over a prolonged period of time, their performance on the current Function Judgement Tasks using the haptic robotic system would be different.

Individuals with disabilities, such as cerebral palsy, may have sensory impairments including sensory processing difficulties that affect tactile object recognition in the hands (Wingert, Burton, Sinclair, Brustrom, & Damiano, 2008) and proprioception (Goble, Hurvitz, & Brown, 2009). Success performing the Function Judgment Task is highly dependent on tactile and proprioceptive feedback in both conditions (with the hands and the teleoperation system). During the no tech condition, if the participant had difficulty extracting tactile sensory information through cutaneous effectors due to a sensory impairment, her ability to judge rigidity might have been affected regardless of her ability to perform the EPs. In addition, when she used the robotic teleoperation system in order to extract information about rigidity and size, she needed to rely on information she received through her muscles (stretching and contraction) about position and force, which is related to proprioception. Therefore, if she had sensory impairments related to proprioception her recognition of object properties though the system might have also been impaired. No assessment was performed with the participant regarding her sensory abilities; therefore it is not possible to know if the participant's performance on the task was influenced by sensory impairment, or strictly by her motor limitations. Overall, the participant's results do indicate that she was successful in the haptic condition using the robotic teleoperation system, therefore it is still possible to say that the system has the potential to allow people with physical disabilities (including cerebral palsy, when there is no or minimal sensory impairment) to learn about object properties and make judgements about tools.

Implications

As mentioned in Chapter 2, for children with disabilities, having the opportunity to independently explore the environment contributes to their participation in play activities, which is essential throughout childhood, and provides opportunities for children to perform haptic exploration and develop a variety of skills including tool use (Fenson & Schell,1985; Lockman, 2000; Parham & Fazio, 2008). This study demonstrated that typically developing children were able to perceive the properties of objects through haptic exploration and make judgements about tools using the robotic teleoperation system. It is possible that if children with physical disabilities are given opportunities to experience haptic feedback through a robotic teleoperation system during play activities, it could provide a means, in addition to visual and manual exploration, to perform EPs and practice perceiving object properties that are required to make judgements about tools.

Performing the Function Judgment Task with the adult with disabilities revealed that not only do children with disabilities miss out on opportunities to perform haptic exploration, so do adults with disabilities. This was demonstrated when the adult with disabilities revealed that she did not have previous experience mixing gravel or sugar. Results from this study also showed that having access to a robotic system may allow adults with disabilities to more easily identify objects' properties, improving their ability to identify objects in their environment as tools and possibly contribute to their independence when participating in day to day activities.

The results from this study could be used as a guide for the development of robotic teleoperation systems with haptic feedback that can be used by children and adults with physical disabilities. Children and adults with disabilities have different abilities and needs that should be considered when developing the technology. By observing a participant with disabilities perform the Function Judgement Task it was possible to identify modifications and features that should be considered when developing a system to improve people with disabilities' experience using a robotic teleoperation system. For example, physical modifications to the system such as various types of interfaces for the user side robot could be beneficial to adults and children who are unable to perform the fine grip movements that are currently required by the system. The interface used by the adult with disabilities was not ideal since it did not allow her to perform the grip she usually used (palmar grip) to control the joystick on her wheelchair. Having various interfaces available to use with the system to match the user's needs may allow performance to be improved when they use the system.

Preliminary in lab trials have been performed using teleoperation robotic system features that were not implemented in the current study (Sakamaki, et al., 2017; Atashzar, Shahbazi, Tavakoli, & Patel, 2017), and this study verifies that these features could further improve the performance of adults and children with disabilities during haptic exploration. The participant with disabilities did not have a very large range of motion in her upper extremities, so scaling could be used to increase the range that the environment-side robot spans. This feature could be especially useful when determining objects' rigidity since it could allow the participant to perform Pressure more comfortably in a smaller workspace. The participant with disabilities also had difficulties initiating voluntary movements in a desired direction; the robot could help her perform haptic exploration more easily by guiding her to the tool and the area that needed to be explored. Specifically, it may have allowed her to perform the Contour Following EP by guiding her hand around the spoon's contour. Although this was not the case for the participant in the current study, for adults and children that have involuntary movements or ataxic movement patterns, filtering involuntary movements is a feature that could be used to help them control the system by smoothing out the movements at the environment side end effector.

Conclusions

This study aimed to understand how children, adults without disabilities and an adult with disabilities perform haptic exploration when they use a robotic teleoperation system. The goal was to provide opportunities for more independent interaction with objects and the environment. This study was able to demonstrate that when typically developing children and adults without physical disabilities used the haptic robotic system to perform haptic exploration in a Function Judgement Task, they were able to make judgments about tool use based on haptic exploration. The exploratory study with one adult with disabilities suggested that use of the haptic system may be a feasible tool for people with physical disabilities but this requires further investigation. These findings are a first step in demonstrating the potential use of robotic teleoperation systems for haptic exploration. Future studies comparing different robotic features as well as end effectors and interfaces could further guide the development of assistive robots. In addition, studies recruiting adults and children with physical disabilities to explore robotic use for haptic exploration are imperative to understand how limited mobility while haptic exploration is still developing will influence performance using a haptic robotic system.

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Appendix A: Recruitment Poster for Typically Developing Children and Adults

Alberta Health Services

FACULTY OF
REHABILITATION
MEDICINE
UNIVERSITY OF ALBERTA

Robotics for Children!

Come learn about science, research and much more!

We are looking for typically developing 5 year old children to participate in a study aimed at developing technology for children with physical disabilities. The title of the study is "Using a Robotic Teleoperation system for Function Judgements"

Children who participate will:

- be exposed to different types of professions and technologies
- learn about the scientific process through active participation
- practice expressing opinions and ideas and develop social skills
- contribute towards the care, treatment and well-being of others

If interested contact Lina Becerra
Tel: 587-989-6659
Email: becerrap@ualberta.ca

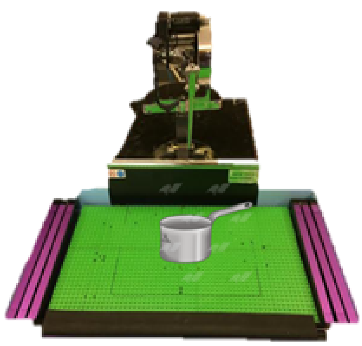
Alberta Health Services

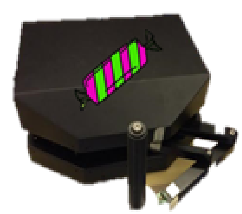
FACULTY OF REHABILITATION MEDICINE
UNIVERSITY OF ALBERTA

Would you like to experience the latest in Robotic innovation?

Come try out a robotic system with haptic feedback!

We are looking for adults over the age of 18 to participate in a study titled: Using a Robotic Teleoperation system for Function Judgements.





If interested contact Lina Becerra
Tel: 587-989-6659
Email: becerrap@ualberta.ca

Appendix B: Letter of Initial Contact for Adult Participants

Dear Mr. /Ms. _____________,

We are writing to let you know of a research study that we think you would be a great candidate for. Some researchers at the Faculty of Rehabilitation Medicine at the University of Alberta are conducting a research study. They have been studying how children who have physical disabilities can use robots to play with objects. They think that the devices that the user touches to control the robot, like switches or joysticks, can be improved. They are making new devices for playful tasks and want adults to try them. This will inform them if the new devices are helpful.

We have enclosed an information letter about the study and a consent form. If you would like to participate, you can contact the investigators at the Assistive Technology Lab at the University of Alberta.

Assistive Technology Lab

University of Alberta

Corbett Hall room 3-59

Telephone: 587-989-6659

E-mail: becerrap@ualberta.ca

You are under no obligation to participate.

Sincerely,

Lina Becerra

Appendix C: Letter of Initial Contact for Parents

Dear Mr. /Ms. _____________,

We are writing to let you know of a research study that we think your son/daughter would be a great candidate for. Some researchers at the Faculty of Rehabilitation Medicine at the University of Alberta are conducting a research study. They have been studying how children who have physical disabilities can use robots to manipulate objects. They think that the devices that the user touches to control the robot, like switches or joysticks, can be improved. They are making new devices for playful tasks and want children to try them. This will inform them if the new devices are helpful.

We have enclosed an information letter about the study and a consent form. If you would like your son/daughter to participate, you can contact the investigators at the Assistive Technology Lab at the University of Alberta.

Assistive Technology Lab

University of Alberta

Corbett Hall room 3-59

Telephone: 587-989-6659

E-mail: becerrap@ualberta.ca

You are under no obligation to participate.

Sincerely,

Lina Becerra

Appendix D: Parent Info Letter and Consent Form

FACULTY OF REHABILITATION MEDICINE UNIVERSITY OF ALBERTA

Alberta Health Services

Title of Project: Using a Robotic System for Haptic Exploration

Principal Investigator:

Kim Adams, Assistant Professor, Faculty of Rehabilitation Medicine, Glenrose Rehabilitation Hospital

Co-Investigators:

Lina Becerra, Research assistant, MSc Student, Faculty of Rehabilitation Medicine

Contact info: **Phone: (587) 9896659 Email: becerrap@ualberta.ca**

Purpose: We have been studying how children who have physical disabilities can use robots to manipulate objects. We think the interfaces could be improved. Interfaces are the devices that the user touches to make the robot move, like switches or joysticks. We are making new interfaces for playful tasks and we want typically developing children and children who have disabilities to try them. This will inform us if the new interfaces are helpful.

Background: Children develop perception and thinking skills when they explore objects. Children who have disabilities have trouble holding and moving objects. Therefore, they miss many chances to explore objects and learn how they can be used as tools. In our studies so far, children with disabilities used robots to move objects in play and school activities. Children pressed one to four switches with their hand or head to make the robot move, or they can use something like a joystick. However, these interfaces and robots had limitations.

1) Typically developing children usually use seeing, hearing and touching to learn about objects, but with our systems, children only saw and heard the objects while moving them.

2) To control all of the functions of the robot, children need to be able to control the interface well. In addition, children need to understand how the interface movements relate to robot movements. Not all children have those skills.

We will see if the interface can give the user information about what the robot is touching in the environment, like if it is soft or hard. Another term for this is "haptics".

Your child will use an interface that looks like a joystick to control a robot. We will ask your child to try several exploration tasks involving toys. We will ask your child to tell us if objects can be used as tools to complete a task. We will observe how your child uses the interface and robot. This is to see if the interface can give your child information about what the robot is touching. Videos of the sessions will be made only with your consent

Benefits: Children have fun when they use robots. They also may develop skills to control interfaces for other activities. This project may lead to better assistive robots for children in the future.

Risks: Your child may get tired during the task. Breaks will be given as needed. The interfaces for the robots are isolated from a power supply, so there is no danger of electrical shock. The interfaces are lightweight, and will have an emergency off switch controlled by a research assistant. The robots will be out of reach of the children, thus, there is no risk of a robot contacting the child.

Confidentiality: The information you provide will be kept confidential. We will use the videotapes to do data analysis. If you consent, we may use video clips for research presentations. We will not identify anyone by name. The information will be kept for at least five years after the study has ended. It will be kept in a locked file cabinet. The information will be only available to the researchers.

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

Additional Contact:

If you have any questions about the study please contact: Lina Becerra (Phone 587-989-6659, e-mail - becerrap@ualberta.ca) Faculty of Rehabilitation Medicine, University of Alberta.

If you have any questions or concerns about the ethical aspects of this study please contact University of Alberta Research Ethics Office at 780-492-2615.

Title of Project: Using a Robotic System for Haptic Exploration

Principal Investigator:

Kim Adams, Assistant Professor, Faculty of Rehabilitation Medicine, Glenrose Rehabilitation Hospital

Co-Investigators:

Lina Becerra, Research assistant, MSc Student, Faculty of Rehabilitation Medicine

Contact info: **Phone: (587) 9896659 Email: becerrap@ualberta.ca**

To be completed by the research participant or guardian:

Do you understand that your child has been asked to be in a research
study? Yes No

Have you read and received a copy of the attached Information
Sheet? Yes No

Do you understand the benefits and risks involved in your child taking part in this
Yes No

research study?

Have you had an opportunity to ask questions and discuss this
study? Yes No

Do you understand that you are free to refuse to participate or to withdraw from

the study at any time without giving a reason and without negative consequences?
Yes No

Do you understand that we need information such as age, date of birth,

clinical records/active client files and
diagnosis? Yes No

Has the issue of confidentiality been explained to you?
Yes No

Do you understand who will have access to the information you provide?
Yes No

Do you consent to have your child videotaped for research purposes?
Yes No

Do you consent to have short videotaped clips of your child used in research presentations? Yes No

By signing this consent form you are saying it is okay for the study team to collect, use and disclose information about your child from his/her personal health records as described above.

This study was explained to me by: ______________________________

I agree to allow my child to take part in this study.

_____________________________ __________________

Signature of Parent or Guardian Date

____

Printed Name

____

Name of Child

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

___________________________________ ___________________

Signature of Investigator or Designee Date

Appendix E: Child Information Script

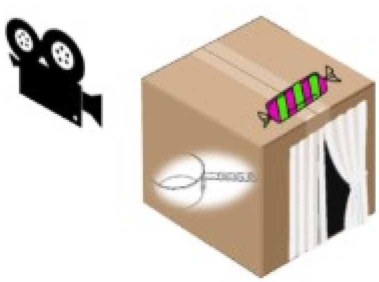
We want to tell you about a research study we are doing. A research study is a way to learn more about something. We would like to find out more about how children can use robots. We have some fun activities for you to try with a robot. We want you to try them so we can see how they work.

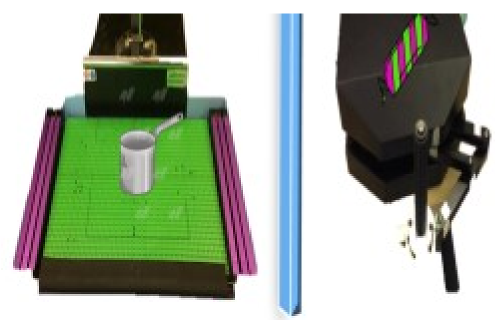
What will you have to do?

My friend wants to make a cake and fill a candy bowl for a party. You will feel some objects with your hands and with the robot and tell me if they will help my friend. We will play this game for about half an hour or until you want to stop.

- First you will look at some objects and tell me if they will work to drink some water or draw a picture.
- Then, you will play with other objects using this robot. You can do whatever you want with these objects. I will be here to help if you need it. You will have five minutes.
- Then, you will feel some objects without looking at them either using your hands or this robot. I will ask you questions about the objects.

Here are pictures of where you will feel the objects and the robot.





We will watch you to see what it is like to use the robot. We will make a video of you and watch it later. Afterwards, will ask you to tell us what you think of the robot.

Will it help?

It might help you feel some objects more easily. You may enjoy playing with the robot.

Will it hurt?

No, it will not hurt.

Can you quit?

You don’t have to take part in the study at all. You can quit any time. No one will be mad at you if you don’t want to do this. You can even stop part way through. Just tell your parents or the researcher if you want to stop.

Who will know?

No one except your parents and the researchers will know you’re in the study. If you want you can tell other people. Your name and your information won’t be seen by anyone except the investigators. The videos will be locked in a drawer.

Appendix F: Data Collection Sheets

*Areas in Grey must be randomized and filled in before the session

Participant Code:	Age:
Date:	Hand Preference:
Grip:	Gender:

FUNCTION JUDGMENT TASK

We are going to play a game.

1. See this? My friend wants to take a drink of water. Do you think my friend can drink water out of this? (repeat x2)
2. See this? My friend wants to color a picture, do you think she could color a picture with this? (repeat x2)

1- Drinking			2- Coloring		
Trial	Object	Participant Answer	Trial	Object	Participant Answer
1			1		
2			2		

We are going to continue playing this game with different objects. Now instead of looking at the objects, you are going to feel them in order to tell me if my friend can use them. First you will use ________ and then you will use ________.

CONDITION 1	CONDITION 2

My friend would like to make a cake/mudpie. She needs help finding a stick that she can use to mix the sugar/gravel. Feel this! Do you think my friend could use this stick to mix this sugar/gravel?

Mixing Sub Task

Target Object 1		Gravel / Sugar	
Trial	Stick (A-E)	Participant Answer	Confidence in Response
1			
2			
3			
4			
5			
Target Object 2		Gravel / Sugar	
Trial	Stick (A-E)	Participant Answer	Confidence in Response
1			
2			
3			
4			
5			

Mixing Sub Task

Target Object 1		Gravel / Sugar	
Trial	Stick (A-E)	Participant Answer	Confidence in Response
1			
2			
3			
4			
5			
Target Object 2		Gravel / Sugar	
Trial	Stick (A-E)	Participant Answer	Confidence in Response
1			
2			
3			
4			
5			

My friend will throw a party and wants to fill the candy bowls with candy. She needs help finding a spoon to carry the candy because she is not allowed to touch the candy with her hands.
Feel this! Can my friend use this spoon to put this candy in a bowl?

Transport Sub Task

Target Object 1		Small Candy / Large Candy	
Trial	Cup (A-E)	Participant Answer	Confidence in Response
1			
2			
3			
4			
5			
Target Object 2		Small Candy / Large Candy	
Trial	Cup (A-E)	Participant Answer	Confidence in Response
1			
2			
3			
4			
5			

Transport Sub Task

Target Object 1		Small Candy / Large Candy	
Trial	Cup (A-E)	Participant Answer	Confidence in Response
1			
2			
3			
4			
5			
Target Object 2		Small Candy / Large Candy	
Trial	Cup (A-E)	Participant Answer	Confidence in Response
1			
2			
3			
4			
5			

Participant Code:	Mixing		Transport		Condition:
Date:					
Grip:	Sugar	Gravel	Big	Small	Order: 1st 2nd

	______	______	______	______	______	TOTAL
Code/Time	Start: End: Total:	Start: End: Total:	Start: End: Total:	Start: End: Total:	Start: End: Total:	
None						
Lateral Motion						
Pressure						
Static Contact						
Unsupported Holding						
Enclosure:						
Contour Following						
Function Test						
OTHER						

NOTES: