Facilitating collaboration among children with autism through robot-assisted play

by Josh Wainer

Submitted to the University of Hertfordshire
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy
under schedule A

May 2012

Acknowledgements

Firstly, I would like to thank my supervisors Kerstin Dautenhahn, Ben Robins, and Farshid Amirabdollahian for their analytical insight, strategic vision, and practical advice. Our discussions have always left me more knowledgeable than before, and I have greatly benefitted from their experience and counsel. I would also like to thank my friends and fellow researchers at the Adaptive Systems Research Group, Ester, Sven, Dag, Moritz, Frank, Tom, Antoine, and many others. If not for them and my many dear friends in the UK, these past few years would not have been nearly as enjoyable or memorable.

I would like to thank the organizers of the student group SNAAP, Christine Haugh, Steph Moriarty, and Matt Connoly, as well as the heads of Southfield School, Mike Philp and Bob Deacon, for allowing their students to participate in my studies. I would also like to thank the many teachers and parents for their support and insights into the student's behaviours. Most importantly, I would like to thank the children who participated in my research. They have taught me much and have been the driving force behind this work.

Lastly, I'd like to thank my parents Mitchel and Suzi. If not for their constant encouragement, support, love, and generosity, this whole process would have been infinitely more difficult!

Josh Wainer

University of Hertfordshire

May 2012

Abstract

This thesis discusses how autonomous robots can be used to foster and support collaborative play among children with autism in a number of different settings. Because autism impairs one's skills in social communication and social interaction, this makes it particularly difficult for children with this disorder to participate in many different forms of social play, particularly collaborative play due to the interpersonal skills needed to coordinate and synchronize people's actions through constantly communicating with them. Since these children have trouble playing collaboratively, this further hinders their ability to develop the necessary skills of interacting and communicating with others.

I approached this idea from an empirical, behaviourist perspective instead of a theoretical one, in the sense that I conducted three different experiments in which I observed the behaviours of children with autism participating in controlled play sessions both with and without robots. To this end, I designed simple, effective control architectures which allowed LEGO NXT robots and KASPAR the humanoid robot to autonomously interact with people while playing with them. Additionally, I designed many collaborative video games such as arena games, "Tilt & roll", and "Copycat", that served as environments in which children with autism could play with the autonomous robots.

The experiments in this thesis attempted to show that not only would children with autism improve their social behaviours while playing collaborative video

games with autonomous robots, but these improvements would also transfer into similar settings in which the children would only interact with other people. By recording videos of the children's interactions and performing observational analyses on the children's behaviours, the data from my first exploratory experiment indicated that the amount of enjoyment the children showed in an after-school robotics was more positively correlated with their social behaviour than the number of play sessions in which they interacted. Using similar means, the results from my more streamlined second experiment suggested that children with autism displayed more social behaviours while playing with a typically developed adult after playing with KASPAR than they did beforehand, and the findings from my more rigorous third experiment strongly indicated that different pairs of children with autism showed improved social behaviours in playing with each other after they all played as groups with KASPAR compared to before they did so.

Contents

Chapter 1

Introduction

The research and experiments conducted in the course of working on this dissertation are part of the AuRoRA (AUtonomous mobile RObot as a Remedial tool for Autistic children) project, an ongoing initiative of the University of Hertfordshire's Adaptive Systems Research Group to study how robots can act as toys and play partners to help children with autism to socially communicate and socially interact with others [aur, 2010]. Although the research in the AuRoRA project addresses this issue in many different ways, it is all motivated by the same core ideas, which are that children with autism will want to play with autonomous, interactive robots, all of which are capable of successfully displaying basic interpersonal interaction skills such as appropriately directed gaze, turn-taking, and imitation. In addition, these robots should be theoretically capable of slowly adding behaviours to their performance repertoires and increasing their degree of unpredictability in interactions in order to gradually steer children with autism toward more complex social interactions and better prepare them to successfully interact with other people. Furthermore, because the long term goal is to potentially have these robots operate in school and home settings, they should be usable by teachers, carers, and parents instead of only scientists and engineers [Dautenhahn and Werry, 2004].

This thesis focuses specifically on how autonomous robots can be used to foster and support collaborative play among children with autism in a number of different settings. This topic was approached from an empirical, behaviourist perspective instead of a theoretical one, in the sense that I conducted many different experiments in which I observed the behaviours of children with autism participating in controlled play sessions both with and without robots. While each study featured collaborative games designed and implemented by myself as well as interactive robots running autonomous control software that I wrote, the design and analysis of these systems is not the sole focus of my research. In addition to concentrating on the aformentioned software, the research in this thesis is also focused on interpreting the behavioural data from the collaborative interactions between both the children and autonomous robots as well as the children and other people.

The work contained in this thesis is entirely my own; although my colleagues and supervisors were listed as co-authors on my conference papers and journal articles, I conducted and designed all of the experiments, I implemented all of the novel hardware setups and software systems, I analyzed the data from each study, and I wrote up the results and findings from each experiment. Although I use the term "we" in writing this thesis, I only do so for stylistic reasons. While my supervisors regularly gave me sound advice on the direction in which my research should progress and also provided much-needed editorial feedback on my written work, I performed the actual work described in this dissertation.

1.1 Motivation

Autism is a developmental disorder that impairs how one communicates with and conducts all social interactions with other people. A child with autism will have a difficult time interpreting the emotional reactions of other people and understanding why others react to the child's own behaviours in specific ways. Additionally, children with autism have difficulties in using language to communicate with others; some will use nonverbal means to express their needs and respond to others, some will speak phrases or sentences that have little to no meaning, and some will use words, phrases, or scripts that they have been explicitly taught in order to communicate. While some children with autism will be able to speak at length about specific topics that interest them, such children will typically speak as though they are lecturing. Furthermore, all children with autism have great difficulty engaging in two-way conversations. Because of these impairments, children with autism have great difficulty in forming and maintaining social relationships [Landau, 2001].

This difficulty is especially apparent in observing how children with autism play, since when they are left to their own devices, they will typically play by themselves with their own toys [Wing et al., 1977]. This is because it can be quite difficult or tiring for them to engage in organized social play, much less collaborative play, due to their social impairments and the amount of social interaction that occurs in these forms of play [Howlin, 1986].

Unfortunately, there are a number of different approaches to children's mental development which suggest that play and collaboration directly factor into a child's ability to learn, and all of these theories suggest that the impairments of children with autism in play and social situations impede their mental development. According to Vygotsky's theories of social development, children learn a great deal by socially interacting with others, especially when they collaborate or cooperate with more highly-skilled individuals. Specifically, children benefit from a hands-on form of instruction in which a skilled individual both explains to a naïve individual, i.e. the child, how one should accomplish a particular task and guides the child's actions towards their intended goal [Vygotsky, 1978]. Additionally, Piaget's stage theory of cognitive development suggests that children alter their mental schemas of how the world works and truly learn new concepts through play by accomodating new information into their mental representations of the world. Piaget states that such a process only occurs when children imitate an action that they have seen before, and that all other forms of play are ways of assimilating information into their existing mental schemas of the world [Piaget, 1962]. Furthermore, Bruner's theories of developmental psychology state that children can become more creative, can develop new cognitive techniques, and can develop rich sets of experiences that will help them in future learning by experimenting with different kinds of behaviours during playtime. In fact, social play among children allows them to engage in even more creative and riskier behaviours, as the consequences for their actions in social play will not be as severe as the consequences incurred during solitary play [Bruner, 1974]. Similarly, according to Lave and Wenger's theory of situated learning, a great deal of learning takes place when children socially interact with others and form *communities of practice* based on their shared interests. As children collaborate and interact with members of these communities to solve problems and accomplish tasks, they learn about both the tasks at hand as well as how to better socially interact with others [Lave and Wenger, 1991]. In short, there are a variety of approaches to learning which would suggest that because of the unique difficulties that children with autism face with respect to participating in social play, imitative play, and collaborative interaction, such children are more hindered in their cognitive development than children who do not have autism.

Because of the far-reaching and life-long implications of autism, a great deal of research has been conducted on how different forms of technology can assist children with this disorder. While it is known that children with autism particularly enjoy playing with computers and mechanical devices by themselves [Moore, 1998] [Powell, 1996], robotic devices such as the artificial turtle LOGO have been found to elicit unique social responses from such children [Weir and Emanuel, 1976]. In fact, Scassellati believes that not only can robots can be used to treat autism, they can be used to diagnose the disorder, as well [Scassellati, 2005a] [Scassellati, 2005b]. Many different robot shapes and designs have been found by Michaud to positively affect these children's social interactions [Michaud and Théberge-Turmel, 2002], although humanoid shapes seem to offer the most promise [Duquette et al., 2008]. Kozima's snowman-shaped robot Keepon has been used extensively to study and encourage joint attention among children with autism [Kozima et al., 2005] [Kozima et al., 2007] [Kozima et al., 2009], and Matarić's work with Bandit has shown that robots which respond contingently to the behaviours of children with autism show particular promise in eliciting positive social responses [Feil-Seifer and Matarić, 2008a].

Research affiliated with the AuRoRA project at the University of Hertfordshire has made similarly impressive findings. In addition to learning that children with autism enjoyed playing with the vehicle-like robot "Labo-1" more than playing with inanimate vehicle-like toys [Dautenhahn, 1999] [Werry et al., 2001a], researchers also discovered that children with autism would use robots as mediators in order to interact with other people [Werry et al., 2001b] and that the manner in which such children played with toys at home was similar to how they played with the robotic vehicle "Pekee". Similarly, researchers found that when children with autism played with a robotic dog "Aibo" which adapted in real-time to children's individual styles of play [François et al., 2008], the children gradually played with the robot in more developed and interactive ways over the course of multiple play sessions [François et al., 2009]. However, the most promising work in AuRoRA has come from research with children with autism interacting with humanoid robots. Specifically, research with the robot doll known as "Robota" showed that it elicited more engaged interactions from the children than did people, and that it acted as a social mediator to promote interaction among children with autism and the co-present adult experimenter [Robins et al., 2005] [Robins and Dautenhahn, 2006]. Interestingly, Robota elicited spontaneous imitation from children with autism [Robins et al., 2004a] and also promoted more engaged interactions from the children when its face was obscured by silver foil [Robins et al., 2004c]. Additionally, recent work with the humanoid robot "KASPAR" has shown that the remotely-operated robot can act as a catalyst for two children with autism to play next to each other and imitate the robot, even when one child directly controls the robot's behaviour [Robins et al., 2009].

Building on the previous research conducted in the AuRoRA project as well as earlier work on assistive robots for children with autism, the goal of my doctoral research is to use autonomous robots as mediating agents to help foster collaborative play among children with autism. If such children are able to socially interact with an autonomous, reactive robot and possibly another child in the context of a collaborative game, then their experiences in these robot-assisted settings should be able to generalize into other, similar settings. Specifically, the skills they learned while interacting with a robot should help them to better socially interact and collaborate with other people in settings that do not include the robot or its effect of social mediation.

1.2 Key research questions

The overarching goal of the work in this thesis is to *use an autonomous robot to facilitate collaborative play among children with autism.* In order to accomplish this, I first needed to address a number of different design issues which applied to the whole of my research. These issues were organized into three categories:

- **Collaboration**: How should collaboration be defined in the context of my research? What behaviours should be observed in my experiments in order to quantitatively measure how much the children collaborated, both with other people and the autonomous robot?

- **Game design**: How should I design an easily understood, explicitly collaborative game which will require teamwork and interaction among its players? How can this game be designed to be playable by a robot as well as a human? How can it be particularly enjoyable for children with autism?

- **Human-robot interaction**: Considering the nature of autistic children's impairments in social communication, how can most children with autism communicate with an autonomous robot in the context of a collaborative game? How should this method of human-robot communication be designed such that children with autism could easily transfer skills between learning to communicate with the robot and learning to communicate with other people? How could this method of communication be implemented in the autonomous robot such that it would correctly and reliably interpret the children's in-game commands and requests?

In the course of addressing these topics, I also developed two research questions that my experiments attempted to answer:

- **Question 1**: Will interacting with an autonomous robot in structured, explicitly collaborative play sessions promote social interaction and social engagement among children with autism?
- **Question 2**: Will the social interaction skills that children with autism have learned by playing collaboratively with an autonomous robot transfer over to the children's subsequent collaborative play sessions, which are only with other people?

The first question asks whether the children would focus their attention on the autonomous robot, be responsive to its behaviours, and attempt to interact with it during an explicitly collaborative play setting. While earlier research has shown that such behaviours can occur among children with autism and robots controlled through various means, whether autonomous or remotely controlled [Dautenhahn, 1999] [Werry et al., 2001a] [Werry et al., 2001b] [Robins et al., 2004a] [Robins et al., 2005] [Robins and Dautenhahn, 2006] [François et al., 2008] [François et al., 2009] [Robins et al., 2009], my experiments attempted to address whether these behaviours can also occur between such children and autonomous robots programmed to play in explicitly collaborative environments; my work did not attempt to compare one method's effectiveness with that of another. The second question asks whether children with autism would be able to generalize social behaviours that they learned while playing collaboratively with autonomous robots into settings in which they play collaboratively with people instead of robots, despite the fact that skill generalization is acknowledged to be difficult for children with autism. While earlier research has often relied on interviews with parents or carers to compare typical social behaviours of children with autism to those exhibited while the children interacted with robots [Robins et al., 2004d] [Robins et al., 2005] [Robins and Dautenhahn, 2006] [Robins et al., 2009], my research attempted to directly compare both the children's behaviours with and without the robot's presence, as well as the children's behaviours with only other people in the context of my experiments both before and after the robot's introduction.

1.3 Methodology and practical effort

Because human-robot interaction is a multidisciplinary field, I had to read a great deal of background research in a number of different areas in order to conduct the research described in this thesis. Naturally, I read about human-robot interaction, robot control architectures, and assistive technology, but because the target group of users in my research was children with autism, I also read a great deal on autism research, therapy, and education, childhood learning and development, and robot-assisted play for children with autism. Because collaborative play was a central theme of my research, I also studied group learning and collaboration, theory and design of cooperative games, and social play among children.

For each experiment that I conducted, I developed a unique, collaborative game for children with autism to play. In the first experiment, the children programmed small LEGO® robots to play inside of a 6 ft x 6 ft walled arena that I built out of wood. I designed the arena to automatically respond to specific game-based actions of the robots by attaching a variety of sensors, coloured LEDs, and a speaker to the inner walls of the arena and connecting these components to my laptop. The children played a number of different collaborative games with their robots and the other children's robots over the course of the experiment, with each game requiring them to utilize basic programming concepts to make their robots perform simple actions and cooperate with other robots within the arena. Because the software for these games were relatively simple and developed fairly quickly, I extensively tested each game by myself in the lab before I asked the children to play them. In both the second and third experiments, I designed and implemented separate collaborative video games in which the co-located players used the motion-sensing capabilities of Nintendo Wii controllers, or Wiimotes, to select 3D shapes on a horizontally-oriented screen while facing each other. To select these shapes, the players had to communicate with each other to coordinate their intentions and synchornize their actions. Because the software for each of these games was far more complicated than the software running the arena games in my first experiment, particularly in terms of graphical sophistication, algorithmic complexity, and resource management, both the second and the third experiments' video games were repeatedly and extensively tested by myself, fellow labmates, and typically developed children before it was fielded in trial runs with children with autism.

In each experiment, I also programmed robots, whether directly or indirectly, to behave autonomously; instead of anyone directly controlling a robot when it performed actions, each robot was programmed beforehand to behave in certain ways and react to specific stimuli. For my first experiment, I built three robots from LEGO Mindstorm NXT kits. Although the children in this first experiment programmed these robots to behave in certain ways using LEGO's proprietary NXT-G programming environment, I myself designed and implemented many subroutines which the children used in the course of programming their robots. This was done to make the programming easier and faster for the children to accomplish. Before I let any child use these subroutines to program their robots, I tested each one on each NXT robot in my lab. For my second and third experiments, I programmed KASPAR, a child-sized humanoid robot developed by the Adapative Systems Research Group at the University of Hertfordshire, to autonomously play each experiment's collaborative game. For each experiment, I designed and implemented a sense-plan-act control architecture to allow KASPAR to play the collaborative game without direct control from anyone. In addition, I also created and developed separate sets of protocol which governed KASPAR's social interaction, verbal communication, and body language with the children in each experiment. All of KASPAR's game-based behaviours were extensively tested by myself, fellow labmates, and typically developed children before the robot was deployed in my second and third experiments.

Because all of my experiments were conducted in school settings with groups of children with autism, I had to spend a reasonable amount of time and effort to organize, schedule, and logistically plan out each one. Once I decided that my doctoral research would require children to participate in my experiments, I signed up to receive a background check by the UK's Criminal Records Bureau, or CRB, in order to confirm that I did not have a criminal record and was therefore allowed to work with children. In addition, I also submitted a draft proposal of my research plans to the University Ethics Committee to ensure that my experiments conformed with the University of Hertfordshire's ethical codes and guidelines. Before running each experiment, I contacted teachers from local schools and organizations for special needs children to see if they would be interested in having their children participate in my research. Once I found an interested school or organization, I met with either my point of contact or the interested head teacher in order to compile a list of the children from their classes who would be both willing and able to participate in my study. After I selected from this list a a group of children suitable for my specific study, I then developed a schedule for running all of the trials in the experiment. This schedule took into account various factors such as the number of trials needed for each child, the order in which they needed to be conducted, the number of trials I could conduct in a given day, which days of the week I could use to conduct trials, the dates of relevant bank and school holidays, and a reasonable amount of buffer days that would allow me to absorb any lost trials due to children being sick, on vacation, or otherwise unavailable to participate in the experiment without negatively impacting my expected completion date. I then had to receive signed consent forms from the parents of each participating child, indicating they had no problems with their children participating in my research or with their likenesses being used in scientific publications.

During every experiment's trials, I used camcorders to record the interactions of the children with other people and/or robots. Over the course of all my experiments, I recorded over 58 hours of video footage. I used the event logging software The Observer XT to manually code over 24.5 hours of this video footage second by second, and in some cases frame by frame, in order to get timestamped logs of the children's social behaviours during the trials. These logs were then automatically analyzed to determine trends and patterns in the children's behaviours, allowing me to quantitatively compare and statistically test the children's degrees of social interaction at different points in each experiment. Although very time-consuming, this form of quantitative behavioural analysis of manually coded observations formed the backbone of my research and allowed me to track the changes in children's social behaviours in very fine detail.

1.4 Overview of the thesis

Chapter 2 opens by presenting background information on autism as a disorder and detailed descriptions of how children with autism behave differently from non-autistic, or neurotypical, children. It then defines the study of human-robot interaction and describes a number of different approaches taken in the field, and proceeds to connect the two fields together by describing how robots have been used in autism therapy as well as autism research. I then discuss studies on how typically developed children collaborate while in group learning environments as well as how people and robots have collaborated together in various scenarios, and then tie the two areas together by describing how social play has been studied in children with autism.

Chapter 3 describes the robots used in my research, both the LEGO Mindstorm NXT robots and KASPAR, the humanoid robot. For each robot, I first discuss the principles that went into their designs as well as their intended methods of usage. After discussing each robot's sensory and motor capabilities, I then describe the layouts of these components as well as the robot's physical configurations and dimensions. I then recount previous studies that used each robot in their research, and then describe how the robots were used in my doctoral studies.

Chapter 4 discusses the cooperative games that I used in my research: the arena-based games in my first experiment, the tilting/rolling game used in my second experiment, and the pose-mimicking game used in my third experiment. For each game, I describe the rules for how they were played and laid out for the children. I then defend design choices for specific features of gameplay and conclude with describing the game input devices and display systems as well as the software architecture and algorithms used for each game.

Chapter 5 describes my first experiment, an exploratory study involving the design of an after-school robotics class for groups of children at the higher-functioning end of the autistic spectrum. The aim of the study was to foster collaboration among the children in the context of a class where they programmed LEGO Mindstorm NXT robots and played cooperative games with them in an interactive arena under the guidance of an experimenter. The class took place once a week over several months and used many different measures to assess the childrens collaborative behaviours. Detailed analysis of behavioural data is presented, and despite the small sample size, our findings suggest that the number of potentially collaborative behaviours the children displayed during a class is more strongly related to the amount of enjoyment the children derived from the classes than to the number of classes in which the children participated. Parallel-run, free-form drawing sessions conducted before certain classes gave some indication that these behavioural changes partly generalized to a different context. Additionally, many of the children in the class either found their experiences in class to be helpful in other social interactions or expected them to be.

Chapter 6 discusses my second experiment, a pilot study in which children with autism alternated between playing a cooperative, dyadic video game with an adult human and playing the same dyadic game with an autonomous humanoid robot, KASPAR. The purpose of the study was to determine whether the children, all of whom had difficulties communicating and engaging in social play with others, would display more collaborative behaviours when playing with an adult after playing and interacting with the humanoid robot. Based on our analysis of the childrens behaviours while playing the cooperative game, our findings suggest that the children were more entertained, seemed more invested in the game, and collaborated better with their partners during their second sessions of playing with human adults than during their first. One possible explanation for this result is that the childrens intermediary play session with the humanoid robot had an impact on their subsequent play session with the adult. Furthermore, while the children saw the robotic partner as being more interesting and entertaining, they played more collaboratively and cooperated better with the human adult.

Chapter 7 presents my third experiment, a study in which pairs of children with autism switched between multiple sessions of playing a dyadic, cooperative video game with each other and multiple sessions of playing the same game in a triadic manner with each other as well as a humanoid autonomous robot, KASPAR. The goal of the study was to determine whether the children, all of whom were impaired in participating in social play and communicating with others, would exhibit more collaborative actions after participating in a set of triadic play sessions with both the humanoid robot and another autistic child. To determine whether there was any change in the children's displays of collaborative behaviour, we had the children participate in a set of dyadic play sessions with another autistic child both before and after the triadic sessions and then compared the behaviours in the first set of dyadic interactions to the behaviours in the second set. Our analyses of the children's behavioural data suggest that they were more socially engaged, more communicative with respect to cooperative play, and more interested in sharing their enjoyment with the other autistic child during their second sets of dyadic play than during their first sets of dyadic play with the same children. Furthermore, the data suggest that the children's unique interactions in the intermediary set of triadic play sessions involving the autonomous robot were responsible for the change in social behaviours between the two sets of dyadic play sessions involving pairs of children.

Chapter 8 draws conclusions on all of the research described so far and reviews the fundamental research questions of this thesis. I conclude by discussing the contributions as well as limitations of this thesis and discussing future directions for my research.

1.5 Contributions to knowledge

Due to the multidisciplinary nature of my research, the findings and techniques described in this thesis have contributed to the advancement of many fields of research.

1. **Human-robot interaction:** I have demonstrated in my experiments that autonomous robots can promote social interaction among children with autism

by playing collaborative games and interacting with them, whether the robots are humanoid like KASPAR or clearly mechanical like LEGO NXTs. The fact that both kinds of robots, each with such drastically different appearances (humanoid **vs** modular insectoid, respectively), behaviours (moving humanoid arms, head, and eyes **vs** moving around on a flat surface and pushing objects, respectively), and interactive capabilities (speaking, gesturing, making facial expressions in human ways **vs** beeping and turning, respectively), could help children with autism by interacting with them has very interesting implications for future research in human-robot interaction.

2. **Robot-assisted play:** I developed a collaborative video game in which players faced each other and gathered around a horizontally-oriented screen, which is a novel scenario for studying styles and patterns of play between children with autism and robots. This play configuration could be well-suited in using robots to develop joint attention and mutual gaze in children with autism through co-located play.

   Additionally, having the game exist as a physical, responsive entity which is separate and distinct from the robot (who also participates in the game) could promote new directions for research in robot-assisted play. Instead of a game being an abstract concept, the binding of a game to a physical form with which the robot can interact could make children with autism play with the robot in a more engaged manner.

   Lastly, using a video game as a collaborative medium allows researchers to "cheat" by having the video game process communicate with the robot control process and directly transmit the game's complete state information to the robot's sensory subroutines. This allows researchers to completely bypass the problem of designing a game that the robot can reliably "sense" (e.g. knowing the state of a real-life checkerboard by giving the robot impressive computer vision algorithms related to shape detection and feature extraction) as well as "impact" (e.g. designing a robot arm and gripper specifically for moving checkers), and instead devote all of their efforts to allowing the robot to have rich interactions with the children using many different modalities.

3. **Assistive robotics:** The findings from my experiments suggest that autonomous robots, whether LEGO NXT robots or KASPAR the humanoid robot, can positively impact the way that children with autism socially interact with other people in the context of a collaborative game. Moreover, instead of simply observing how the children interacted with people *while in the presence* of the robot, my experiments also examined how these children behaved with people *after* they interacted with the autonomous robot and found that their behaviours were more socially interactive.

   Further research in assistive robotics could benefit from observing and measuring the children's social behaviours both before and after interacting with the robot. Instead of only focusing on how the robot can be beneficial to the children's interactions as long as it is present, this technique could show differences in the children's behaviours in more typical settings, perhaps even those outside of the collaborative game. Showing such a difference would strongly suggest that the robot's interactions would have enduringly therapeutic effects on the children's behaviour.

4. **Autism research:** While my research merely focused on the interactions of the children with autism and autonomous robots in the context of playing a collaborative game and did not study autism itself, the experimental setups and hardware as well as software systems used in my research could be used by other reserachers to study many other aspects of autism in novel ways. Although specialists would be needed to modify the robot's behaviours and alter aspects of the collaborative game, as the systems I developed were not constructed as modifiable elements in a framework, these individuals could

work together with psychologists to design new experimental play scenarios for studying autism.

Chapter 2

Background and Related work

As the previous chapter has established, my doctoral research deals with how autonomous robots can promote social interaction among children with autism through collaborative play. This topic is very interdisciplinary since it requires background knowledge of such varied and distinct fields as autism research and treatment, human-robot interaction with respect to robots that assist and interact with people in physical or social ways, robotics with respect to the study and treatment of autistic spectrum disorders, collaboration among people as well as among mixed teams of robots and people, and the nature and definition of play as it relates to treating and assessing autistic spectrum disorders (see figure 2.1). As such, I had to study these field in great depth in order to conduct novel, relevant research into how robots can play autonomously and collaboratively with children with autism in order to help improve their social interaction skills.

2.1 Autism

Autism is a lifelong developmental disability that affects 0.34% to 0.6% of the population of any given country [Fombonne, 2003]. It appears in many possible forms and degrees of severity, making people with autism a very heterogeneous group. In

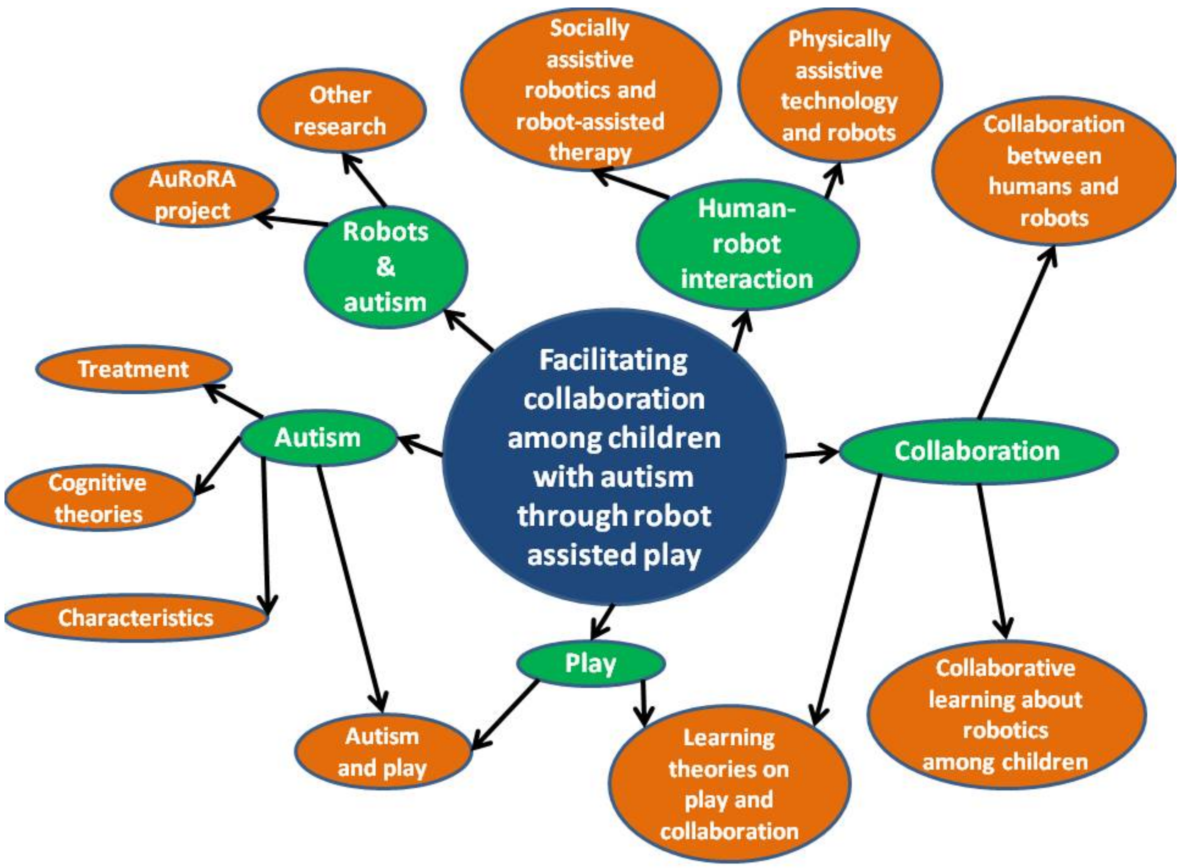


Figure 2.1: An idea map which describes the different fields in which I needed background knowledge to understand my interdisciplinary research topic. The blue circle in the middle is the central topic of my thesis, the green circles surrounding it are research areas associated with the central topic, and the orange circles around them are the fields which contributed to each reserach area.

fact, autism is said to exist as a spectrum of disorders which range from the most severe diagnoses (low functioning autism) to the most mild diagnoses (Asperger's Syndrome). Autistic disorders are diagnosed based on the outcomes of a series of tests that assess a variety of phenomena described in the most recent version of Diagnostic and Statistical Manual of Mental Disorders, or DSM-IV [American Psychiatric Association, 1994].

2.1.1 Characteristics

When researchers study how children with autism interact with robots, they will often describe the interactions in the context of the following behavioural characteristics, known as the triad of impairment [Wing, 1996]:

1. **Impaired social imagination** - A child with autism can have difficulty engaging in imaginative pretend play and may instead play in a stereotyped, excessively structured, and repetitive manner. For example, instead of pretending that a toy car or train is real and 'driving' the toy around while making engine noises, a child with autism will be more likely to stare at the toy's wheels and spin them for long periods of time or repeatedly arrange the toys by size or colour. They can also have difficulties predicting what circumstances or situations could occur in the future. This can become manifest as problems dealing with changes in schedules, understanding how to behave in new situations, or be familiar with the concept of danger.

2. **Impaired social communication** - Some children with autism do not develop useful speech, while some of those who do may not fully understand that it is a means of communicating ideas and feelings between two or more parties. While higher-functioning children with autism will be able to speak, they may interpret language in an overly literal way and have difficulty understanding jokes and common phrases. Additionally, children with autism may have difficulties with non-verbal communication such as body language and gestures,

and will probably not understand how different facial expressions and tones of voice can affect the meaning of one's speech.

3. **Impaired social interaction** - A child with autism may react inappropriately in various social situations as they may have problems expressing their own emotions and feelings, in addition to having difficulties recognizing these same feelings and emotions in others. They also might not know of or understand basic rules of social interaction that others intuitively understand, such as the concept of personal space or appropriate topics of conversation. Children with autism also may prefer spending time alone instead of in the company of others: on the severe end of the spectrum, a child may seem uninterested in other people, while on the mild end of the spectrum, a child might respond when approached socially but will display a lack of proactive social behaviours.

Among children, measurable manifestations of these social impairments include:

- initiating joint attention using pointing (the selection and focus of gaze on the same object as someone else) far less than other children [Frith, 1989];
- finding it difficult to initiate and sustain social play [Jordan, 2003];
- spontaneously displaying helpful behaviours far less than other children, even those with other developmental disabilities [Liebal et al., 2008];
- displaying positive affect in social settings significantly less often than children who have not been diagnosed with autism [Dawson et al., 1990];
- combining eye contact with smiling significantly less often than either neurotypical or mentally retarded children [Kasari et al., 1990];
- having much more difficulty than neurotypical children in imitating the subtle nuances or styles of performing an action [Hobson and Lee, 1999];

- having difficulties with taking turns, resulting in performing turn taking less often than other children [Mundy et al., 1986];
- having difficulties with generalizing behaviour and skills between settings [Gaylord-Ross et al., 1984];
- not forming social expectations of someone's behaviour until they have noticed them act in an explicitly socially contingent, or imitative, manner with them [Nadel et al., 2000].

Since these impaired behaviours are inherently social ones, the number of times that they are exhibited can be used to measure the degree to which a child socially interacts with someone else [Bauminger, 2002].

2.1.2 Cognitive theories

Psychologists and behavioral specialists have studied the underlying mechanisms behind the behaviours of people with autism from a cognitive persepctive, and the theories developed from this approach can be separated into two groups: those that deal with the impairments in social cognition of autistic chldren and those that deal with their difficulties in nonsocial or general cognition.

Social cognition

One theory that attempts to explain the social cognition deficits in autistic people is the empathizing-systemizing theory, which classifies people along two axes: a tendency to systemize, or to construct and/or analyze systems of inanimate objects in order to control them and understand the rules that govern their behaviour, and the tendency to empathize, or to know how another person thinks and feels in order to respond with a fitting emotional response and care about how they feel. According to self-response questionnaires developed by Baron-Cohen, Richler, Bisarya and others, most normally-developed men have higher systemizing quotients than empathizing quotients, while the reverse is true for women. Furthermore, people diagnosed with Asperger's Syndrome or high-functioning autism have significantly higher systemizing quotients as well as significantly lower empathizing quotients than non-autistic people. This supports what is known as the extreme male brain, or EMB, theory of autism [Baron-Cohen et al., 2003].

This has some similarities to Baron-Cohen's earlier model of mindblindness, in which he shows how children with autism seem to lack a 'theory of mind', or the ability to attribute a set of beliefs and intentions about the world both to oneself as well as to other people [Premack and Woodruff, 1978]. Specifically, Baron-Cohen designed a study using the now-famous Sally-Anne test to show that while typically-developed children as well as mentally retarded children could successfully infer what another person's (false) beliefs were about a particular situation, very few children with autism could do the same. This inability to identify as well as understand another's beliefs and intentions, or mindblindness, has been used to explain how children with autism cannot understand how their behaviour can affect others as well as how children with autism have difficulties with social reciprocity [Baron-Cohen et al., 1985].

General cognition

While the abovementioned theories describe the social impairments encountered by people with autism, they do not explain their non-social cognitive impairments, such as being preoccupied with parts of objects, obsessions with sameness, and repetition in routines and meaningless rituals [American Psychiatric Association, 1994]. One such theory is Frith and Happe's concept of central coherence, which describes how typical people gather various details about a phenomenon and combine them to form a comprehensive, higher-order abstraction using clues from the environment. Some examples of this are how people tend to remember the main themes and gists of stories while glossing over details, and how people can get confused about specific parts of images on a jigsaw puzzle piece based on where we expect the part to fit into the whole puzzle. Frith and Happe believed that people with autism have a weaker form of central coherence, meaning that they would excel at picking out details of phenomena while being impaired in understanding how the details fit together [Frith and Happ, 1994]. As supporting evidence, Shah and Frith cite their study in which they show how children with autism completed the block design test (a test where a specific black-and-yellow shape must be copied using individual blocks with black and white patterns on them) consistently faster than typically developed children as well as mentally retarded children, but only when the black-and-yellow shape to be copied was complete and needed to be segmented. When the shape was already segmented, children with autism did not perform better than the other children. This showed that children with autism were better at breaking down an image into its constituent parts, which would result from a weak form of central coherence [Shah and Frith, 1993].

Another theory which addresses the same behaviour is that of executive dysfunction. This term encompasses a number of different high-level cognitive processes such as planning, task-switching, working memory, and impulse/interference (action/sensory) control [Pennington and Ozonoff, 1996]. Consequently, executive dysfunction is an impairment to one or more of these processes. It is not only children with autism who have significant or persistent executive dysfunctions; on the contrary, children with developmental disorders that are believed to involve congenital impairments to the frontal lobes of the brain (e.g. attention deficit hyperactivity disorder, obsessive compulsive disorder, Tourette syndrome) as well as children with acquired damage to the frontal lobes of their brains also have different forms of executive dysfunctions [Hill, 2004]. However, because there is a great deal of evidence showing that children with autism have significant impairments in their ability to plan effectively as compared to typically developing children [Ozonoff and Jensen, 1999] and children with other psychological disorders [Ozonoff et al., 1991], long-term consistent impairments in their ability to effectively shift to more appropriate behaviours when necessary [Ozonoff and McEvoy, 1994], and impairments in their ability to inhibit innappropriate reactions [Russell et al., 2003] [Hughes and Russell, 1993], the theory of executive dysfunction seems to describe and model many behaviours of children with autism particularly well.

2.1.3 Neurophysiological theories

Neuropsychologists and psychobiologists have analyzed the fundamental causes of autistic behaviour and symptoms from a physiological perspective. Although there are many theories which attempt to explain specific kinds of autistic behaviours, this thesis will focus on the mirror neuron system theory, the underconnectivity theory, and the event-related potential theory of autism.

Mirror neuron system (MNS) theory

A mirror neuron is a nerve cell that “fires”, or emits action potential, under two conditions: when an organism observes another organism performing a goal-oriented action, and when the same organism performs a similar or identical action themselves [Rizzolatti and Craighero, 2004]. These neurons are believed by many researchers to play crucial rules in allowing humans to understand the actions of others and to learn by imitating others [Keysers, 2011], with some proposing that these cells form the physiological foundation which allows humans to feel empathy for other people [Carr et al., 2003]. Because combining these skills can give a person a better social comprehension of another individual’s actions, the mirror neuron system (MNS) theory suggests that a deficit in these skills and an impairment in the functioning of these neuron systems would seem to fit many criteria of the behaviours and symptoms of children with autism [Williams, 2008]. Research seems to support this, as individuals with autism have structurally different mirror neuron systems compared with typically-developed individuals. Furthermore, the activation of imitation neurons of lip movements for people diagnosed with Asperger syndrome are delayed when compared with typically-developed people, and children with autism showed both reduced mirror neuron activity while imitating and observing facial expressions compared to typically-developed children as well as an inverse correlation between the severity of their autism diagnosis and their degrees of mirror neuron actitivity [Iacoboni and Dapretto, 2006]. Although these findings support the MNS theory, both the equal performances of children with and without autism on goal-directed imitation activities and the fact that people with autism have different or delayed neuron activation patterns in many other parts of the brain in addition to mirror neurons suggest that the role of mirror neurons in autism could be more complicated than was originally thought [Hamilton, 2008].

Underconnectivity theory

Research using functional neuroimaging has shown that human thought depends on a collaborative network of simultaneous and/or sequential neuronal activity in many different parts of the brain instead of the lone activation of one specific part. In describing the relationships between distinct brain area and structures, functional connectivity refers to the statistical correlation/covariance, not the nature or meaning, of simultaneous neuronal activity patterns among disparate sections of the brain [Friston, 1994]. While typically-developed people show specific patterns of functional connectivity between different areas of the brain while performing simple tasks such as sentence comprehension, the underconnectivity theory of autism suggests that individuals with autism have reduced functional connectivity among the same regions when performing the same tasks [Just et al., 2004]. For example, research using fMRI scanning has shown that although children with autism and typically-developed children matched for age and IQ showed similar degrees of neuron activation in similar parts of their brains while performing the Towers of London task, the children with autism showed less functional connectivity between the frontal and parietal areas of activation than did the control group [Just et al., 2007]. Similarly, research using EEG scans has also shown that even while individuals are resting with their eyes closed, people diagnosed with autism have weaker functional connectivity between the frontal lobes and the rest of the brain than do typically-developed individuals [Murias et al., 2007]. In fact, research using PET scanning has also shown that children with autism show lower functional connectivity than typically-developed individuals between the extrastriate cortex and the temporo-parietal region of the brain while attributing mental states to moving objects in animated sequences [Castelli et al., 2002]. Because reduced levels of functional connectivity have been reported among people with autism while performing tasks in which they are known to have impairments, such as verbal sentence comprehension, executive function, and mentalization, this theory seems to explain many different cognitive and behavioural aspects of autism fairly well.

Event-related potential (ERP) theory

An event-related potential (ERP) is a measured brain activity which occurs in response to any sort of stimulus, whether sensory, motor, or cognitive. Because studying these phenomena allow one to determine how an individual processes specific stimuli using inexpensive equipment and without observing the individual's behaviour, they are of particular interest to researchers studying autism, as those diagnosed with the disorder might seem to ignore or outwardly appear unresponsive to a wide variety of stimuli [Jeste and III, 2009]. Research in ERPs has shown that children with autism have a limited capacity to direct their attention to novel visual and auditory stimuli as compared to typically-developed children; since orienting to novel stimuli is crucial for one's cognitive development, this limited capacity could potentially translate into a cognitive impairment [Courchesne et al., 1985]. There is evidence that this limitation in orienting oneself to novel auditory stimuli is specific to speech-related sounds [Ĉeponiené et al., 2003] due to the fact that children with autism do not naturally choose to focus on speech-related sounds unless specifically told to do so, which would explain children with autism's impairments in language comprehension and usage [Whitehouse and Bishop, 2008]. Research in ERPs has also shown that children with autism show similar delays in timing and characteristics of brain activation regardless of whether they are shown pictures of strangers or pictures of their own mothers [Dawson et al., 2002], and similar research has shown that adults with Asperger's syndrome display slower brain activation when they see pictures of faces or individual facial features while displaying normal activation when seeing pictures of objects [O'Connor et al., 2007]. These ERP-based abnormalities in perceiving and orienting to social stimuli seem to suggest a physiological foundation for many of autism's underlying impairments, social or otherwise.

2.1.4 Treatment

While there is no known cure for autism, there are a number of treatment options for managing the specific symptoms and behavioural issues present in each autistic child's diagnosis [Levy et al., 2009]. All forms of educational treatments share certain practices:

- all treatments suggest early enrollment in order to allow the child to learn as much as possible while their minds are at their most receptive;
- all programs require many interventions with upwards of 25 hours of education scheduled for every week of every year, with parents or family members participating as often as possible;
- all methods use a detailed intervention plan tailored to suit each child's needs and geared to address each child's developmental issues;
- all treatments emphasize a low teacher-to-student ratio to allow each child to experience as much one-on-one time with an instructor as possible, thereby allowing them to learn most effectively;

- all programs utilize continual monitoring and documentation of each child's progress toward each of their goals, allowing for changes to be made to each child's education schedule as necessary [Myers and Johnson, 2007].

Although it has not yet been determined whether one specific method of educational treatment is more effective than another, the general consensus is that any form of treatment is preferable to none [Seida et al., 2009]. Additionally, regardless of which form of treatment is chosen for a child, all methods share the same goals: to reduce the symptoms of their core deficits, to increase their quality of life and ability to function on their own, and to ameliorate the social burden placed on their families [Myers and Johnson, 2007]. While some people with Asperger's Syndrome or other very high functioning forms of autism have been able to live independently and succeed in their professions after many years of treatment [Grandin, 1995], most people with autism will never fully acheive these goals. Furthermore, all people on the autistic spectrum will always have to deal with their social impairments throughout their lives. While certain specific behaviours can be unlearned, autistic traits can only become less severe through education and time and will never go away completely.

2.2 Human-robot interaction

Human-robot interaction is the study of how people and robots can interact with one another. It is a rapidly-developing multidisciplinary area of research that integrates concepts from diverse fields such as computer science, robotics, artificial intelligence, psychology, linguistics, ergonomics, and human-computer interaction. While robots were originally designed to be used in factory-like settings free from human contact, advances in sensing technologies and artificial intelligence have not only made it possible for people to work and interact alongside robots in parallel, but for robots and people to cooperate in order to help each other [Goodrich and

Schultz, 2007]. Research in human-robot interaction can range from topics such as human teleoperation of one or many distant robots to physically assistive interactions between humans and robots to cooperative social interactions between humans and robots.

2.2.1 Physically assistive technology and robotics

Assistive robots give support to people with disabilities by physically interacting with them. Researchers have typically examined how such robots could help people in areas such as physical therapy rehabilitation and assisting those with disabilities to perform simple tasks. Because they are rarely designed to interact with people in social contexts, the robots are seen as helpful tools by their users.

Robotic wheelchairs

Frustrated by the lack of mobility options available to disabled people, Miller and Slack described two different low-cost robotic wheelchair systems that they built with off-the-shelf components and could be used to help disabled people to avoid obstacles, autonomously navigate from one location to another, and maneuver through confined areas. The first wheelchair, Tin Man I, features three modes of semi-automatic operation and was positively received by potential users despite the authors' reports of slow travel speeds. The second wheelchair, Tin Man II, featured similar modes of semi-automatic operation, traveled faster than its predecessor, and received positive qualitative reviews from non-disabled people [Miller and Slack, 1995]. Bourhis and Pino developed another kind of robotic wheelchair for the AVHM project based on a Robuter mobile base and gave it three operating modes: automatic for entering a global trajectory and a user-defined destination, assisted-manual for using wall-following and obstacle-avoiding behaviours, and manual for joystick-based control. In an evaluation which tested how well able-bodied individuals could navigate through an apartment, it was found that assisted-manual mode was easier to use than manual mode and that a fully automatic mode of operation would be very useful for certain users who could not use joysticks very well [Bourhis and Pino, 1996].

Yanco and Gips compared two different methods of controlling a powered wheelchair, which were single-switch scanning (manual control by pressing a switch at specific times) and robotic operation with emergency stop/selection. After having able-bodied participants practice each control method, followed by the participants running a short test course using each control method, the researchers determined that the number of switch presses and the time spent scanning through movement options were both significantly lower during the robotic control runs. Participants also took less time to navigate the course in robotic control, but not significantly less. Furthermore, all participants rated robotic control as significantly better than single-switch scanning in questionnaires [Yanco and Gips, 1998]. Levine, Bell, Jaros et al described the NavChair assistive wheelchair navigation system, a prototype robotic wheelchair based on the Lancer powered wheelchair that could operate in three modes: obstacle avoidance using the minimum vector field histogram and vector force field techniques, manuevering through doorways as narrow as 32 inches 70% of the time, and wall-following [Levine et al., 1999].

Full-contact robots used in physical rehabilitation

Researchers have also designed robotic systems meant to help individuals undergoing upper-limb physical therapy after suffering from strokes. Because stroke rehabilitation is labour-intensive and requires one-on-one interaction between therapists and patients, robotic systems for post-stroke rehabilitation have the potential to allow each physical therapist to treat more patients and to also help patients recover from strokes more quickly. Because this is a new field of research, there are few large-scale, long-term studies of the effectiveness or feasibility of various systems. However, comprehensive literature reviews which compared different kinds of systems found that in general, robot-assisted post-stroke rehabilitative therapy can help to improve short-term and long-term control and strength of upper limbs, can help both chronic and acute stroke patients to recover motor control, and leads to greater restoration of upper-limb motor control than conventional therapy. However, the literature reviews did not find evidence that robot-assisted physical therapy leads to improvements in activities of daily living and could not determine which factors of robot-assisted therapy (e.g. type of system, number of repititions per session, frequency of therapy) most affected motor control recovery [Prange et al., 2006] [Mehrholz et al., 2008].

Burgar, Lum, Shor et al conducted a series of studies on using robot arms to assist in post-stroke physical rehabilitation. After determining that a proof-of-concept elbow-forearm manipulator could help participants in patient-controlled mirror-image therapeutic exercises, another study was conducted in which a robot manipulator-assisted pair of planar mobile arm supports known as MIME (mirror-image motion enabler) were used to help participants carry out therapeutic exercises while gathering position, force, and torque data on the patients' movements. Because this robot-aided therapy setup helped the participants to perform their exercises and gave objective data on the participants' progress, a set of clinical trials were carried out over the course of two months which showed that while robot-assisted therapy using the MIME robot did not result in significantly greater improvement in upper-limb movement than conventional therapy, it did result in significantly greater improvements in shoulder and elbow mobility, which are the two areas that the robot targeted [Burgar et al., 2000]. This robot system was later updated to a design called ARCMIME which did not limit patients movements as much as MIME, in addition to being evaluated as safer, simpler, and easier to use [Mahoney et al., 2003].

Dubowsky, Genot, Godding et al developed various PAMM (Personal Aids for Mobility and Monitoring) robots based on traditional walkers and canes to help elderly individuals in assisted living facilities. The robots were meant to help the elderly to walk and keep their balance, to monitor their health and vital signs, to guide them through their care facility as well as keep them from stumbling into obstacles if they became disoriented, and to remind them to take various medications at the appropriate times. In a series of field tests, the elderly seemed to accept using the device fairly quickly and appreciated its use as a mobility aid [Dubowsky et al., 2000]. Later, Kahn, Zygman, Rymer et al compared the effectiveness of two kinds of post-stroke physical therapy: active-assist rehabilitative training using the ARM (Assisted Rehabilitation and Measurement) Guide and unassisted, unconstrained "free reaching" training. However, with nine stroke patients in the "free reaching" group and the ten patients in the robotic active-assist group all participating in three exercise sessions per week for eight weeks, a set of single-blind evaluators could not find any significant differences in improvement between the robotic and unassisted groups; instead, the patients in both groups made great improvements in their upper-limb mobility after attending physical therapy for eight weeks [Kahn et al., 2006].

2.2.2 Socially assistive robotics and robot-assisted therapy

Social robots are robots which mainly interact with people using speech that takes social context into consideration as well as facial expressions, physical gestures, and other social cues. They can be used to help people by acting as teachers, rehabilitative coaches, assistants for the physically impaired, carers for the elderly, and other non-contact assistive roles. In addition, they often function as research platforms for investigating features about specific modes of social interaction [Dautenhahn, 2007] [Fong et al., 2003a].

Evaluating and classifying social robotics

Feil-Seifer and Matarić described a taxonomy of socially assistive robotics, a subset of assistive robots which aid their human users via their social interactions. They categorized the robots according to such factors as their user populations, examples of the tasks the robots perform, the sophistication of the interactions, and the role of the robot in relation to other humans with whom it will work. In addition, they also described ways that such robots should be evaluated [Feil-Seifer and Matarić, 2005]. Feil-Seifer, Skinner, and Matarić later elaborated on different benchmarks that could be used to evaluate socially assistive robotics, such as the safety and scalability of the robotic technology itself; the suitably-trusted degree of autonomy, the best usage of the robot's imitative capabilities, and the impact of data privacy on the success of the robot's social interactions; how well the robot had achieved its desired social identity and whether the robot's social understanding of people had helped in its performance of necessary tasks; and how the assistive technology itself had impacted the quality of care given to the users, the users' overall quality of life, and, in the cases where the robot will be supervised by human caregivers, the ease of the human caregivers' jobs [Feil-Seifer et al., 2007]. In another review of socially assistive robotics, Tapus, Matarić, and Scassellati described the biggest challenges in socially assistive robotics: the role of embodiment in people's interactions with robots; how a robot's interactions should be matched to suit the user's personality; how the robots' simulations of empathy could affect their interactions with people; how a robot could monitor the level of engagement that a human had in their interactions; how a robot could learn the behaviours of its users and adapt its approaches over time to maintain social engagement; and how easily the skills learned with the robot could transfer into other contexts

Paro

Shibata first described Paro, the robot that featured very prominently in his research, as a robotic pet or artificial emotional creature. The robot's emotions would gradually change over time according to the data it got from its visual, audio, and tactile sensors, and the robot would express these emotions in its actions [Shibata et al., 1996]. When Paro was used in robot-assisted therapy at a children's hospital, participants reported that they felt happier while playing with the interactive form of the robot than during sessions when the robot was a "stuffed animal" and did not respond to any stimuli. The robot also seemed to act as a social mediator and conversation piece for the children at the hospital, and anecdotal evidence seemed to suggest that children with autism also responded to it [Shibata et al., 2001]. When Paro was later used in free-form group robot interaction sessions at a nursing home, the participants' questionnaires showed that they felt more energetic after interacting with the robot than they did beforehand. Additionally, some participants also spoke to Paro as well as touched the robot more after the final interaction session than they did after the first one [Wada et al., 2002]. Physiological data in the form of urinary analyses also showed that the patients were better able to deal with stress during the weeks that they interacted with Paro, and the staff at the nursing home also reported lower feelings of burnout among themselves during the weeks that the patients interacted with Paro [Wada et al., 2004]. When a similar longitudinal study was conducted, the participants' questionnaires consistently showed that they were happier after interacting with Paro for a 5-month period. Caregivers also noted that the participants looked forward to interacting with the robot, interacted more with their peers during the robot therapy sessions, and were happier as well as more energetic while interacting with Paro [Wada et al., 2005].

Probo

Saldien and Goris's robot Probo was designed with the appearance of a child-friendly furry mastodon or mammoth, and was meant to be used as a robot companion and communication aid for children in hospitals. In addition to the robot being able to keep children entertained with its interactive behaviours, the screen on the robot's stomach is also meant to allow children to communicate with the outside world using standard video-conferencing techniques as well as explain medical procedures to children using multimedia techniques in order to alleviate their fears [Saldien et al., 2008b]. Because the Probo has a very expressive face with eyes, eyelids, eyebrows, a mouth, and a trunk-like nose, the robot is able to express a fair number of basic emotions. Probo's emotions are represented as vectors in a two dimensional space bound by a unit circle, with one axis for valence (happy/sad), one axis for arousal (surprised/tired), and the length of the vector as the intensity of the emotion. When participants were asked to describe Probo's various facial expressions, each of which represented a unique emotional state of the robot, by looking at pictures of a virtual representation of Probo's face, children successfully recognized five of the eight displayed emotions while adults successfully recognized six of the eight emotions [Saldien et al., 2008a] [Goris et al., 2008]. Furthermore, because Probo is meant to give soft hugs to children in a safe manner, the robot uses soft or springy materials whenever possible and also uses a novel, extensively-tested set of compliant acutators which use Bowden cables and non-backdriveable servos to either transmit rotational motion or a pulling force across a large distance [Goris et al., 2011].

IROMEC

The European project IROMEC (Interactive RObotic MEdiators as Companions) is aimed at designing a robotic play companion for children with limited play skills due to physical or mental impairments, since play has been recognized as an activity that helps children achieve their full learning potential and promotes social interaction.

The IROMEC robot was designed so that children could play with it in a variety of different play scenarios that are meant to have specific therapeutic or beneficial effects [Kronreif and Prazak-Aram, 2008]. In addition to the project using the ICF-CY (International Classification of Functioning and Disability, Children and Youth), a compendium developed by the World Health Organization to describe and code all health-related experiences, as a set of guidelines for designing the robot, evaluating the robot's interactions with children, and outlining the robot's play scenarios [Besio et al., 2008], the project has also used interviews and focus groups involving therapists, teachers, care-givers, and parents from each group of children that the project is meant to help. By gathering information about the cultural, social, emotional, and functional implications of different design choices for the robot, the IROMEC project has been able to design a modular robotic system that should address the needs of many different groups of children with disabilities [Marti et al., 2009]. Specifically, to address the needs of children with autism for help with social interaction and social communication, the IROMEC robot can play simple games involving imitation, sensory rewards, and turn-taking. Furthermore, because children with autism tend to be a diverse group of individuals with different manifestations of the same impairment and very particular preferences, the robot's games can be tweaked and modified to focus on the specific issues of each child and its hardware is designed to be plug-and-play to allow the children to participate in the games using various devices and input methods. However the robot and its games are tailored, it will still help children with autism and other children with disabilities in their social, cognitive, sensory, motor, communication, and emotional development [Ferrari et al., 2009].

2.3 Robots and autism

As previously stated, children with autism prefer playing in repetitive ways in highly structured situations. This makes it difficult for them to play with other people, since most people do not enjoy playing highly repetitive games and do not behave as predictably as inanimate objects. Instead, children with autism prefer playing with computers and electronic devices, which are quite capable of being played with in the abovementioned ways [Moore, 1998].

2.3.1 Research affiliated with the AuRoRA project

Children with autism also enjoy playing with robots because they are also capable of playing in highly repetitive ways and can react predictably to external stimuli, and the AuRoRA project at the University of Hertfordshire has done a great deal of research on how children with autism play with robots and how this special form of play could be therapeutic for the children.

Vehicular or zoomorphic robots

In the early years of the AuRoRA project, it was found that children with autism were happier when playing with the wheeled robotic toy Labo-1 which moved autonomously than they were while playing with similar but inanimate toys, such as a wheeled truck [Dautenhahn, 1999] [Werry et al., 2001a]. Children with autism could also interact with and play near other children with autism when an interactive wheeled robot was present [Werry et al., 2001b]. Furthermore, there is reason to believe that the manner in which children with autism behave at home, specifically with respect to how cautiously and actively they play with toys, is reflected in how they play and interact with the wheeled, toy-like robot Pekee [Salter et al., 2004]. This shows that robots in the form of toy wheeled vehicles could act as "social mediators" for children with autism, thus making it easier for the children to interact with other people. In addition, studies have shown that when the dog-like robot Aibo was programmed to adapt to the play styles of children with autism in real time using the cascaded information bottleneck method [François et al., 2008], the children played in more developed and interactive ways over time [François et al.,

2009].

Humanoid robots

Children with autism socially interacted with the humanoid robot Robota in a much more engaged manner than they did with people, and socially interacted with an adult in novel ways when the robot was present and active during the interaction [Robins et al., 2005] [Robins and Dautenhahn, 2006]. Robota has also been found to make children spontaneously imitate its actions and postures, with the children even going as far as playing a simple imitative game with the robot when it was controlled by the experimenter [Robins et al., 2004a]. Similar results for spontaneous imitative play were found with the humanoid, minimally expressive robot KASPAR; in addition to imitative play being observed between a child and the robot, who was controlled by the experimenter or a carer, such play was also observed when the robot was controlled by another child with autism. This is particularly interesting because the two children initially did not want to play together, much less sit at the same table, but KASPAR's presence and play style as a social mediator seemed to convince the children to play with each other using the robot as a tool do so [Robins et al., 2009]. This strongly suggests that humanoid robots can be used to teach simple behaviors to children with autism using imitation, as well as humanoid robots having the potential to foster interactive social play between children with autism. Additionally, when children with autism participated in free-form play sessions with KASPAR after it was outfitted with touch sensors on its arms, hands, feet, shoulders, and head, researchers learned that children tended to mainly pull on and grab KASPAR's hands as well as probe and prod its face while playing with it. This helped researchers to devise new play scenarios in which KASPAR would respond to specific kinds of touch and help children with autism to learn about proper tactile interaction, which is a problem for many children with autism [Robins et al., 2010].

Robot design issues

A robot's appearance also seems to affect how children with autism will socially interact with it. In one study in the AuRoRA project, children with autism seemed to be initially more socially interactive with a featureless humanoid robot in silver-foil colour than with a robot which looked like a little girl's doll. However, they became equally interactive with the robots over time [Robins et al., 2004c]. Additionally, children with autism even responded in a more socially engaged manner to a person dressed up in silver foil and acting like a robot than they did to the same person in an normal outfit [Robins et al., 2004b]. This suggests that while a simpler design may initially elicit more social interaction from children with autism, they are ultimately fascinated by robots no matter their appearance. In another comparative study, children alternated once between participating in play sessions with KASPAR the humanoid robot and playing with IROMEC, a mobile modular companion robot designed to play with children with different disabilities in many different ways [Marti, 2010] [Robins et al., 2008]. Preliminary data from this study seemed to suggest that while the children enjoyed playing imitative and turn-taking games with both robots, children found it both easier to mimic KASPAR and more enjoyable to interact with it than they did with IROMEC [Iacono et al., 2011].

2.3.2 Other research on robots and autism

Since it was first discovered that robots such as the turtle-like LOGO can positively affect the social interactions of children with autism [Weir and Emanuel, 1976], many researchers have studied this phenomenon from a number of different perspectives.

Keepon

In addition to the abovementioned projects, Kozima and Yano first suggested using games with robots that could establish and maintain joint attention in order to teach children with autism skills for social interaction [Kozima and Yano, 2001]. Later, Kozima, Nakagawa, and others developed a simple snowman-like robot, Keepon, to implement these ideas. They found that the robot was capable of establishing triadic interactions between itself, a 2-4 year old child with autism, and another individual, whether another child or the parent / caregiver [Kozima et al., 2005]. Keepon was also used in a three-year longitudinal study of interacting with children with autism, during which it was found that a child who originally would not make eye contact with the robot (which was remotely operated by an experimenter) gradually drew closer while making eye contact and interacting with Keepon over the course of the study [Kozima et al., 2007]. Another child in the same study developed a simple imitative game between itself and the robot as well as triadic interactions between itself, its caregiver, and the robot after five months of no interest in Keepon. Another child became possessive, gentle, and interactive with Keepon after being initially violent with it, which their therapist said was their typical behaviour when encountering someone new to whom they did not how to relate. The researchers believe that this suggested that the children gradually came to sense a "mind" behind Keepon's simple attentiveness and emotional responses, which would refute a commonly-held conception of children with autism [Kozima et al., 2009].

Matarić's robots

Feil Seifer and Matarić conducted a pilot study in which a mobile robot equipped with a bubble-gun and large buttons interacted with children with autism, and they found that the children displayed more social actions such as speaking, interacting with the robot, and pressing its buttons when the robot's behaviour was contingent on the child's than when the robot's behaviour was random [Feil-Seifer and Matarić, 2008a]. When the robot operated in its "contingent" behaviour, it used a control architecture which allowed the robot to engage children with autism in DIR (Developmental, Individual-difference, Relationship-based) /Floortime therapy. In this architecture known as B^3IA, the robot's behaviour at any given time was determiend not only by its immediate sensor data, but also by user-specified preferences, the robot's interaction history with each child, and an automatic evaluation of the quality of its recent interactions with each child [Feil-Seifer and Matarić, 2008b]. In an ongoing longitudinal study, Feil Seifer and Matarić also found that when Bandit, a humanoid robot torso mounted on a mobile base, engaged in DIR/Floortime therapy with children with autism, an automatic classifier applying Gaussian Mixed Models to overhead-camera images of the interactions between the children and the robot was able to correctly group the children's behaviours 91.4% of the time [Feil-Seifer and Matarić, 2011].

Robots for studying joint attention

Fasel et al suggested a study that would use computer graphics and robotic systems to study the development of joint attention in infants with and without autism [Fasel et al., 2002]. In a similar vein, Scassellati proposed using a system to help diagnose children with autism by observing measurable behaviours such as gaze direction and focus of attention, position tracking, and vocal prosody while the children interacted with a social robot. Furthermore, because social robots can be programmed to consistently perform specific actions and social cues in precise ways, can make their behaviours more or less nuanced over time according to the severity of an autisticc child's diagnosis, and are naturally engaging for children with autim, Scassellati argued that robots would be ideal tools for diagnosing, treating, and understanding autism [Scassellati, 2005a] [Scassellati, 2005b]. Ravindra, De Silva, Tadano et al also conducted a study along similar lines by using an autonomous humanoid HOAP robot to try to initiate joint attention with children with autism. By tracking the children's eye movements from the perspective of a camera looking straight up at the child's face and classifying the children's points of gaze according to a mixed Gaussian-based cluster method, the researchers showed that the children gradually increased the amount of time spent participating in joint attention with the robot in each trial [Ravindra et al., 2009].

Other robots used in autism research

Pioggia, Sica, Ferro et al developed an android head called FACE with an array of touch sensors embedded below its "skin" which is capable of making basic facial expressions, opening and closing its mouth, and moving its eyes. In a preliminary set of trials with four children with autism, the researchers noted that the children spontaneously began to mimic FACE's head motions and facial expressions during their interactions and also followed its eye gaze after being prompted by their carer [Pioggia et al., 2007]. Later, Liu, Conn, Sarkar et al developed a robotic basketball hoop (a basketball hoop mounted on a 5-degree-of-freedom robot arm) which altered its position, movement speed/patterns, and background music in real time to make an child with autism like it, be engaged with it, and have as little anxiety as possible while playing with it. Each child's support vector machine-based affective model had to be determined beforehand by having the children engage in tasks of concentration under specific, changing circumstances and measuring physiological data (e.g. cardiac activity, skin temperature, electromyograhic activity). After developing models for each child, the researchers found that by reading the children's physiological data in real time and comparing it with each child's model, the robotic basketball hoop successfully chose behaviours that promoted engagement, reduced anxiety, and were liked by the children slightly over 75% of the time. Such a system could be used to have a robot socially interact with children with autism and record the child's physiological reactions to specific behaviours as well as adapt the robot's behaviour to make the children like it, be more engaged, and not feel anxious [Liu et al., 2008].

Michaud and Théberge-Turmel studied many small robotic designs (an elephant, a spherical robotic 'ball', etc) to see which one best engaged children with autism in playful interactions that helped them develop social skills [Michaud and

Théberge-Turmel, 2002]. Later, Duquette, Michaud, et al's preliminary results showed that for a pair of children with autism, a simple humanoid robot elicited more shared attention and imitations of facial expressions than a human was able to, while a human was able to elicit more imitation of kinesic movements and familiar actions than a humanoid robot [Duquette et al., 2008].

2.4 Collaboration

"Collaboration" is a term applied to many different behaviours in a variety of settings, but in a very broad sense, it is the working and interaction of multiple parties towards one or more common goals. While the terms "collaborative" and "cooperative" are often used in an interchangeable fashion, Roschelle and Teasley distinguish the two terms by describing collaborative activities as ones in which the participants are both actively working together to coordinate their actions in order to solve problems, while cooperative activities will feature distinct distributions of labour, with each participant focusing their efforts on a different, specific part of a problem [Roschelle and Teasley, 1995]. This is not to say that the distribution of labour is the sole criteria for distinguishing the two methods of problem solving; instead, Roschelle and Teasley argue that is is the way in which a task's work is divided. While cooperating, tasks are seperated hierarchically into distinct subtasks and coordination is only needed when the subtask's results are brought together. In contrast, the tasks of a collaborative endeavour are heterarchically separated into overlapping layers and require continual coordination and synchronizing [Roschelle and Teasley, 1995]. As such, collaboration is described in this thesis as any shared activity which requires continual communication, coordination, and synchronization among two or more co-located parties in order for all to achieve a common goal.

Collaborative interactions can be described as such even though only one aspect of them involves collaboration:

- **Situation** - the circumstances surrounding participants can be set up in a collaborative manner if the participants have roughly symmetric levels of knowledge and ability to perform actions, if they have goals that all parties are aware of and actively share, and if they work together by taking turns instead of dividing the work between themselves and working independently on their own;

- **Interactions between agents** - the participants' interactions are said to be collaborative if there is a high degree of interactivity between them with every exchange affecting each participant's thought processes about the task at hand, if they communicate in a synchronous way and have to figure out who will speak at a given point in time, and if they can negotiate over goals and how to get there;

- **Learning mechanisms** - the way that the participants learn are considered collaborative if they use inductive reasoning, if there are efforts to reduce everyone's cognitive load, if explanations are given or requested, and if there are conflicting statements or positions about the task that must be resolved [Dillenbourg, 1999].

In the case of the interactions in my research, all of the situations in my experiments were specifically designed to be collaborative, as all participants were meant to perform the same or similar actions, all the participants were meant to have the same goals in each experiment, and the participants were meant to work together by switching roles and taking turns. Furthermore, it was the goal of my work that the interactions as well as the learning which took place between the children with autism would gradually develop to become more collaborative.

Researchers have also examined the nature of collaboration when computers and people are involved. Dillenbourg, Baker, Blaye, et al recognized that in such interactions, the design of the computer interface can allow an external agent to control certain aspects of the collaboration, such as when or how participants should take turns or how the labour should be divided among the participants. If the interface were designed well, it could promote learning among the participants by supporting helpful interactions. Furthermore, when two people collaborate to solve a task on a computer, different facets of the computer software could change the socio-cognitive dynamics among the people [Dillenbourg et al., 1996]. Specifically, software interfaces that promote different, distinct roles among the collaborative partners help to promote social interaction between them [O'Malley, 1992]. In addition, when one or more people directly collaborated with a computer-based agent and all parties could perform the same actions, similar behaviours and phenomena occured as when people directly collaborated with each other without a computer

2.4.1 Collaboration between humans and robots

Robots were once programmed to perform repetitive actions in an open-loop manner in industrial settings that had been specially designed for them, and only certain people were allowed near robots in order to reprogram or repair them. However, because robots can now operate autonomously or be tele-operated in a variety of settings and are often asked to work with and interact alongside people, researchers have begun to study how humans and robots can successfully collaborate with each other and to design paradigms and protocols for doing so.

Robots and humans interacting as equals

Drawing inspiration from how groups of people work together to solve problems, some human-robot interaction researchers have studied how groups of people and robots collaborate together for mutual benefit. Hinds, Roberts, and Jones studied the effects of different robot appearances and different robot status roles on the task-solving capabilities of different human-robot collaborative pairs. Ultimately, they found that people collaborated better with human-like robots when the people had to delegate responsibilities to them or ask them to perform tasks too demanding for people, while more machine-like robots and people collaborated better in situations where the robot had a higher chance of being unreliable or where personal responsibility was emphasized [Hinds et al., 2004]. Drury, Scholtz, and Yanco outlined an awareness framework for describing different human-robot collaboration scenarios and were able to re-evaluate different failures in a collaborative human-robot search-and-rescue competition in terms of various deficiencies in human-robot awareness [Drury et al., 2003]. Later, Yanco and Drury outlined another framework that categorized all forms of human-robot collaboration according to how cooperatively the humans and robots behaved in temporal as well as spatial terms; how the humans and robots communicated their collaborative efforts to each other; the organization of the robots themselves; and the nature of the human-robot collaborative task itself [Yanco and Drury, 2004]. Sidner, Lee, and Lesh studied how robots could use conversational gestures and gaze patterns to better engage and sustain people in collaborative, socially assistive interactions. By focusing on turn-taking, interpreting human actions, and shared-goal decision-making, they adapted human-human collaborative conversation techniques in order to use in human-robot collaborative conversation [Sidner et al., 2003].

Human as manager of robots

Laengle, Hoeniger, and Zhu examined how robots and humans could work together in groups and determined that such groups had four requirements: intelligible communication among all parties, proper interpretation of what was communicated, coordination of activities, cooperation among the agents when teamwork is required, and safety precautions implemented on the robots for the benefit of the humans. In these groups, the humans would be coordinators and managers for the robot workers, and such principles seemed to have promising results when implemented on the KAMRO robot and its multi-agent architecture, KAMARA [Laengle et al., 1997]. Fong, Thorpe, and Baur studied how a properly designed human-robot communication protocol could lead to an easier-to-use collaborative robot teleoperation system (using the definitions described earlier in the thesis, such a system should really be called a cooperative system). Specifically, by having humans cooperate with multiple independently-controlled robots, both were able to accomplish more than the instances where the humans had to manually control every aspect of the robots [Fong et al., 2001]. In a follow-up user study on the same system, the researchers found the the roles and capabilites of the human controller and robots should have been more clearly defined. Additionally, the study suggests that control strategies should be developed that would not require a human to control the general movement of any single robot, such as global (large-scale swarm) control. Such a strategy should also allow a human to easily resume control of a single robot to determine the cause of robot problems via a dialogue system while increasing the autonomy granted to other robots [Fong et al., 2003b].

Leonardo

Breazeal, Hoffman, and Lockerd developed a humanoid robot Leonardo which was capable of being taught in naturalistic ways by people to execute simple tasks and then performing them collaboratively with another person [Breazeal et al., 2004]. Leonardo communicated with partners via social gestures and facial expressions, and its sensing as well as learning systems were motivated by the idea of joint intention, or multiple agents continually coordinating their actions and intentions in order to collectively achieve a mutual goal (e.g. executing a coordinated attack, maneuvering of a heavy object) [Levesque et al., 1990]. Lockerd and Breazeal found that Leonardo's speed in successfully learning a simple task (collaboratively pressing buttons with another participant) using its technique of socially-guided learning was superior than its expected performance if it had used Q-learning in a number of different configurations [Lockerd and Breazeal, 2004]. Later, Breazeal, Kidd, Thomaz et al analyzed self-report questionnaires and coded video footage from people teaching and collaborating with Leonardo under two different conditions: in one case, the robot would continually express its internal state both implicitly via gaze as well as other non-verbal behaviours and explicitly using expressive gestures and other social cues, while in another, the robot would only express its internal states using expressive gestures when it was asked to do so. According to the questionnaires, the researchers determined that participants understood the robot's abilities and states at any given time as well as understood what the robot was "thinking" better when it communicated implicitly as well as explicitly. Furthermore, the coded video footage showed that the humans took less time interacting with the robot overall, found errors in its behavior faster, and corrected the errors better when the robot communicated both explicitly and implicitly [Breazeal et al., 2005].

2.4.2 Collaborative learning about robotics among children

Robotics is an interdisciplinary science that uses ideas from many different fields of study. Therefore, when teaching its fundamentals to students, an effective technique is to ask them to design their own robots by working together in groups [Avanzato, 1999] [Avanzato, 2000]. Each group member usually focuses on one particular aspect of the robot, so while one group member would focus on programming, another would focus on the robot's mechanical structure, and another would focus on its sensors and actuators. This method poses both a unique set of challenges for the students as well as a unique opportunity to observe how groups of students learn by collaborating together.

Puntambekar et al found that in a mobile robotics course with multiple groups, intragroup communication focused more on details of models, while intergroup communication focused more on justifying the roles and methods each group's robot used in gathering scientific data [Puntambekar et al., 1997]. Denis and Hubert found that children in robot design groups chose specific, distinct roles for themselves and that a group's discussions on why their robot behaved a certain way were always beneficial to the robot's design [Denis and Hubert, 2001]. Järvinen observed that given the chance, children in robotics groups were able to correctly learn about robotic technologies for themselves as well as from their teammates, and only asked the teacher's advice when they needed it [Järvinen, 1998]. Later, Järvinen and Hiltunen conducted a similar study on children learning about automated systems with LEGO/Logo control labs and they found that the children were more emotionally engaged in their work and felt a sense of ownership towards it when they the class material was related to issues that they wanted to solve in their own lives [Järvinen and Hiltunen, 2000]. Beer, Chiel, and Drushel found that students in a group-based, interdisciplinary robotics course felt that being in a group comprised of different perspectives was helpful in designing a robot, since there were many instances in which more than one solution would solve a problem [Beer et al., 1999].

Nourbakhsh, Hamner, et al found that while groups of students in a summer robotics course reported the most trouble with technical issues, they reported breakthroughs with these issues as well as non-technical ones, such as teamwork and problem solving [Nourbakhsh et al., 2004]. In fact, "teamwork" was the issue that had the greatest difference between how many children expected to learn about it and improve their mastery of it going into the robotics course (under 10%) and how many responded after attending the summer course that they saw improvement in it (over 70%) [Nourbakhsh et al., 2005]. Similarly, when a group-based collaborative course on mechatronics was offered at Bucknell University to upper-level students, the collaborative approach that the course took in teaching the students, assigning homework, having them design and program their devices, as well as test the groups for competency in specific skills was rated more highly than half of the other features of the course [Shooter and McNeill, 2002].

2.5 Play

Although people can often identify when children are playing and can distinguish such activity from work, it is difficult to define play or to describe what actions or behaviours comprise it. Even when Garvey described play as having a number of key characteristics, namely that it is pleasurable; that it is spontaneous in the sense that one cannot be persuaded or forced into play; that its form is voluntarily chosen; that it has no productive goals; and taht it involves "active engagement on the part of the players", she ultimately had to define play in relation to what it was not when she described its last charactertistic as having "certain systematic relations to childhood activities that are not play" [Garvey, 1977]. While earlier work by Parten with preschool children did not attempt to give a strict definition of play, it was very influential in how play was categorized with respect to its social aspects. Specifically, Parten observed that children played more socially as they grew up and categorized play into distinct types according to its degree of social interaction:

- **Unoccupied** - child does not play and instead occupies themselves by watching some non-play-related phenomenon or walking around;
- **Onlooker** - child spends most of their time watching other children play and talks with those involved, but does not participate in play;
- **Solitary** - child plays with toys by themselves and does not attempt to communicate with other children, be near them, or imitate them;
- **Parallel** - child plays with toys by themselves, but plays near other children and beside them instead of actually playing with them;
- **Associative** - child plays with toys with other children and commmunicates with them about their activities, but there is no overarching structure to how the children play together;

- **Cooperative** - child plays with toys with other children in an organized game or activity with rules and a common goal [Parten, 1932].

These categories were very influential in my descriptions and codings of the children's forms of play in my experiments.

2.5.1 The roles of play and collaboration in different theories of learning

Despite the fact that play is a difficult concept to describe, it is generally acknowledged as having an essential role in how children learn and mentally develop, even if its exact role is contested. Furthermore, the concept of collaboration, whether in play or in work, is also recognized as playing a key role in children's social and mental development.

Piaget's stage theory of cognitive development

In Piaget's theory of early childhood development, children tend to progress through specific forms of play and cognitive development at certain stages of their lives, with each form of play and level of development building cumulatively on top of the concepts that are learned in previous developmental stages. From birth until the age of two, in which children are in their sensorimotor stages, children tend to engage in *sensorimotor* play by learning to control their movements, experimenting with different ways of sensing the world, and understanding how their actions can change what they sense. Between the ages of two and six, children are in their *preoperational* phase and tend to engage in symbolic or representational play, in which they use one object to represent or symbolize another object. In this form of play, a child can pretend that a block is a plane or use a broom to represent a guitar. Children in this age range can also engage in sociodramatic play, in which they pretend to be other individuals in different circumstances. Finally, from the age of seven onwards, children tend to play games with rules, e.g. sports and board games, after learning about cooperation and competition [Piaget, 1962].

Piaget's theory also states that in every stage of development children are practicing *assimilation* and *accomodation* whenever they learn. According to Piaget, assimilation is the taking of information from one's surroundings and changing it to match one's cognitive schema of how the world works. Assimilation is performed whenever someone encounters new information, or finds themselves in an unfamiliar situation and attempts to understand the new phenomenon by refering back to previously learned concepts. In contrast, accomodation is performed when someone modifies their own cognitive schema in order to make room for new information from their environment. While both processes are necessary requirements for cognitive development, Piaget claims that whenever a child engages in play, they are mainly assimilating information from their environment into their existing schemas. However, whenever a child imitates a behaviour that they have seen before, they are trying to accomodate information from the novel behaviour into their own mental schema [Piaget, 1962].

Vygotsky's social development theory

In contrast, Vygotsky's theory of social development views the concepts of play and collaboration from a different perspective. Unlike Piaget's claim of individual cognitive development preceding certain kinds of learning, Vygotsky believes that social interaction plays a pivotal role in children's development and that any changes in a child's thought processes will first come to them in their interactions with others. According to Vygotsky, children learn a great deal by engaging in collaborative or cooperative dialogues with other individuals (teachers, adults, peers, or computer systems) who are more skillful in certain tasks or more knowledgeable about certain subjects. These individuals are known as *more knowledgeable others* and in their social dialogues with children, they transmit information by modeling certain tasks or giving verbal instructions on how something should be done; alternatively, individuals can also provide *scaffolding*, an externally-enforced educational structure/arrangement, to give children hints and allow them to accomplish a skill or learn a fact. These individuals and helpful interactions are necessary for a child to learn certain concepts that they cannot learn on their own, and the theory of social development states that skills which can be learned with careful guidance from another are said to reside in a child's *zone of proximal development*. Children can internalize more knowledge and develop their cognitive abilities further than they could on their own by using these forms of social learning [Vygotsky, 1978].

Additionally, Vygotsky also believed that play helped children to learn and develop cognitive abilities. He felt that Piaget's concept of symbolic play was pivotal for a child's development of abstract thought - by first using one object to symbolize another one, e.g. a broom for a guitar, a child has learned to use the object (in this case, the broom) as a *pivot* which helps to separate the concept of an object from the object itself. As a child grows, Vygotsky claims that they will learn to internalize pivots as imagination and abstract concepts which will help them to better comprehend the world. Furthermore, when a child participates in imaginary play with other children or by themselves, they begin to understand the idea of social roles and comprehend the rules that govern their relationships as children assume roles which are not their own and imitate others' actions. Because imaginary play involves an understanding of social rules, it also prepares children for participating in more complex social games with clearly defined rules and allows them to understand the social concept of intentionality [Vygotsky, 1978].

Other constructivist theories

Bruner has similar thoughts as Vygotsky on the nature of play and how it factors into a child's development. Bruner describes play as a means of gathering information about one's surroundings and a way of developing experiences in particular settings. In play, children can experiment with novel combinations of behaviours which allows them to be more creative, more mentally flexible, and develop a foundation of experiences for later learning, particularly to learning by imitation. Bruner sees social play as an activity that allows for even more creativity since the consequences of ones's actions are greatly reduced than they would otherwise be in non-social play, thus enabling one to engage in riskier behaviour. Bruner also sees play as a means for learning about social communication since children use "switch signals" and "play faces" during play in order to show that their actions should be interpreted in a more playful context. This helps children to learn about multiple levels of social communication and to use context to interpret someone's behaviours [Bruner, 1974].

Lave and Wenger also have similar thoughts as Vygotsky, but their theories focus on how social learning and collaboration can contribute to a child's development. Lave and Wenger's theory of situated learning states that learning is not merely what occurs in a classroom setting, i.e. transmission of abstract knowledge from one individual to another without any sense of context. Instead, learning is usually an unintentional process that occurs within activities, context, and culture; it begins with people trying to solve real-life problems and requires individuals to imitate others' actions, to socialize with others, and to collaboratively visualize problems with others. Situated learning takes place in *communities of practice*, which are communities that have a common interest or profession and learn from each other by sharing experiences and information with each other. These communities are created by a process known as *legitimate peripheral participation*, in which newcomers to a community begin participating by taking part in simple, low-level tasks that are necessary and productive for the community's goals. By taking part in such peripheral activities, new members can learn a community's particular jargon and become accustomed to the way a community is organized. When members have physical and social access to the knowledge of a community's group of experts, they can understand how each and every member's contributions fit into a more general context [Lave and Wenger, 1991].

2.5.2 Autism and play

Although it was generally known that children with autism played in qualitatively different and less developed ways that typically-developed children, children with learning disorders, and children with physical disabilities, it was originally seen as difficult to get children with autism to participate in more sophisticated forms of play than mere sensory stimulation. As such, it was believed that play among children with autism was best used as an assessment and diagnostic tool for the disorder instead of being used in a therapeutic manner as treatment for such children mainly due to the lack of research in regards to play therapy [Wulff, 1985]. However, with more research being conducted on play therapy and with more of it showing positive results, play is now used both as a tool for assessing and researching autism as well as a form of treatment for the disorder.

Play as therapy for autism

In a study by Thorp, Stahmer, and Schreibman, three children with autism received 80 sessions of sociodramatic play training (symbolic play which told a story) at 12 minutes per session, with two to three sessions conducted per week. Metrics were gathered before the intervention, immediately after each session was completed, and during a follow-up session three months later. The data showed that the intervention dramatically increased displays of sociodramatic play by the children, improved their language skills, and improved their social behaviour not only between the first session and the last one, but also between the first session and the follow-up period. Furthermore, these changes generalized across toys, individuals, and settings [Thorp et al., 1995].

In another study by Field, Field, Sanders et al, an adult either played socially in dyads with children with autism as a control group or actively imitated the behaviours of different children with autism in dyads during three different sessions. Although the researchers did not report findings on the control, they did show that during the second session of imitative play, the children displayed more social behaviours with the adult such as looking at them, vocalizing, smiling, and engaging in social play, and that during the third session of imitative play, the children moved closer to the adult, sat next to the adult, and touched the adult, in addition to engaging in more social play and mirror play than in the first session. These findings suggest that imitative play helps children to be more engaged with adults, to socially interact with them more, and to socially play with them more [Field et al., 2001].

Kasari, Freeman, Paparella et al also conducted a study in which children with autism received one of three interventions over a period of 5-6 weeks using applied behaviour analysis: joint attention training in play, symbolic play training in play, or no training as a control group. The study showed that in addition to the children actually learning how to initiate joint attention or engage in symbolic play (depending on their intervention) and generalizing these skills to use them in post-intervention play sessions with their caregivers, the children who received training interventions also displayed these behaviours more frequently and were more engaged while playing with their caregivers than the children in the control group. Furthermore, while the children participating in a particular intervention usually only improved in the skills for which they received training, there were also cases of crossover, or children improving in skills which were not explicitly taught to them in the intervention sessions [Kasari et al., 2006].

Bass and Mulick conducted a review of peer-mediated social interventions, a form of social play therapy that has a great deal of empirical data to support its efficacy. In this form of therapy, typically developed peers or siblings are trained to 'intiate, prompt, and reinforce' social play with a child with autism. This is because typically developed children naturally tend to play with other typically developed children; without proper intervention, the social impairments of children with autism keep them isolated from typically developed children's activities. By utilizing typically developed children and typical play activities to teach social skills to children with autism, there is a much higher likelihood that children with autism will learn how to generalize the social behaviours and skills that they learn into other settings with other children [Bass and Mulick, 2007]. Pioneered by Strain, Odom, Goldstein and associates, peer-mediated social intervention has been developed over the course of 35 years and has a great deal of empirical data to back up its efficacy [Strain et al., 1979] [Odom and Strain, 1986] [Odom et al., 1999].

Play as assessment/research tool for autism

While social play has been recognized as a useful means for learning about social interaction as well as other skills, children with autism unfortunately do not engage in social play easily or often because of the social impairments which characterize their disorder [Howlin, 1986]. Meyer, Fox, Schermer et al found that in intetgrated classrooms which paired up typically developed children to play with autistic ones , there were not many differences in the dyad's interactions regardless of whether the teachers adopted a more *laissez-faire* attitude toward the interactions or whether they adopted a more vigilant attitude. However, the sessions which featured fewer teacher intrusions into the dyad's interactions featured more contact of the autistic child with the toys in front of them, more appropriate play (isolate, parallel, interactive, and cooperative play) as well as inappropriate play (self-stimulating), and fewer spontaneous vocalizations from the child with autism. This suggests that pairs of children with autism and typically-developed ones can play together and socially interact well even with minimal adult supervision [Meyer et al., 1987]. Dewey, Lord, and Magill found that different kinds of play materials elicited different play responses in dyads comprised of a neurotypical child and a child with autism. Specifically, rule governed games such as board games elicited more fun and more complexity of social play (how much active participation was required by both participants to reach a common goal) than did construction materials used for building structures. Furthermore, construction materials elicited more fun and complexity of social play than either dramatic materials for make-believe games or functional materials used for repetitive, sensorimotor play [Dewey et al., 1988]. Restall and Magill-Evans found that because children with autism have difficulties engaging in solitary symbolic play as well as social play, they are prevented from learning more about social interaction [Restall and Magill-Evans, 1994]. Wolfberg and Schuler later found that children with autism are able to successfully participate in symbolic play with other neurotypical children when there are additional support structures in place for the autistic child [Wolfberg and Schuler, 1999]. Children with autism are also known to have difficulties with taking turns and will actually perform turn taking less often than other children [Mundy et al., 1986]. This might be connected with their impaired imitation abilities, as studies involving infants playfully imitating their mothers' actions have shown that the earliest forms of turn-taking occur when typically-developed infants can recognize that another individual has intentionally imitated their own actions and can signal that they have intentionally imitated the actions of another [Nadel, 2002]. Because engaging in social play and symbolic play are both non-intuitive for children with autism and crucial for their social development, a great deal of research has been conducted on the specific difficulties children with autism have in engaging in these forms of play.

Even when play is not necessarily social, any form of play more sophisticated than sensorimotor play, such as any variation on functional, symbolic, or constructive play, is positively correlated with language development. Unfortunately, children with autism tend to engage in solitary, sensorimotor play or odd, limited forms of functional play (using simple objects correctly and combining related objects) far more often than any other type of play, which does not help them to develop cognitively or socially. Sigman and Ungerer first discovered that children with autism were more limited in their displays of functional play than either typically developed children or mentally retarded children. Children with autism were particularly limited in functional play with dolls and were also more limited than the other children in their imitative capabilities and their displays of symbolic play, both with and without prompting from the experimenter. Because spoken language comprehension was positively correlated with these kinds of play among all children, Sigman and Ungerer suggested that the cognitive impairments of children with autism might be related to their delayed social development [Sigman and Ungerer, 1984]. Charman and Baron-Cohen later found that while children with autism were capable of engaging in symbolic play when experimenters prompted the children to do so, fewer of these children later engaged in symbolic play without the experimenters' prompting [Charman and Baron-Cohen, 1997]. Additionally, a longitudinal study was conducted which tracked the development of children with autism over the course of roughly two years while periodically administering the Vineland Adaptive Behaviour Scale, a standardized interview-based questionnaire of an autistic child's communication skills, in addition to assessing only at the beginning of the study how well the children initiated and responded to joint attention, imitated the actions of others, and played with toys. The study found that engaging in symbolic play as well as imitating a previously-seen behaviour were useful positive predictors for how much the child's language skills would improve over the course of the study. This reinforces the importance of having children screened and treated for autism as early as possible [Toth et al., 2006].

Assistive technology for social play among children with autism

Because children with autism have responded well to the logical, observable rules of video games as well as the sensory rewards that they provide, and because horizontal visual displays promote more group work and cooperation than vertical ones [Rogers and Lindley, 2004], some researchers have used video games displayed on horizontal interfaces to promote collaboration and social interaction among children with autism. Piper, O'Brien, Morris, et al developed a game called SIDES (**S**hared **I**nterfaces to **D**evelop **E**ffective **S**ocial skills) using a Diamondtouch table display to detect and distinguish the hand-table contact of up to four players. In evaluating the game, the researchers found that while one group of children with autism played more cooperatively when the game enforced its own rules of turn-taking and piece ownership, another group played best when the game's rules were not enforced at all [Piper et al., 2006]. Bauminger, Goren-Bar, Gal et al also developed a collaborative electronic interface based on a Diamondtouch display known as StoryTable in which pairs of children could create different stories by jointly touching and dragging items on the display surface. Three pairs of children diagnosed with high-functioning autism played with this interface multiple times per week over the course of three weeks, and the researchers found that after participating in all of the play sessions, the children displayed more social behaviours such as making eye contact, positive affect while making eye contact, and sharing emotions than they did beforehand. [Bauminger et al., 2007]. Additionally, the children displayed fewer stereotypically "autistic" behaviours while playing with the StoryTable than they did while participating in other activities, and also spent more time playing social games, whether simple or complex, as well as less time playing in parallel with another child after participating in the study [Gal et al., 2009]. In a similar study, children with autism played with digital jigsaw puzzles on a Diamondtouch table which could be programmed to require either cooperative or individual touching and dragging in order for pieces to be moved around on the board. After pairs of children with autism repeatedly participated in each of the game's play styles, it was found that the children exhibited more coordinative moves, more moves in general, and had greater proportions of simultaneous activity while playing the puzzle game cooperatively than when the children played parallel but separately [Battocchi et al., 2010].

Since children with autism thrive on the logical, easily-observable rules of video games as well as the sensory rewards that they provide, and because tabletop displays are meant to support interpersonal interaction as well as an easy flow between private activities and group activities [Scott et al., 2003], researchers have used video games displayed on horizontal, tabletop-oriented interfaces to promote collaboration and social interaction among children with autism. Weiss, Gal, Eden et al developed Join-in, a suite of cooperative video games designed to be played on the DiamondTouch tabletop computer system which used concepts from cognitive behavioural therapy to help children with autism improve their social skills. When pairs of children with autism played these collaborative games together while a trained facilitator both explained the games to them and kept them focused, their feedback and comments suggested that the children learned important lessons from the games that would carry over into real-life settings [Giusti et al., 2011]. Additionally, the children's questionnaire answers indicated that they were interested in the tasks and felt both competent in performing them as well as making choices in them. Furthermore, the therapists found the system easy to use and wanted to use it in other educational settings [Weiss et al., 2011]. Moreover, the facilitator's role of "superuser" in the Join-in system allowed them to mediate, control, and influence the children's collaborative interactions, which proved to be very useful in enforcing key concepts of cognitive behavioural therapy during the play sessions [Zancanaro et al., 2011].

2.6 Summary

In this chapter, I first discussed the nature of autism as a disorder and its characteristic symptoms. I then discussed different neuropsychological theories which attempt to explain the disorder's social and cognitive aspects from different perspectives and briefly mentioned the common aspects of different forms of treatment for the disorder. With this knowledge, I could understand different ways that the disorder can manifest itself in each child as well as what behaviours I could look for in children with autism to determine whether they are more or less socially interactive than usual. Furthermore, with knowledge of the similarities and ultimate goals of different treatment programs for children with autism, I could appreciate the amount of time that I needed to devote to running my experiments and gathering data before I would be likely to see any changes in the children's behaviour.

I then briefly defined the field of human-robot interaction and described its goals. I also discussed important research being conducted in the field, with respect to assistive robotics as well as social robotics. Because my dissertation deals with using social aspects of humanoid robots to help children with autism, this background information served as the foundation for my research. Specifically, the research done on phyiscally assistive robotics informed me how robots have been used to help people with disabilities, with respect to how their designs helped their users overcome specific impairments or helped them conduct everyday tasks. In addition, the research conducted on social robotics both helped me understand how to evaluate the social interactions between people and robots, as well as how a robot's gestures, facial expressions, speech, and degree of social reactivity influenced its interactions with people.

Having discussed autism as a disorder and different kinds of research into human-robot interaction, I next described the research already done on using robots to help children with autism. I discussed both research which was affiliated with the University of Hertfordshire's AuRoRA project as well as research conducted by other scientists. This gave me the scientific grounding necessary to understand how robots had been used to help children with autism as well as how they had not, in addition to how different behaviours of the robots affected the children's behaviour and theories as to why various phenomena were observed. This helped me to determine the specific topics I wanted to research for my dissertation and how I wanted go about doing so. Furthermore, examining the experimental designs of similar studies helped me to understand how to structure my own experiments and what results I could expect to see from different approaches.

Afterwards, I attempted to define collaboration among agents and described traits which distinguished it from cooperation. I then discussed different research studies conducted on forms of collaboration among mixed groups of humans and robots, both with robots and humans working as equals as well as a human managing and working with multiple robots at once. I also discussed how different groups of children have learned about topics in robotics in classroom settings. By knowing about issues that could arise when groups of robots and people worked together, as well as how a robot's behaviour, appearance, and social role could affect how people perceived it, I was able to change aspects of the robots used in my research to best suit their roles. Furthermore, by understanding social issues and group learning styles that were used when children studied robots in school, I had an idea of what I could expect to see when I asked children with high-functioning autism to program robots in groups during my first experiment.

Finally, I tentatively defined play and described degrees along its spectrum, ranging between no play at all to social, cooperative play. I described how play and collaboration are viewed in different cognitive theories of learning and examined the relative importance of the two phenomena in each theory. I then described how play is qualitatively different, impaired, and difficult for children with autism, as well as how different forms of play have been used as assessment tools and forms of therapy for them. Understanding the importance of these concepts in children's cognitive development as well as how they have already been used to help treat children with autism greatly informed my design of the games, experiments, and observable behaviours used in my research.

Chapter 3

Robotic platforms

I used a number of different robotic platforms in the course of conducting experiments for my doctoral research. Specifically, I used LEGO NXT robots built in wheeled vehicle configurations for my first experiment and I used KASPAR, the minimally-expressive humanoid robot, in my second and third experiments. Each robot was chosen for specific characteristics, such as sensory capabilities or physical appearance, which made them particularly suitable for an experiment's goals. Furthermore, because each robot used in my research had already been successfully used in similarly-themed studies, I felt confident in successfully using them in my research.

3.1 LEGO Mindstorm NXT

LEGO Mindstorm NXT robots are commercially-available reconfigurable robots which are sold as kits with various construction pieces, a number of different sensors, servo motors, a battery-powered programmable computer module called the NXT Intelligent Brick which has a monochrome LCD display and four buttons, and various wires to connect the Intelligent Brick to its sensors/actuators as well as a USB cable to connect the Intelligent Brick to a host computer for downloading programs.

Because NXT robots can be programmed in a number of different languages, have fairly powerful 32-bit ARM main processors operating at 48 MHz [Perdue, 2008] and a number of different sensors and actuators, and are fairly inexpensive, they are popular with high schools and middle schools that host after-school clubs on robotics or teach curricula on technology as well as universities which offer undergraduate robotics courses. I used NXT robots as the robotic platforms in my first experiment, in which children with autism learned to program the robots and played with them together in groups.

3.1.1 Design

Figure 3.1: Examples of LEGO NXT robot designs, all of which are included in each NXT kit. From left to right, they are Alpha Rex, Tribot, Spike, and the T56 Robo-arm. (from *http://www.active-robots.com/nxt-building-instructions*, ©2011 The LEGO Group)

NXT robots are sold in kits and constructed from a large number of special LEGO pieces. While each kit's instruction manual comes with a handful of distinct designs for robots that can physically interact with their environments, the pieces can be recombined in enough unique ways such that they can construct many different kinds of robotic structures to accomplish a number of different tasks. The high degree of flexibility in physical design and the NXT manual's emphasis on self-motivated learning of technical knowledge through creative experimentation in real-world settings are reflections of Seymour Papert's constructionist theory of learning [Papert, 1980], as Papert's philosophies motivated the development of the first LEGO Mindstorm kit, the RCX model. The kit's instruction manual came with four designs for interactive robots: a humanoid form known as "Alpha Rex" which can walk in a limited fashion on two legs, a vehicular form known as "Tribot" which can drive on wheels, an scorpion-like form known as "Spike" which shuffles on two symmetric sets of legs, and a 3 degree-of-freedom robot arm and gripping claw known as the "T-56" (see figure 3.1). I chose to base my robot design (see figure 3.2) off of the Tribot configuration because this made the robot very versatile; in addition to being able to being fast and maneuverable on a flat surface, the robot was also able to grab small items in front of itself and drag them around.

Figure 3.2: The NXT robot used in my first experiment. Its design was inspired by the Tribot configuration

My design was different from the Tribot configuration in three ways. Firstly, the Tribot's gripper claws used pointed, insect-like appendages which were only suitable for grabbing small plastic balls and gave the robot a scorpion-like appearance. Because I wanted the robots to be able to grab different kinds of objects and did not want the robots' appearances to frighten any children or parents, I designed larger grippers which were more suitable for grabbing a variety of small objects had a more mechanical, robotic appearance. Secondly, I discovered from tests that the Tribot had a difficult time grabbing an object unless it was positioned directly in front of it. This was a result of the sensor that the robots used to detect moveable objects and how that sensor was activated. Because trials showed that the robots would hardly ever be positioned directly in front of moveable objects without human intervention, my design included angled guide-bars above the robot's grippers which allowed for easier gripping by acting as a hopper for leading movable objects toward the center of the robot and the sensor for detecting such objects. Finally, while the Tribot had a sound sensor mounted above and behind the Intelligent Brick, this sensor would not have been useful in my experiment so I replaced it with a magnetic flux compass sensor. However, the compass sensor did not give accurate readings at the sound sensor's old location due to the electromagnetic interference from the Intelligent Brick itself, so I mounted the compass on top of a mast which I attached to the back of the robot.

3.1.2 Sensors and actuators

NXT robot kits come with a number of different sensors, and also have multiple sensors that can be purchased separately. The following sensors were purchased for my experiments, although only the bolded sensors were used in them:

- Sound sensor (included in NXT kit) - a microphone which detects only the amplitude or volume levels of ambient sounds. Its sampling rate is between 20 and 30 Hz and it can detect sounds at volumes up to 90 dB, or about the same volume as an electric lawnmower. It returns an integer number between 0 and 100, with 5 representing a quiet room, 10-30 representing normal conversation close to the sensor, and 30-100 representing people shouting close to the sensor [Perdue, 2008]. This sensor was not used because I felt that its inclusion would make it too easy for someone to inadvertently trigger an unwanted behaviour in a robot by speaking or laughing too loudly. This might make the robots' behaviours appear unpredictable which would not be appealing for children with autism.

- Colour sensor (purchased from HiTechnic) - a light emitter (white LED) and detector (colour-sensitive chip with three separate areas covered by a red, green, and blue filters, respectively) pair on the same sensor unit. When checking the colour of a nearby surface, the sensor can operate in "active" mode by lighting up its LED and using its chip to detect the amount of reflected LED light; when checking the colour of a nearby light source, the sensor can operate in "passive" mode by not turning on its LED and using its chip to detect the amount of ambient light in an area. The sensor can either return an integer value between for each of its three colour filters or a single integer value correpsonding to one of 18 specific, predefined colours in a spectrum [Hurbain, 2011]. This sensor was not used because one of the three sensors stopped working, and since I did not have time to order a new one and wanted all the robots to have the same capabilities, I decided to simply use light sensors on all the robots instead.

- **Light sensor (included in NXT kit)** - a light emitter (red LED) and detector (phototransistor) pair which are separated by an opaque wall. When in dark locations or checking the reflectivity or shading of a nearby surface, the sensor can operate in "active" mode by lighting up its LED and using its phototransistor to detect the amount of reflected LED light, and when it is in bright locations, the sensor can operate in "passive" mode by not turning on its LED and using its phototransistor to detect the amount of ambient light in an area. The phototransistor decreases its resistance as the brightness of the light increases, and returns an integer between 0 and 100, with 0 translating to a high resistance (dark) and 100 translating to low resistance (bright) [Perdue,

2008].

- **Ultrasonic range sensor (included in NXT kit)** - an ultrasonic emitter and detector pair which determines distances between itself and an object. The sensor detects ranges between 3 and 233 cm with a precision of +/- 3 cm. Objects that are flat, hard, and orthogonal to the ultrasonic waves are detected most easily [Perdue, 2008].

- **Touch sensor (included in NXT kit)** - a momentary, normally-open, push-for "on" electrical switch. If pressed with 0.33 N of force (weight of 0.073 lbs) or more, the switch will close [Perdue, 2008].

- **Compass sensor (purchased from HiTechnic)** - a magnetic sensor which returns integer values based on its direction to the nearest degree: north is 0, east is 90, south is 180, and west is 270.

The NXT kit has much fewer actuators: there are three servo motors and the Intelligent Brick itself has a built-in speaker capable of playing sounds and electronic tones. The servos have a built-in gearing ratio of 1:48 from the motor to the output shaft, but this gearing could be further modified by adding different combinations of gear to the servos' output shafts. Other users of the NXT kits obtained speed-torque curves and current-torque curves (see figure) for the servos, which were useful in determining how long the robots could operate with fully charged AA batteries. The servos were also backdriveable and contained encoders within them that returned rotation data even when the motors were not being driven. This allowed them to also serve as rotation sensors at a resolution of 1 degree. Furthermore, although the servos only output rotational motion, this could easily be converted into linear motion by building the necessary mechanical structures around their output shafts.

3.1.3 Programming

NXT robots can be programmed in a number of different languages. Many of these are high-level programming languages which are variants of commonly used languages such as C (Not eXactly C or NXC, ROBOTC) or Java (leJOS NXJ). Others were developed for different robotic platforms but still work on the NXT such as C# with Microsoft Robotics Developer Studio or Urbi, and some such as NBC (NeXT Byte Codes) are based on a low-level assembly language which, after it is converted into byte codes, can run on the NXT Intelligent Brick without installing any additional firmware on it [Perdue, 2008].

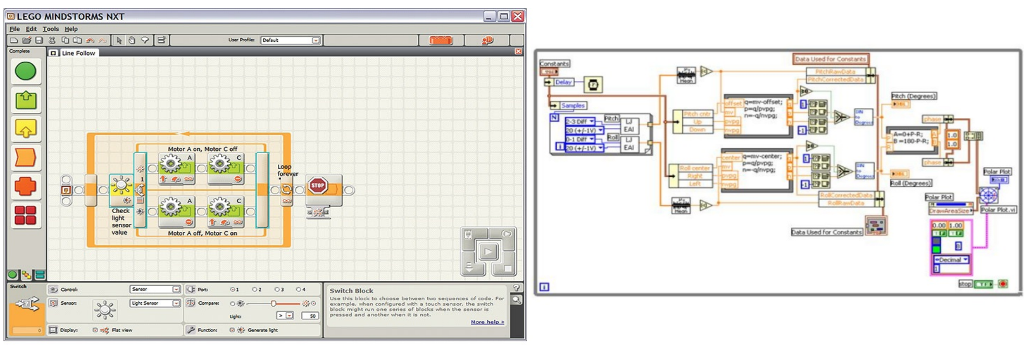


Figure 3.3: Screenshots of the programming languages used on the NXT robots. **Left:** The NXT-G graphical programming environment which the children used (from *http://find.botmag.com/100701*). **Right:** The LabVIEW G programming language which I used to create custom NXT-G programming blocks for the children to use [Litwhiler and Lovell, 2004].

However, the easiest and most intuitive form of programming uses the NXT-G graphical programming environment (see figure 3.3 left), which is included in the software disc provided with every NXT kit. In this graphical environment based on National Instruments LabVIEW (see figure 3.3 right), blocks represent discrete and specific actions that the robot performs (e.g. gathering data from specific sensors, actuating motors, performing operations on data), "wires" that connect outputs of some blocks to inputs of other blocks represent the flow of various kinds of data between the actions, and the blocks' placement along a horizontal "sequence beam" represents the order in which the actions will be executed. Thus, by arranging blocks in sequences and wiring some of them together, one can program a robot to perform basic tasks in very little time.

Programming in this environment is very well suited for teaching inexperienced people about programming computers and robots in a visually engaging manner without having to also teach them about good programming style or language-specific syntax, semantics, and library usage. However, it can also be difficult or take much more time than usual in NXT-G to accomplish many common programming tasks such as performing mathematical operations on data, storing data in specialized structures, and implementing algorithms to sort, filter, and search for data. Because my first experiment involved teaching children with autism to program robots, I decided to teach them to program in NXT-G since this would the quickest and simplest solution. I tried to keep the programs that the children would write as simple as possible, but in the situations where the children would need to write computation-heavy programs to make the robot perform an impressive behaviour, I simplified the process for them by developing and testing custom NXT programming blocks using LabVIEW which automatically performed the heavy/complex computations based on the input that they provided and returned the necessary outputs.

3.1.4 Previous academic use

My research was not the first to use NXTs to study how robots can help children with autism. Virnes found that NXT robots as well as Topobo robots were useful as educational tools for helping children with special needs, including those with autism, when the robots addressed each child's particular interests and allowed the children to teach themselves at their own speeds. In addition, the children were able to work for longer periods than usual as well as collaborate with others when they were allowed physical access to the robots since it gave the children feelings of personal ownership for them [Virnes, 2008]. Nikopoulos, Kuester, Sheehan et al started to evaluate a number of different inexpensive robotic platforms to use in home-based DIR/Floortime therapy sessions for children with autism. In a preliminary study, they found that NXT robots which automatically interacted and spoke with each other according to social interaction scripts captured the attention of four different children with autism while previous technology-based interventions failed to do so [Nikolopoulos et al., 2011a]. In future studies, the researchers intend to use redesigned NXT robots in the same kind of intervention for children with autism and have the robot social actors remotely operated. This will allow the researchers to overcome the NXT robots' memory constraints and have the robots speak and move for longer periods of time [Nikolopoulos et al., 2011b]. Ljunglöf described TRIK, a novel dialogue system for children with communication impairments such as autism and/or cerebral palsy which required a child to point at a symbol on a touchscreen computer in order to make a nearby NXT robot draw a picture associated with the selected symbol. The touchscreen computer and the robot also appeared to "speak" to each other using grammatically correct language in certain circumstances, as this was meant to show the children how two agents verbally communicate with each other [Ljunglöf, 2009]. As a sort of spritual successor, the Lekbot project had similar goals and approaches as TRIK, in the sense that both projects used touchscreens with sybmols verbally communicating with NXT robots to help children with communication impairments. However, while TRIK's NXT robot drew pictures for children, Lekbot's NXT robot playfully interacted with children. The system was tested on three children with cerebral palsy in over 50 free-form play sessions during a five-month period, and the children seemed to really enjoy participating with their peers in playing with Lekbot [Ljunglöf et al., 2011].

3.1.5 Usage in doctoral research

The NXT robots used in my first experiment were capable of certain behaviours as a result of the Tribot-inspired design that I chose. Because I used one servo motor to directly actuate each of the robots' two wheels, the robots were capable of moving forward and backward as well as performing turns using their differentially-driven wheels either while moving forward or remaining in place. Furthermore, because I used a third servo motor to actuate both of the robots' gripper arms, the robots could open and close their grippers to grab small objects.

The NXT robots were also capable of detecting certain aspects of their environments because of where specific sensors were placed on their chassis. Firstly, because I placed an ultrasonic sensor at the front of the robot and facing forward, the robot could tell how far it was from the walls of the arena or other large objects. However, because of the placement of this sensor and the height of objects that could be gripped, such objects did not register as walls or obstacles to be avoided. Secondly, the robot could determine the shading of the carpet, the floor, or any sheet of paper that was placed beneth them because its light sensor was pointed beneath it. Thirdly, because the robot's touch sensor was facing forward at the rear of its "hopper" as well as its grippers, the robot could detect when it hit an object that it could grip. Lastly, the robot could determine the direction in which it was facing because its compass sensor was pointing forward and placed high above it, far from the electromagnetic interference of the Intelligent Brick.

In my first experiment with children with autism, the participants formed up in groups of 2 to 3 children to play with each NXT robot (see figure 3.4). Because we observed during the introductory trial of the experiment before we began gathering data that each group of children had difficulties in playing together with their robots and occasionally got into arguments or got upset, we devised specific and distinct roles for each groupmember in order to help the children manage their play with the robot. The three roles were writing the program for the robot, downloading the

Figure 3.4: Some of the children who participated in my first experiment, seen here playing with NXT robots in groups.

program from the PC to the robot, and testing out the robot's behaviours. The children periodically rotated through these roles to ensure that everyone got to play with the robot in the same way, but if a child wanted to help out another child in their play role, they were allowed to speak with the child or point something out to them in order to give them suggestions, but they were not allowed to take over a specific task for a child. In this way, we tried to make the robot serve as a collaborative point of focus for each group.

By playing together, the children were able to make the robots perform a number of different, progressively more complicated actions: race around the inside of the arena using only motor commands, using motor commands combined with ultrasonic sensor data, and using two commands encased in a loop structure; turn left or right based on how far they were from a wall according to their ultrasonic sensor data; play "chicken" by driving towards each other and stopping before colliding by using their ultrasonic sensors; orient itself to face a certain direction using its compass sensor; turn 90 degrees to their right and drive forward whenever they pass over a white piece of paper; and close their grippers when an object got close to them and hit their touch sensor. Because the robot's programs began as simple and straightforward while they progressively became more and more complex and required repeated testing and reprogramming, we hoped to stimulate social interaction and helpful behaviour among the groupmembers. As such, we tried to have the robots serve as passive social mediators for interactions among group members.

3.2 KASPAR

KASPAR (**K**inesics **a**nd **S**ynchronization in **P**ersonal **A**ssistant **R**obotics) is a child-sized, minimally-expressive humanoid robot which was developed by researchers of the Adaptive Systems Research Group at the University of Hertfordshire. It has been used to study different forms of human-robot interaction and primarily communicates with people through its voice, gestures, and facial expressions. As a humanoid robot it has a head with human-like facial features, two arms, and two legs. While each of its arms is actuated with 3 degrees of freedom and different parts of its face are actuated indepdendently, its legs and hands are not actuated at all. KASPAR does not contain a computer which controls its behaviours - instead, it can be connected to almost any laptop and programming to operate in a number of different ways [Dautenhahn et al., 2009]. I used KASPAR as the robotic platform in my second and third experiments, in which children with autism alternated between playing a collaborative video game by interacting with other people and playing the same game by interacting with KASPAR.

3.2.1 Design

Many aspects of KASPAR's appearance and range of behaviours are the results of careful and deliberate design. Firstly, KASPAR uses a laptop computer for operation instead of using a dedicated network of desktop computer systems to control its behaviour. This is because KASPAR was designed to be used in multiple settings in addition to that of a research lab, so it was very important that the robot could be easily transported and easily set up. As such, a laptop computer offers more portability and faster setup than an array of desktop computers [Dautenhahn et al., 2009].

Secondly, many aspects of the appearance of KASPAR's body were designed to make the robot appear as inviting and non-threatening as possible. Specifically, its size and body proportions are similar to those of a two-year-old child in order to make the robot appear unimposing, and its sedentary position is meant to make the robot appear relaxed and playful. To easily make the robot's body of correct proportions, the torso and limbs were constructed from a child-sized mannequin and filled with actuators. However, the hands were neither filled with actuators nor replaced with dextrous fingers; instead, they were left as carved, wooden, doll-like hands in order to invite children to touch them and play with them [Dautenhahn et al., 2009].

Thirdly, KASPAR's facial layout and degree of facial expressiveness (see figure 3.5) was inspired by a number of different approaches. The face's smooth doll-like appearance is meant to make it more approachable for children and to prompt people to play with it [Billard et al., 2006], while the generalized facial features are also meant to make people perceive the robot and its expressions as iconic representations with which they could more easily identify, instead of something that was intended to look explicitly human [Dautenhahn, 2002]. In addition, KASPAR's facial features were not made overly exaggerated like those of Kismet, as this would promote a nurturing response from people and lead them to perceive the robot as infant-like. As such, KASPAR's facial features were designed to be minimally expressive in order to make people perceive KASPAR as a playmate or companion [Dautenhahn et al., 2009]. KASPAR's range of facial expressions was inspired by the designs of masks used in Japanese Noh theatre, in which only subtle changes

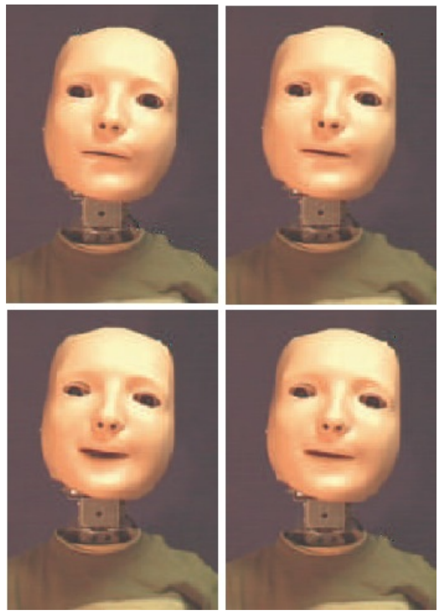


Figure 3.5: Four different facial expressions that KASPAR can make. Clockwise from the top left, they are: neutral, small, medium, and large smiles [Blow et al., 2006].

in the mask's lighting or degree of forward tilting can result in people perceiving a different static facial expression [Lyons et al., 2000]. In fact, research has shown that KASPAR's dynamic transitions from neutral facial expressions to various smiling facial expressions at naturalistic speeds were found to be more appealing than the same non-moving, static displays of smiling facial expressions [Blow et al., 2006].

Lastly, KASPAR's range of behaviours were selected for their suitability in interaction studies. Specifically, KASPAR's arms were actuated in order to allow the robot to communicate using gestures such as waving and pointing in addition to allowing the robot to coarsely manipulate objects in play settings. However, because the robot's arm trajectories would not need to be precisely planned, the arms were designed to be underactuated and used off-the-shelf, inexpensive components. Additionally, KASPAR's neck was designed to allow the robot to perform coarse head motions such as nodding and shaking its head as well as finer motions such as tilting or angling its head in certain directions. This would allow KASPAR to perform social gestures such as exhibiting joint attention and to display subtle emotions such as shyness or mischief. Furthermore, KASPAR's eyes were designed to be able to look in all directions, thus contributing to displays of joint attention and subtle facial expressions, and to blink, which provides many basic social cues in interpersonal interactions [Dautenhahn et al., 2009].

3.2.2 Sensors and actuators

Although the above descriptions of KASPAR might suggest that it is a single robot, there have actually been multiple copies of KASPAR and my research has used two different ones. Although each version of KASPAR uses slightly different sensors and actuators to interact with their environments and reflect different budgetary contraints, all versions of the robot were designed for the same reasons and were intended to be used in similar studies.

KASPAR 1a

Figure 3.6: KASPAR 1a, the first model of minimally-expressive robots built by the University of Hertfordshire [Dautenhahn et al., 2009]

KASPAR 1a (see figure 3.6) was the first model of minimally-expressive robots. At the time of my second experiment, it used RC servo motors (motors designed for radio-controlled model airplanes) as the actuators in its arms and head, with servos capable of outputting increasingly higher torques being used at joints closer to the robot's torso. Although these RC servos were cost-effective, they could not give any feedback data such as position or speed. While this limited the precision with which KASPAR could move, I was able to overcome this by designing an interactive video game (see chapter 4) with a controller that worked around this constraint.

As we described earlier, KASPAR 1a's arms were underactuated with four controllable degrees of freedom in each one; two high-torque HiTec HS-645MG servos were located at the shoulder joint, one HiTec HS-422 servo was located at the elbow, and another HS-422 servo at the wrist. KASPAR's head had three high-torque HS-645MG servos located in its neck to control the panning, tilting, and rolling of the head, as well as two HS-422 servos to control the tilting and blinking motions of the eyes and a smaller Supertec NARO HPBB servo to control the eyes' panning motion. In addition, KASPAR also used two HS-422 servos to control how much the robot's mouth smiled and opened. All of the RC servo motors were controlled by a LynxMotion SSC-32 servo control board near the robot's back, which converted digital commands from a laptop computer into analog output for motor positions.

KASPAR 1a's eyes also contained miniature (20 mm x 14 mm x 25 mm) video cameras using CMOS image sensors that outputted monochrome PAL video footage at a resolution of 288 x 352 pixels. Although these cameras could have been used to track the children's faces or provide live video footage to human controllers of what the robot saw, I did not have the time to implement such functionalities and doubted the performance of facial tracking algorithms in non-laboratory settings.

Figure 3.7: KASPAR 1b, the second and improved model of minimally-expressive robots built by the University of Hertfordshire [Robins et al., 2010]

KASPAR 1b

KASPAR 1b (see figure 3.7) was essentially a new and improved version of KASPAR 1a. Instead of using different kinds of RC servos at different joints, it used Dynamixel AX-12+ servos, which were servos specifically developed for robot hobbyists, in every joint due to the the Dynamixel servos' increased torque output. Dynamixel robot servos were an improvement over the HiTec RC servos as each robot servo came with their own on-board D/A conversion units and control hardware instead of requiring a single large master control board to translate digital commands into motor outputs. Each robot servo could also return feedback data in the form of position, temperature, load, and input voltage information and because only a single servo was used in the robot, the process of maintaining the robot and replacing defective motors became much simpler and more streamlined. However, because Dynamixel servos are physically larger than the largest HiTec servo in every measurement (32mm * 50mm * 40mm vs 19.56 mm * 40.39 mm * 37.59 mm, respectively), the new version of KASPAR appeared bulkier than its predecessor.

KASPAR 1b's eyes contained small video cameras, this time in the form of low-resolution (288 x 352) monochrome webcams. My third experiment did not make use of the robot's cameras for the same reasons as my second experiment, specifically both a lack of time and not enough faith in the robustness of the face-tracking algorithms in a field setting.

3.2.3 Programming

Whenever KASPAR was programmed, either in the course of my doctoral research or in any other study in which it has been used, programmers have used the open-source middleware known as Yarp (**Y**et **a**nother **r**obot **p**latform) in order to communicate with and control the robot's hardware. Yarp is a collection of software libraries and protocols which are used to keep programming modules separete from robotic devices, thus facilitating code reuse and maintenance. It was specifically developed to be used for controlling humanoid robots, as these are typically used in cutting-edge research and are very likely to have their hardware upgraded or replaced often. The libraries also support interprocess communication and functions for image processing, and have been used on such humanoid robots as Kismet, Babybot, and RobotCub [Metta et al., 2006].

Previous research which has used KASPAR in studies involving children with autistm has almost exclusively focused on the robot being remotely controlled by a human operator. In these experiments, the remote operation software consisted of a GUI which allowed users to control the positioning of each of the robot's actuators with movable sliders and pose KASPAR in any possible manner. Users could also save the positions of all the actuators as well as command KASPAR to pose in a manner that they previously saved by pressing a specific button. In this way, human operators could make KASPAR asssume a variety of specific poses by pressing buttons on a wireless keypad. [Robins et al., 2009] [Iacono et al., 2011]. However, because our second and third experiments used a version of KASPAR that operated autonomously, our robot was not constantly controlled by a hidden human operator and did not interact with people in a “Wizard of Oz” setting [Dahlbäck et al., 1993] unlike many previous HRI studies involving children with autism.

Sensing

In the second and third experiments of my doctoral research, I programmed KASPAR to play a collaborative video game and interact with people in an autonomous fashion using sense-plan-act control architectures written in C++. In both of these experiments, my control architectures received sensory data directly from the software running the collaborative video games via Yarp connections instead of grabbing images from KASPAR’s cameras. This was done because given that the robot would only interact with the children in the context of playing a video game, all the pertinent information about the players would be either contained within the video game itself, i.e. what actions each player has taken and when they have taken them, or dictated by the setting in which the video game was played, i.e. the physical location of the child with respect to the robot. Given these experimental costraints, it would have been needlessly complicated to perform feature detection and shape recognition on images from KASPAR’s eye-cameras in order to determine what players were doing. Furthermore, because the video games in my experiments sent sensory data to KASPAR’s control architectures fairly frequently (11.11 Hz), KASPAR could sense the player’s actions in the video game quickly enough so as to be sufficiently responsive to them.

KASPAR’s control architectures in each experiment gathered sensory information in slightly different ways - while the architecture in the second experiment used an event-driven form of sensing and only ran most of its planning and acting modules when it received sensory data from the video game, the architecture in the third experiment constantly checked for sensory data from the video game and always ran its planning and acting modules. However, in both experiments, the sensory data itself took on the same forms; most of the time it was information about the statuses of the remaining shapes in the game and the players' positions in the game, but the data occasionally contained information on special events in the game (e.g. the successful selection of a shape, the beginning of a new round).

Planning

Both of KASPAR's control architectures processed their sensory data and decided on their next courses of action in similar ways. If the sensory data dealt with whether a special event happened in the game, such the successful selection of a shape which would have been signified by the game causing a "reward" sound to stop playing, then the architectures would first reset a number of timer variables regulating when the robot should perform certain periodic actions. The architectures would then set other state variables which would prepare KASPAR to pose and speak appropriately and lock their ability to interrupt KASPAR's observable reactions until it was finished speaking and posing.

However, if the sensory data dealt with the statuses of the shapes and the players in the game (which was much more likely to happen), then the architectures would first process this game data. They would update and re-sort their internal lists of the shapes that were still available as well as their colours and other attributes, the lists of actions that each player was doing as well as the times that they started performing these actions and their validity, and the lists of whose turn it was or which players were being active. Additionally, if the number of available shapes changed from the last time it received sensory data, the architectures would reset a number of the robot's internal state variables and timer variables to reflect the fact that a new round had started.

Second, while the architecture in the second experiment would prepare to move one of its arms to track a specific shape if it had been told to do so or if it wanted, the control architecture in the third experiment would do a number of things. Specifically, it would check to see whether KASPAR was currently in the middle of a reaction involving multiple poses with a single sound file and would react accordingly, then check to see whether the other players had chosen a shape for KASPAR to select, then begin to respond appropriately, provided that such a shape had been chosen and that it was the other player's turns to choose.

Lastly, both the architectures would check to see whether KASPAR should take the initiative in the game. This could be done by wondering out loud what all the players should do next, suggesting that everyone choose a shape on which the robot decided, or (only for the architecture in the third expeirment) prompting an uncooperative player to comply with the other player's choice of shape. Each architecture would use different criteria to decide when KASPAR should announce its own suggestions for choosing shapes, but both architectures would compare how much time had passed since KASPAR's last speech before making any decision.

Acting

KASPAR's primary mode of acting was communicating with the other player through gesture, facial expressions, and speech. In both experiments, the robot's voice was created by the Acapela text-to-speech generator using the male English voice of "Graham", which spoke using a Received Pronunciation or the Queen's English. This speech generator was selected because its English voices had a better cadences to their speech, had more natural speech rhythms, and were generally much easier to understand than freeware speech generators such as Festival for Linux. Furthermore, we selected a male voice speaking the Queen's English because we felt this accent would be the easiest for the children to understand and one that they had probably heard more often than any other accent offered by Acapela. However, in order to make the voice sound slightly more childish, we raised the pitch on all of the speech samples by 21% using Audacity, a free software package used for mixing and editing sound and music files. This form of voice modification was felt to be more suitable on KASPAR than a higher-pitched robotic voice or the normal voice from the speech generator.

Both architectures implemented gestures, facial expressions, and speech by calling one specific function for posing and speaking (controlling the blinking of KASPAR's eyes was handled in a separate function that was called periodically, and having KASPAR move his right arm to play the game was controlled by yet another function). The posing and speaking function first opened up the appropriate gesture file and used its contents to set KASPAR's motor to their appropriate positions as well as determine the title of the sound file that would accompany the gesture. Furthermore, because KASPAR had multiple sound files that could potentially be used in any given situation, the function would also determine which version of the appropriate sound file would be randomly selected. Lastly, the function would modify various state-related variables and make note of the expected duration of the sound file, all of which were necessary in determining KASPAR's actions in the future.

3.2.4 Previous academic use

Much like my work involving the interactions of children with autism and LEGO NXT robots, my research was not the first to use KASPAR in experimenetal settings with children with autism. Robins, Dautenhahn and Dickerson had three children who had been diagnosed with low-functioning autism participate in play sessions with KASPAR and another individual. Although the conditions regarding the play sessions (identity of other individual, number of play sessions, etc) varied for each child, KASPAR was always operated via remote control either by the child with autism or the experimenter if the child was not capable of doing so. By analyzing video footage from every child's interactions with KASPAR, the researchers determined that all of the children seemed engaged in playing with KASPAR, either by imitating KASPAR's behaviours or generalizing their playful interactions with the robot to interactions with other people present during the sessions [Robins et al.,

2009].

Later, Robins and Dautenhahn described how they conducted field trials with KASPAR to determine what kinds of tactile play scenarios should be developed for children with autism [Robins and Dautenhahn, 2010]. In one set of field trials, they examined video footage from fourteen children with autism interacting with the robot and classified the ways that the children touched the robot according to two types of intensity, firm and gentle, and three kinds of style, i.e. grapsing, stroking, and poking [Amirabdollahian et al., 2009]. In another set of field trials the researchers conducted one study in a laboratory setting and another study in a school setting, with both studies being conducted after the researchers placed tactile sensors on KASPAR's hands, arms, and face. For the experiment conducted in the school setting, three children with autism interacted with a remotely-controlled version of KASPAR with their carers and the experimenter in the room, while in the laboratory setting, five normally-developed volunteers interacted with a remotely-controlled version of KASPAR [Robins et al., 2010]. The temporal and spatial tactile data from these studies contributed to the development of a play scenario that is designed to teach children with autism about proprioception, psychomotor control, and basic interpersonal interaction, in which KASPAR will automatically respond in specific ways to the different intensities and forms of touching [Robins and Dautenhahn, 2010].

In another study by Iacono, Lehmann, Marti et al, children with autism played with two different robots: the stationary humanoid KASPAR operating under remote control and a mobile autonomous robot platform developed for the IROMEC project. To determine whether the robots encouraged different reactions from the children, the participants were randomly assigned to engage in multiple play sessions first with one robot and then with the other. After playing imitation games, turn-taking games, and with each robot, preliminary data from pre-trial and post-trial questionnaires suggests that some of the children improved their communication, interaction, cognitive skills. Furthermore, reports from teachers indicate that all of the children both benefitted from the robot interactions and were also interested in playing with both robots, although they found it easier to play imitation games with KASPAR than they did with the IROMEC robot [Iacono et al., 2011].

3.2.5 Usage in doctoral research and justifications for interaction designs

Figure 3.8: Screenshots of KASPAR playing with children with autism. **Left:** KASPAR 1a plays with one other child with autism in my second set of experiments. **Right:** KASPAR 1b plays with two other children with autism in my third set of experimenets. The child with glasses is correcting his partner on which arm they should be extending

KASPAR was utilized in my second and third experiments to play collaborative video games with children with autism (see figure 3.8). Although section 3.2.3 discussed how KASPAR spoke and acted as well as the conditions under which it did so, this section will address why we made certain design choices with KASPAR's interactive capabilities. Specifically, the robot's interactions with the children were designed along the dimensions of speech, gesturing, and facial expressions, and certain decisions regarding these modes of communication were made in order to implement the particular goals of each experiment.

Speech

KASPAR would always greet the children at the beginning of each game session in both the second and third studies by introducing itself and inviting the children to play together with it. Unlike other instances of speech which existed in multiple versions to convey the same information in slightly different ways, there was only one introductory sentence that KASPAR would always say at the beginning of a game. This was done because the children would only start a new game once during each play session, so it was important to make this starting signal constant for every session. In contrast, the children were likely to encounter multiple versions of the other forms of speech (e.g. congratulating, prompting) during any given session because these other speeches would be used in situations that would crop up many times during a single session. As such, the children did not need these other instances of speech to have single forms and seemed to enjoy the small amount of variety in KASPAR's speech.

If a specific child hadn't chosen a shape within a certain time limit during both the second and third experiments, KASPAR would prompt the child by saying something which indicated that it did not know what both of them should do (e.g. "Can you think of what we should do?", "What should we do?", "What do you think we should do?"). This was intended to make the children think about what shape they wanted to select, and the children seemed to understand this after hearing KASPAR say this a few times. In contrast, when KASPAR was used in the third experiment and urged a non-compliant child to pose like the directing child, the robot said one direct sentence, "Please select the shape that your team-mate has chosen". Looking back, we now know that KASPAR's promptings should have been more direct in both experiments; the robot should have stated or commanded the child to choose a shape (e.g. "It's your turn. Please choose a shape", "Go ahead and choose a shape") instead of asking what to do. This is because the children's carer's often said similarly direct statements to the children after KASPAR had prompted them, and the children almost always reacted after hearing this direct speech. Therefore, future studies should program KASPAR to be as direct in its speech as the children's carers.

Whenever the children chose a shape during the second or third experiments, KASPAR would first say which colour shape the player seemed to want the robot to pick, and then it would happily agree to do so. This practice in communication of repeating a received command back to its transmitter is known as "read-back", and it is standard practice in the United States when pilots respond to commands from air traffic controllers [United States of America, 2012]. The practice served two purposes in these experiments: in the overwhelmingly common event that the player held their arm steadily enough to choose properly, KASPAR's stating of the shape's colour would confirm for the child that the robot correctly acknowledged what it should do; additionally, in the unlikely event that the player did not actually choose the shape that they intended to, KASPAR's stating of the colour would expose the miscommunication to the child. In turn, this usually made the child reselect their intended shape properly, thereby correcting their error. If KASPAR did not practice read-back, players might have become confused in the few instances where KASPAR did not comply with their choice and could have incorrectly inferred either that KASPAR wanted to make its own choice or that the robot was being mischievously disobedient. In future studies, however, KASPAR should allow the child to acknowledge (verbally or otherwise) whether the robot's read-back was correct before it would attempt to choose the shape, as this would reduce the children's potential frustration and increase the amount of interactivity between the child and the robot.

Similarly, whenever KASPAR selected its own shape, the robot would always first indicate that it had made a decision (e.g. "I think I know what to do", "I've got an idea") before describing which shape it wanted to select. We feel that KASPAR's practice of announcing its intentions helped prepare the children to pay attention to the robot's subsequent shape selection. Furthermore, KASPAR always specified a shape's colour in its selections because we felt that more children would know the names of basic colours than would know the names of platonic solids.

Although KASPAR would "talk" with the children in many different situations, the robot could not respond to the children's speech in either the second or third experiment. We originally wanted KASPAR to be able to recognize certain key words that the children would say while playing the game (e.g. square, triangle, blue, red) because people would probably expect that a robot which was capable of "talking" would also be capable of "hearing" [Tasaki et al., 2005] [Wrede et al., 2010]. However, using a speech recognition system as a means of communication was ruled out for two reasons. Firstly, the children would probably be so bored and/or frustrated by the extensive amount of training that the system would have to undergo to learn each child's pronunciation and intonation of each word as to dissuade them from participating in our study. Secondly, it might be difficult for any speech recognition system to consistently and correctly interpret some of the children's speech due to their limited communicative abilities. As such, we instead programmed KASPAR to respond to the children's poses (i.e. changes in the pitch values of the Wiimotes on their arms) because all of the children would required to pose in specific ways to direct others to choose shapes and comply with another player's choice, and the robot would reliably and correctly interpret the children's poses by performing some low-pass filtering and simple classification of the Wiimotes' pose values.

Physical communication

KASPAR was also similarly communicative with its facial expressions and arm gestures during both the second and third experiments. Specifically, whenever KASPAR greeted children at the beginning of each game session or said goodbye at the end of each session, it would smile while looking in the direction where each child was expected to be and waved using its left arm, which was not used to select shapes (see figure 3.9). This gesture was done to make the children feel welcome, as a one-handed waving gesture while smiling and looking at the other person is acknowledged in British culture as either a friendly greeting or a friendly parting. Furthermore, since this gesture was different from a handshake in the sense that it did not require bodily contact between two people, it was an ideal form of physical communication for KASPAR to practice. This is because we did not want the participants in our second and third experiments to come into physical contact with the robot for safety reasons.

Figure 3.9: KASPAR greets the children while waving and smiling at them during the start of the play session. The same gestures were also used when KASPAR said goodbye to the children at the end of each play session.

When the robot prompted the children to choose a shape, it would tilt its head slightly to the left while looking at the other players and hold its left arm in a shrugging sort of gesture (see figure 3.10). In Western culture, this body language suggests that an individual does not know the answer to something, which we felt suited KASPAR's inquisitive speech while prompting the children (e.g. "What do you think we should do?", "I don't know what to do. Any thoughts?"). Upon reflection, if KASPAR had used more direct speech while prompting the children, such as "It's your turn to choose a shape", we would have programmed KASPAR to instead look at the child whose turn it was and extend its left arm halfway toward the the child while rotating the palm of its hand upward as it spoke. This gesture would mimic the act of giving an object in order to indicate that KASPAR was politely "giving" control to a particular child instead of pointing at them and telling them to choose.

Figure 3.10: KASPAR asks the children what they should all do while making a one-armed "shrug".

Whenever KASPAR began its own process of selecting a shape, it made two poses, holding the first pose for roughly 1.5 seconds and holding the second pose for over 3 seconds: first, it made a "eureka" gesture by holding its left arm nearly straight upward next to its head while smiling and announcing that it was its own turn (see figure 3.11); next, it tilted its head downward and to its right, narrowed its eyes, and touched its left hand to the bottom of its chin in a "thinking" gesture (see figure 3.12). The first pose was meant to visually announce to the children that the robot would soon be taking its turn by making the large, sweeping movement with its left arm away from its body. If the children were focusing too much on the game, this gesture was meant to draw the children's attention away from the screen below them and toward the robot in front of or next to them. On the other hand, the second pose was meant to suggest that the robot was trying to make a choice about which shape to select. We specifically had KASPAR hold this pose for over 3 seconds so as not to overexcite the children with the robot's rapidly-changing poses and also to suggest that it was alright for the children to think carefully before making their own choices in the game.

Figure 3.11: KASPAR announces that it is its own turn while making a "eureka" pose.

Whenever KASPAR either announced its shape decision to the children or later congratulated the children on successfully selecting a shape with it, the robot smiled broadly and held its gaze directly where the children should have been during the duration of its speech. The robot's looking at the children was meant to hold their attention and make the children focus on what the robot was saying, as focus-

Figure 3.12: Immediately after accouncing that it is the robot's own turn, KASPAR evaluates its choices of shapes while making a "thinking" pose.

ing directly at someone while speaking to them is meant to establish an intimate connection between individuals. Similarly, the robot's broad smile was meant to reward the children for cooperating successfully and to make them smile back at KASPAR.

When KASPAR was not speaking to the other children, its head and eyes were angled downward at the game while it occasionally blinked its eyes and held its left arm down at its side. This form of body language was meant to communicate both that the robot was temporarily not paying attention to the child and was focused on the game. While ignoring another person in such a manner during a conversation is considered very rude, such behaviour is socially acceptable when the two people are playing a game which is located between them and below their normal visual fields of view.

Goals of interaction

In addition to designing the robot's speech its physical behaviours, KASPAR was also designed to play similar roles and to fulfil similar scientific aims in the second and third experiments. Both the second and third experiments used KASPAR as a co-present partner of children with autism who played a collaborative game with them. Additionally, the same experiments also aimed to use KASPAR's robotic appearance and behaviours as focal points of attention for the children, thereby making them interested in playing the video game, which the robot prompts them to do, and interacting with the robot while doing so. Both studies also used KASPAR's repetitive behaviours and speech to try and reinforce certain ideas about how to play collaboratively with someone else and how to interact with others while doing so. Furthermore, both studies tried to use KASPAR's human appearance and human behaviour to hopefully invite comparisons between itself and the human players with whom each child would also play, thereby hopefully making it easier for social behaviours learned while interacting and playing with KASPAR generalize into settings with other people.

In addition to the abovementioned similarities, the two different forms of KASPAR were also used in slightly different ways in each of their experiments. Firstly, while the version of KASPAR used in my second study (KASPAR 1a) would take the initiative and make its own suggestions about which shape to select provided that the child with whom it played hadn't made their own suggestions within 15 seconds, the version of KASPAR used in the third study (KASPAR 1b) would only make suggestions and select shapes during its own turn. This is because the second experiment was designed to have more open, free-form interactions in order to see how often the children would display enough interest in the game and take the initiative. In contrast, the third experiment used more structured and clearly-defined interactions in the hope of teaching children with autism about turn-taking and switching between roles, since these are social concepts that can be difficult for such children to understand.

Secondly, although the experiment using KASPAR 1a only had the robot interact with a single other child at a time, the experiment using KASPAR 1b was meant to have the robot interact with up to two children at once. As such, although KASPAR 1a's programming and gestures only had to focus on how well the robot played with a single child at a time, KASPAR 1b's programming and gestures had to be cognizant of both children at once and determine how well both of these children were playing with each other as well as with the robot; by way of example, KASPAR 1b would make comments intended to positively reinforce good interaction among the other two children as well as to foster better interaction among them if the robot did not sense that it was taking place. In conclusion, while the two different versions of KASPAR behaved similarly, were programmed in similar ways, and were used in similarly-themed experiments, the two robots were also used in distinct ways to study fundamentally different phenomena.

3.3 Summary

In this chapter, I discussed the various robots that I used in my doctoral research. I first described how I built LEGO Mindstorm NXT robots from commercially-available kits and based my robots' designs off of one of the provided schematics, the wheeled Tribot model. I explained how this design made the robots versatile and more capable of cooperating with other robots, after which I described the changes that I made to the Tribot schematic and my reasons for making them. I then described how the robots' sensors and actuators worked, both those that were used in my designs (compass sensors, light sensors, touch sensors, ultrasonic range sensors, and servo motors) and those that were not (colour sensor, sound sensor). I discussed different languages that can be used to program NXT robots, including NXT-G, the programming environment and graphical language used by the participants in my first experiment to program their NXTs, and Labview, the graphical programming language that I used to implement my own NXT-G programming blocks which made coding simpler for my first experiment's participants. To show that my decision to use these robots in my study has scientific precedence, I then described earlier research that had also used NXT robots to study different aspects of children with autism. I then concluded with discussing how the robots' sensors helped it to make sense of its environment, as well as how participants in my first study played with the robots and my reasons for having them do so.

Secondly, I described KASPAR, the minimally expressive humanoid robot and how it was used in my second and third experiments. I began by explaining the design choices behind KASPAR's construction, from its lack of an on-board computer and its child-friendly appearance to the layout and principles behind its facial design and its behavioural capabilities geared toward interaction studies. Next, I described how the original version of KASPAR used a variety of servo motors typically found in remote-control hobby vehicles while the newer version used a single variety of high-torque servo designed for use in robotics in all of its joints, and how these actuator choices affected the overall appearance of the robot. I then discussed how I designed and implemented a sense-plan-act architecture which used the Yarp middleware to allow both versions of KASPAR to interact with, communicate with, and play a collaborative video game with a child with autism. Following that, I showed how using KASPAR in my experiments was scientifically valid by mentioning a number of previous studies which successfully used KASPAR to interact with children with autism. Finally, I described how KASPAR behaved and interacted with the participants in my second and third studies and explained the scientific reasoning behind using the robot to try and help children with autism to play more collaboratively with others.

Chapter 4

Collaborative games used in doctoral research

When children with autism interacted with robots and/or other people in my experiments, they did so in the context of playing collaborative games. All of these games were developed by me and were specifically designed to require participants to socially interact and communicate with each other in order to "win" in each game. Additionally, because using sensory rewards is a very effective means of making any activity for children with autism more pleasant and engaging [Robins et al., 2007], every game also provided multiple forms of sensory rewards whenever the participants satisfied a set of winning conditions. Furthermore, each game was implemented electronically and used sensors to automatically determine the players' actions. This was done both to remove any potential bias from having a human moderating over game rules and conditions as well as to prevent the children's prior impressions and feelings of specific human moderators from influencing their behaviour while playing the game.

4.1 Arena games

In my first experiment, the collaborative games took the form of simple tasks that required multiple LEGO NXT robots to work in progressively more cooperative ways with each other. Groups of children would program the robots to drive in specific patterns and carry out certain behaviours within the arena, and when various sensors in the arena would register that the robots had successfully behaved in specific ways, sounds and music samples would play and lights would flash to reward the children. Such games might be challenging for children with autism, as their social impairments would make it difficult for them to play with and near other individuals as well as other groups of children.

4.1.1 Description and mechanics of gameplay

The games played with the robots in the arena served two purposes: to demonstrate the concepts learned during a given week's lessons and to gradually make the groups of children more comfortable with different groups of children playing together collaboratively. While the games played at the beginning of the experiment involved one robot in the arena at any given time, used open-loop control to perform simple tasks, and did not require inter-group interaction among the children, the games played at the end of the experiment were more complicated in a number of ways. Specifically, these later games featured the robots reacting to changes in their environments in real time and presented teams of children with the choice to work together to coordinate the robots' actions and make them elicit complex reactions from the arean's sensors. A list of the different arena games is presented below, with the first games appearing at the top of the list and the last games appearing at the bottom:

- single-robot race in sensor-equipped arena with each robot using "dead reckoning" for navigation (with and without the use of iteration in programming the robot)

- robot using sensor feedback to move to a certain distance from an arena range sensor
- multiple robots using sensor feedback to perform a relay race together with arena range sensors as finish lines (see figure 4.1)
- single-robot race in sensor-equipped arena with each robot using iteration and sensor feedback
- multiple robots simultaneously moving around arena with guidance from children to trigger arena range sensors
- single robots using grippers to move and manipulate sensor-identified objects and triggering arena range sensors
- children deciding how multiple robots should collaborate in free-form moving and manipulation of sensor-identified objects in arena and triggering of arena range sensors

In all of these games, the children played with the robots and tested their behaviour in the arena after programming them to act in specific ways. Although the robots would sometimes have specific starting positions and orientations inside of the arena, the children were always allowed to stand wherever they wanted at all times. Furthermore, the children were allowed to include specific features into the environment to help their robots succeed in their tasks, but they were never allowed to either manually interfere in their robots' behaviours or to manually trigger any of the arena's sensors.

All of the games were played in a square "arena", an enclosure 6 feet long on each side with walls 1.5 feet high. All of the games involved the robots triggering range sensors attached to the walls of the arena in various ways, and occasionally

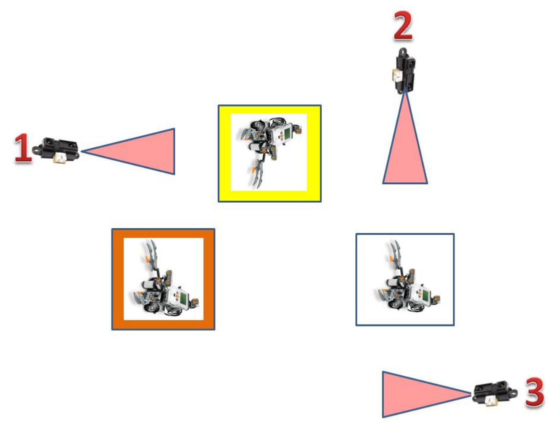


Figure 4.1: Positioning of arena sensors and robots at the beginning of the "robot relay race". The robot in the orange square is at the beginning of the relay race chain and is meant to drive forward until it's within a few inches of the upper arena wall, putting it within close range (one of the pink triangles) of arena sensor "1" and the distance sensor of the robot in the yellow square. This will start a chain reaction of each robot turning around by 180', driving forward until it almost hits a wall and gets within range of the next robot's distance sensor, thus continuing the race.

also required them to manipulate sensor-identified objects inside the arena in specific ways. All of the arena sensors' data were read by a Java program running on a laptop, and when this program determined that the robots successfully completed different parts of the game according to the data from the arena's sensors, the Java program both made short, happy sounds play from speakers near the arena and made lights located on the edge of the arena and near the robot turn on. When the data from the arena's sensors told the Java program that the robots successfully completed each game and were located at their goal positions, the Java program made all of the lights around the arena repeatedly flash and made happy music play from the speakers.

4.1.2 Justification for design choices

There are many reasons why I made specific design choices in implementing the arena games. For example, the arena games take the form of physical tasks that the robots have to perform by behaving in increasingly collaborative ways in order to achieve their goals. We chose this form of progression, of having the first game involve each robot take turns playing in the arena by themselves and having the last game involve multiple robots in the arena at the same time having to work together, because we wanted to gradually make the children comfortable with the idea of collaborating with others. We felt that having the children with autism, who already have difficulties in engaging in social play with others, play with their robots in each of Parten's forms of social play (solitary, parallel, associative, and cooperative [Parten, 1932]) would help them to learn about cooperative and collobrative play with less mental stress than if we asked them to both immediately program their robot to interact with and play constructively with other robots. Additionally, because having the robots play collaboratively required the groups of children to work together to coordinate and synchronize the actions of their robots, which is itself another layer of social interaction and collaboration for the children to comprehend, we felt it would be less stressful for the groups of children if their inter-group play styles followed similar paths of starting out playing by themselves and gradually interacting more with the other groups of children.

All of the games involved the robots performing tasks inside of a sensor-equipped arena for a number of reasons. Firstly, having the children play with their robots in a specific, clearly-defined area centralized all of the activities that took place during the first experiment and made it easier to maintain order and monitor the children's behaviours (see figure 4.2). Although some children might have enjoyed it more if they were urged to play with the robots wherever they liked, it could have led to disagreements among each group of children about where and how they should play with their robot, to say nothing of making it more difficult to

Figure 4.2: Children participating in my first experiment gathered around the edges of the arena to watch their robots play games. In this picture, I am holding a robot in my hands and examining it for errors while the children speak.

observe how each group of children interacted while playing. Secondly, having the children convene to play at a single location made it much easier to teach them about robotic collaboration. Although the children might have found more enjoyment in making their robots play and interact with whichever parts of their environment that they liked, having a single location for playmade it much easier to demonstrate specific behaviours that they children were meant to program into their own robots. Additionally, having a single location in which the robots played made it much easier to show the children how the robots could interact in collaborative ways because it gave all of the robots a common environment to explore, common objects with which to interact, and a common set of constraints for their behaviours; if each group played with their robots however they liked, it is unlikely that any two robots would be programmed to interact with their environments in quite the same way, making it much more difficult for both multiple robots to work together and for multiple groups of children to coordinate their robots' actions.

4.1.3 Hardware and software used

The games that the robots played within the arena used specific sensors and materials. As we described earlier in section 4.1.1, the arena itself was a square 6 feet long on each side and was made of interlocking wooden boards 1.5 feet high. Velcro tabs were attached to the inside of the arena walls at regular intervals so that, depending on the game that the robots were supposed to play, Sharp GP2D12 infrared range sensors (see figure 4.3 on the far left) could be attached to the appropriate locations for sensing the robots' positions. Each infrared range sensor could sense objects between 4 and 30 inches away which made them suitable for sensing robots in close proximity to them. Each range sensor was connected to their own Phidget IR distance sensor interface board (see figure 4.3 on the middle left), and each board was attached to an analog intput port on a Phidget 8/8/8 I/O Interface Kit (see figure 4.3 on the middle right), which allowed us to easily read multiple analog and digital inputs as well as to drive multiple digital outputs over a single USB connection on a computer. Four LEDs in blue, yellow, red, and green were attached to digital output ports of the Interface Kit, and one LED was placed in each corner of the arena. These LEDs were lit up whenever the robots accomplished parts of their tasks and were repeatedly flashed on and off whenever a robot successfully completed all of its tasks. Additionally, a single Phidget RFID Reader (see figure 4.3 on the far right) was used to tell when an object with an RFID tag was successfully moved to a certain location during games that required the robots to move and manipulate objects inside the arena. Both the Interface Kit and the RFID Reader were connected to a laptop computer via USB cables and their data was read by the program controlling the arena.

The program that controlled the arena's responses was written in Java, was relatively short and simple, and used proprietary Phidget libraries to read sensor data and toggle the states of the LEDs. It was comprised of simple conditional statements and sensory reward functions, although the structuring of the statements

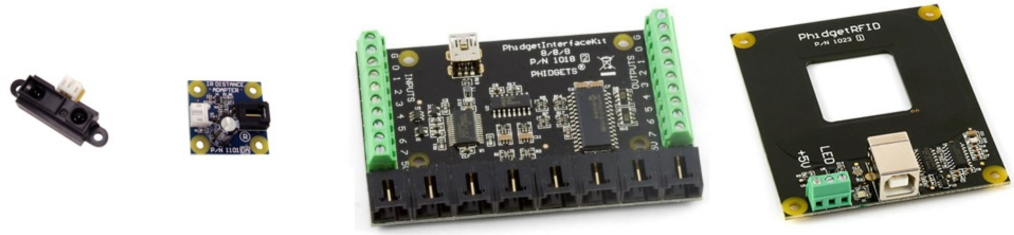


Figure 4.3: **Far left:** Sharp GP2D12 infrared range sensor. **Middle left:** Phidget infrared distance sensor interface board. **Middle right:** Phidget 8/8/8 I/O Interface Kit. **Far right:** Phidget RFID Reader (from *http://www.trossenrobotics.com/phidgets.aspx* and *http://www.trossenrobotics.com/sharp-ir-distance-sensor-gp2d12.aspx*).

and the expressions used in them were changed depending on the specific arena game for which it was being used. For example, while a robot relay race or full-lap robot race might require specific conditions to be met before certain infrared range sensors were sampled (to properly simulate the passing of racing checkpoints in a specific order), a simpler game involving the robots driving toward a single range sensor would constantly sample the infrared range data from said sensor without fulfilling any conditions. Additionally, while the sensory reward function usually made the coloured LEDs flash on and off by rapidly toggling the digital outputs connected to them and played happy music for a short period of time, this changed when the games involved completing subtasks which contributed to a larger task, such as passing a single checkpoint in a race. In these circumstances, the sensory reward function would distinguish between full and partial task accomplishment and give a lesser sensory reward (e.g. turning a light on and playing a pleasant sound) when the robot completed one part of a multi-stage task and a more satisfying sensory reward for completing all the tasks in a game.

4.2 "Tilt and roll"

The collaborative game in my second experiment required two players, a child with autism and either a typically developed adult or KASPAR the humanoid robot, to manipulate Nintendo®Wii controllers or Wiimotes [wii] in order to jointly select shapes on a single horizontally-oriented computer screen. When both players successfully selected the same shape at the same time, the shape would spin around and flash while victorious music played. The difficulty in this game stemmed from having the children with autism communicate with the other player about which shape to select and when to do so.

4.2.1 Description and mechanics of gameplay

The goal of this game was to provide children with autism a means to socially interact with another person in a fun, stimulating, and collaborative setting. Specifically, the game required a child with autism to pay attention to another player and communicate with them in order to coordinate and synchronize their actions. This was meant to be a scenario which was direct, engaging, and fun for the child, as well as conducive to a certain amount of social interaction among the players. By constructing a play setting that was both founded on dyadic interaction and easy to observe, we hoped to gather easily interpreted data on whether children with autism collaborated more with a human partner in this game after interacting with a robotic one.

In this game, the two players stood on opposite sides of a horizontally-oriented screen while facing each other. The screen showed a number of colourful 3D shapes such as spheres, donuts, and Platonic solids on a black background as well as two perpendicular lines, one orange and one light blue (see figure 4.4). The austistic child was given a Wiimote with an orange stripe, and by rolling their controller to either side (rotating it along the axis running from the front of the controller to the back), they could make the orange line move left and right. The other player,

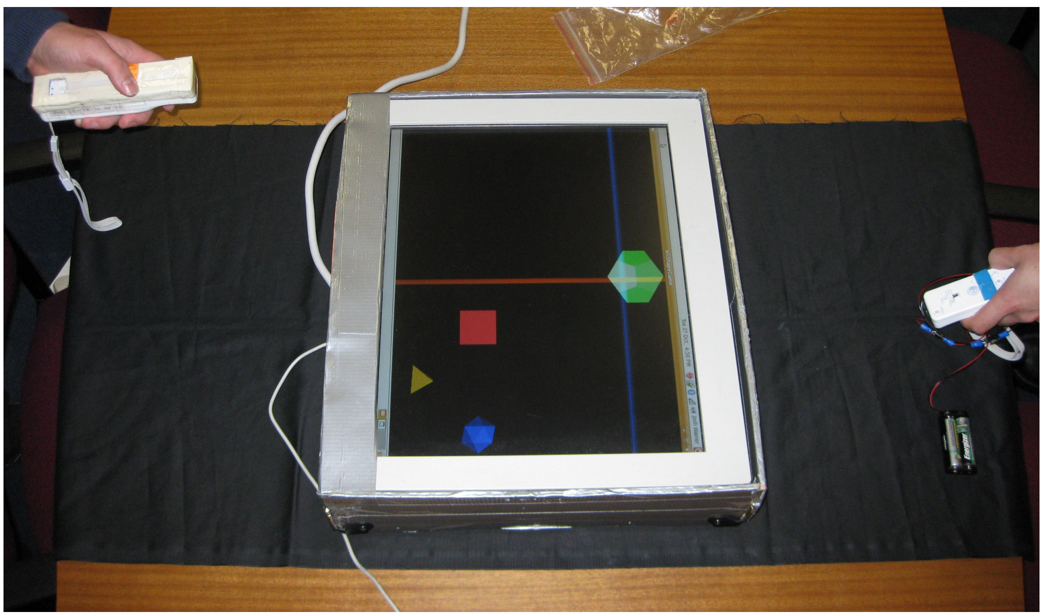


Figure 4.4: The setup for playing "Tilt and roll". The player on the left (stand-in for the child with autism) controls the location of the orange selection line, while the player on the right (stand-in for the human adult or the humanoid robot) controls the location of the blue selection line.

whether a human or a robot, was given a different Wiimote with a blue stripe. By tilting their controller forward or backward (rotating it along the axis running from the left side of the controller to the right side), the other player could make the blue line move up or down. When both lines intersected near a shape and both players pulled the triggers on their Wiimote controllers at the same time, a happy sound or music sample would play from a nearby speaker and the shape would spin around while fading in and out of transparency before disappearing. After all of the shapes had disappeared, a different set of shapes would appear on the screen and the game would continue.

In order for either player to coordinate the joint selection of a specific shape, they had to communicate their intentions to the other player by keeping their line on the screen positioned over the desired shape, speaking about the shape or pointing to it, and pressing a button on the top of their Wiimotes. When this was done successfully, the non-autistic player would then try to arrange it such that both players would pull the triggers on their Wiimotes when they counted to three. Because the focus of the experiment was to see how well the child with autism would collaborate with the non-autistic player, the role of the non-autistic player was to try and prompt the other child to pick a shape once every six seconds if the latter were being unresponsive or were not taking the initiative. If the child with autism was not looking at the game or if they had trouble picking a shape properly, then a nearby carer would assist them. The only time that the non-autistic player could pick their own shape would be if they unsuccessfully prompted the child with autism to pick a shape three times in a row.

4.2.2 Justification for design choices

In the design and implementation of "Tilt and roll", we incorporated certain features into it for specific reasons. We decided to have the two game players stand on opposite sides of a flatbed monitor instead of having them stand next to each other while facing an upright monitor because a horizontally-oriented screen has been found to promote greater collaborative interaction and turn-taking than a vertical, upright one [Rogers and Lindley, 2004]. Furthermore, because children with autism have difficulties in understanding the importance of another individual's gaze changes or bids for joint attention [Leekam et al., 1997], we felt that if the game players were standing side by side while facing a screen in front of them, the fact that each player would be out of each other's visual fields of view would exacerbate the existing difficulties of children with autism and negatively impact their ability to play our game.

Instead of designing the game such that two individuals could potentially act independently of each other and still play successfully, despite there being little to no active cooperation between them (such as in the video games Rampage [Bally/Midway, 1986], Bubble Bobble [Taito, 1986], or Joust [WilliamsElectronics, 1982]), we designed the game to require coordinated, synchronous, and cooperative actions on behalf of both players. If the gameplay were not designed to be as collaborative as possible, then because children with autism will naturally engage in nonsocial, solitary play much more frequently than social play [Sigman and Ruskin, 1999], we felt that, given the option, children with autism would readily engage in solitary, noncommunicative play in our video game.

Because we also wanted the children to play the game freely without feeling overly pressured or stressed, we excluded time limits, losing conditions, and elements of scoring or grading from gameplay. If these elements were included in the game design, we felt it would put unnecessary pressure on the children to perform and make it more difficult for them to socially interact with others.

To make the game accessible and appealing to people with potentially different levels of cognitive development, we designed the game with bright, distinct colours, a simple visual layout, and easily identifiable 3D shapes such as cubes, diamonds, and pyramids (see figure 4.5). Additionally, since the children playing the

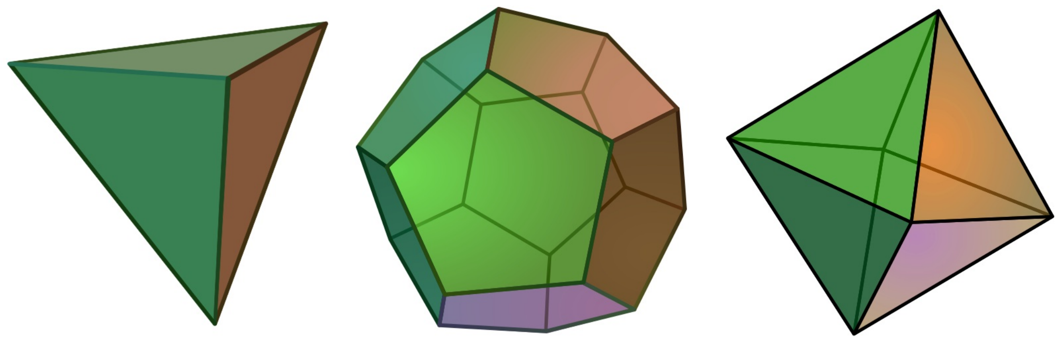


Figure 4.5: Some of the 3D shapes, or Platonic solids, used in my game. From left to right, they are a tetrahedron, a dodecahedron, and an octahedron, respectively (from *http://en.wikipedia.org/wiki/Platonic_solid*).

game had impaired communication skills, we designed the gameplay and the game's visual layout to require as little explanation as possible. Furthermore, we allowed each player to control a line on the screen by playing with the orientation of a Wiimote. This intuitive set of controls was used to allow the game to automatically track which shape the players selected in real time, to make it as easy as possible for the children to control what happened in the game, and to allow KASPAR, a robot without functional hands, to appear to play the game as easily as a human.

4.2.3 Hardware and software used

The "Tilt and roll" game used off-the-shelf hardware and third-party software libraries for some software features, although I implemented the mechanics and rules of the game itself. Specifically, the game used Nintendo Wiimotes by reading data from their ADXL330 three axis accelerometer chips in order to sense the pitch and roll of the controllers (rotations about the X-axis and Y-axis, respectively, in figure 4.6), by reading data from their buttons in order to determine when the players were selecting shapes or prompting the other player to move their line toward a specific shsape, and by activating their rumble motors to provide the players with a sensory reward. Because the game did not learn to recognize patterns of accelerometer data or classify gestures and only required basic reading of Wiimote data such as pitch, roll, and button statuses, we only needed to use the wiiuse v0.12 open-source libraries to interface the game with the Wiimotes' data.

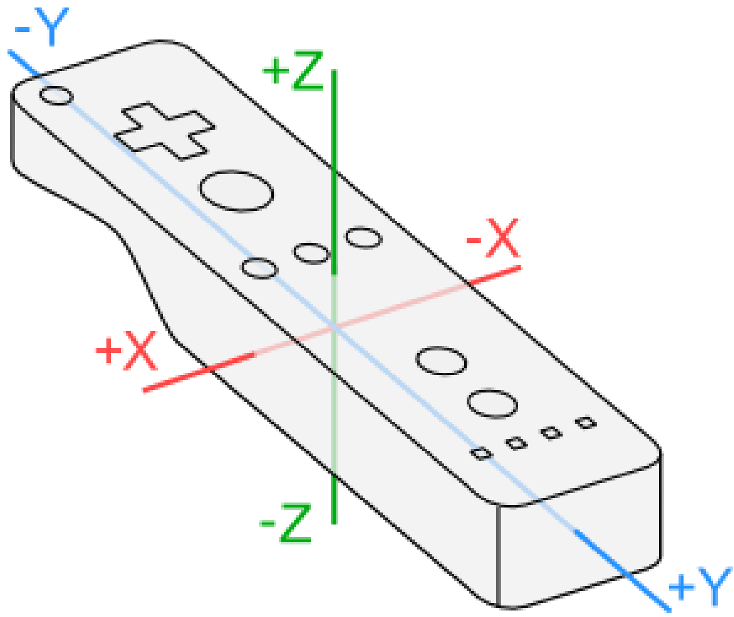


Figure 4.6: The axes of each Wiimote according to their accelerometers. "Pitch" or "Tilt" was considered a rotation about the red X-axis, and "roll" was considered a rotation about the blue Y-axis (from *http://wiibrew.org/wiki/Wiimote*).

The game rendered its 3D graphics using the OpenGL v3.2 libraries because it let us easily draw impressive-looking three-dimensional Platonic solids and other shapes as well as change many of their visual qualities, such as orientation, colour, lighting conditions, and opacity. The graphics were displayed on a horizontally-oriented flatscreen monitor. Although we wanted to utilize people's intuitive abilities to touch/point to objects that they might want by having shapes in our game be selected by touching their images on a screen, we unfortunately could not arrange the use of a touchscreen monitor to enable this functionality.

Our game was found to be impressive by the children with autism and accomplished what it was meant to perform. After successfully connecting to two specific Wiimotes and initializing a number of different data structures, the game entered a perpetual loop of checking for and handling any button activity from the

Wiimotes, displaying its shapes at a rate of 77 frames per second, and checking for any keyboard input (pausing the game or toggling between typical gameplay and a one-player mode used to verify that the child with autism understood the basic game mechanics) or the game being quit. In displaying the shapes, the game applied a low-pass filter to the roll and pitch values of the appropriate Wiimotes in the forms of windowed running averages and drew the players' colour-coded selection bars accordingly, determined whether each shape should be lit up if a player's selection bar was close to it, and determined whether the players simultaneously selected the same shape and displayed a sensory reward, if appropriate. While all of this happened, the game also kept a text-based log of every significant event that happened and continually sent all game-related data to the software process controlling KASPAR.

4.3 "Copycat"

During my third experiment, pairs of children with autism played a collaborative game called "Copycat" with each other and also occasionally played with a third player in the form of KASPAR the humanoid robot. In this game, players would alternate between choosing to pose in a specific way from a shared, horizontally-oriented screen, and mirroring/copying the pose of the "choosing" or "directing" player. When all players posed in the same way for long enough, a shape would spin around on the screen, victorious music would play, and the players would rotate through the role of directing and the roles of "copying". This game was challenging because in addition to it requiring the directing player to capture the attention(s) of the other player(s) and describe the pose, verbally or physically, that they wanted the other(s) to copy, the game also required the children with autism to take turns in a game, which can be a difficult concept for such children to understand and practice.

4.3.1 Description and mechanics of gameplay

The goals of this game were similar to those of "Tilt and roll", in the sense that in both games, children participated in engaging scenarios that were meant to be fun, and the children were required in both settings to pay attention to another player and communicate with them in order to coordinate and synchronize their actions. However, "Copycat" involved two children with autism playing together, which fundamentally changed the social learning and communication dynamic inherent in the game; instead of simply learning how to communicate in the context of the game with a typically-developed individual, each child with autism now had to learn how to communicate and interact with another child with autism. Additionally, this game required the children to take turns and switch roles in order to successfully select shapes. Taking turns in play is a fundamentally social concept and is therefore particularly difficult for children with autism to understand, so while "Tilt and roll" required children with autism to take the initiative and or listen to the prompting of others, "Copycat" required the same behaviours of children with autism as well as for them to learn to cooperate by taking turns and understand that different behaviours and social roles were required of them depending on whose turn it was.

While "Copycat" used a similar setup as "Tilt and roll" in the sense that it had its players standing around a horizontally-oriented monitor playing with Wiimotes, the fundamentals of "Copycat" were quite different. Specifically, this game was played by two or three players who wore Wiimotes strapped onto one of their arms and took turns in selecting shapes. To keep the players on track, an arrow on the side of the screen pointed to the directing player at all times. Whenever a player got to direct the other player(s), they would look at a screen which featured coloured stick figures with their arms posing in different ways and matching-coloured wireframes of shapes between the stick figures (see figure 4.7). The directing player would pick a shape that they wanted to see fill with colour, pose like the stick figures next to the shape, and then communicate that the other players should imitate

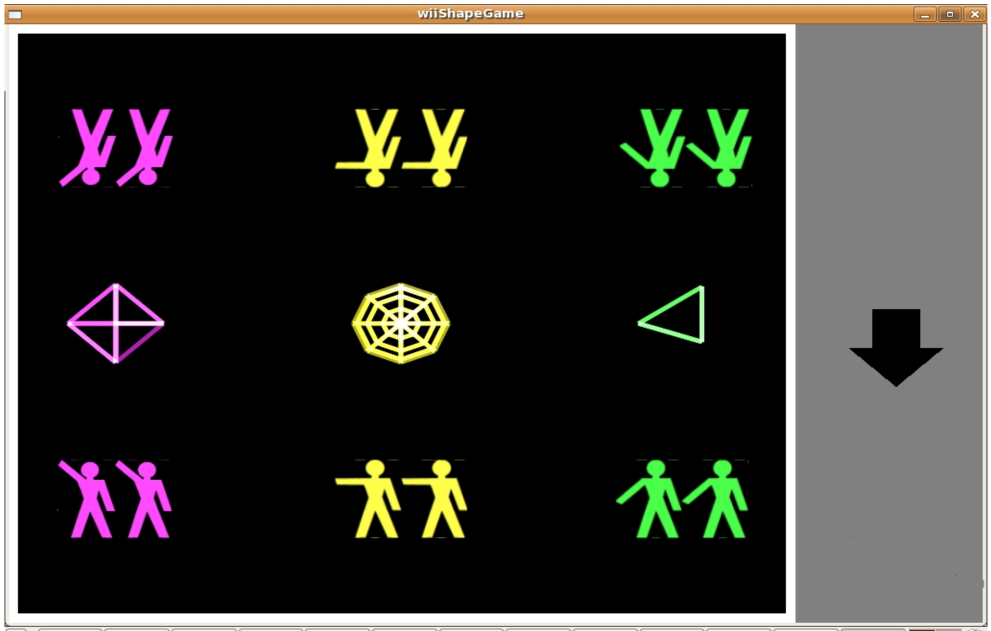


Figure 4.7: A screenshot of "Copycat". Each wireframe shape on the screen had a unique colour and was associated with a distinct pose, shown by the colour-coded stick figures flanking each shape.

their pose. When all players posed like the directing player, the shape in question would slowly fill with colour until the game gave a sensory reward in the form of playing happy sounds, spinning the shape around, and flashing the shape's colour. Afterwards, the selected shape would vanish, all the players would rest for a few seconds with their arms down, and the next player would get their turn to direct the others. When all the shapes on a screen had been selected, a new set of shapes and posing stick figures would replace them.

To make the other players pose in a specific way, the directing player had to use speech and/or gestures to communicate the shape or colour for which they were posing while holding their arms in the correct pose. In the event that any players did not follow the rules of the game, we did not prevent any of the children from trying to enforce the rules along with the carer. Specifically, if the directing player did not choose a shape, they would have been prompted to do so by a carer

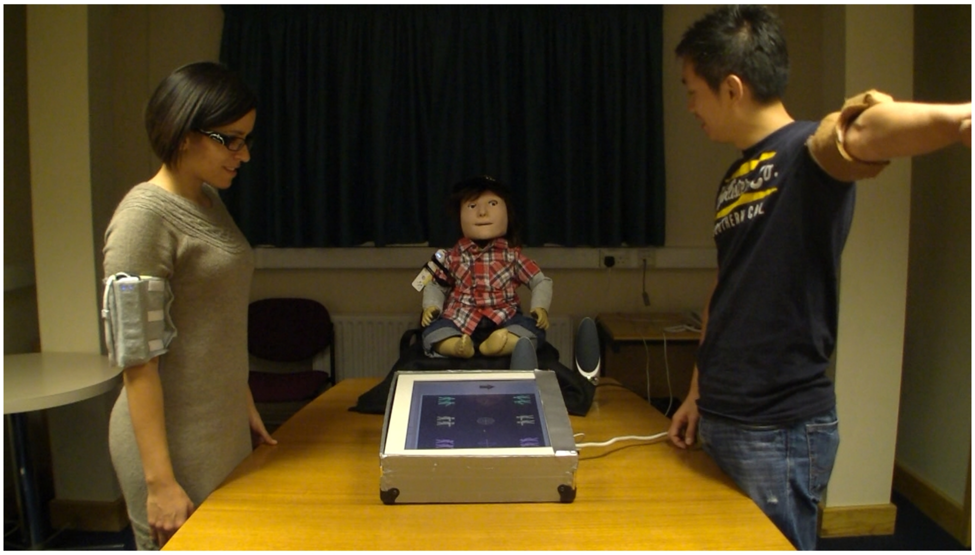


Figure 4.8: Two researchers demonstrate how to play "Copycat" with KASPAR the robot for illustrative purposes. It is the player on the right's turn to choose a shape and direct the other players in how to pose.

or possibly another player. Similarly, if one of the non-directing players did not comply with the choice of the directing player, either the carer or another player would have urged them to comply with the directing player's choice (see figure 4.8).

4.3.2 Justification for design choices

In addition to incorporating previously successful aspects of "Tilt and roll" in new or similar ways, such as the positioning of the children with respect to the screen, the screen's horizontal orientation, the minimalistic approach to the game's visual design, and the explicitly collaborative nature of the gameplay, we also implemented specific aspects of gameplay and changes to the game's appearance for good reason. For example, although "Tilt and roll" required the players to press buttons on the Wiimotes to select shapes or communicate their choices, we felt that the children would have an easier time playing the game if we eliminated the need for button-pressing. As such, we made it so that the players would choose shapes by posing like similarly-coloured stick figures. Furthermore, we specifically did not want the screen to directly indicate which shape the directing player had chosen as it did in “Tilt and roll” because such a design choice would require a player to pay attention to the game screen instead of the other players. Instead, we wanted the players in “Copycat” to constantly look at the directing player and/or listen to them to figure out what they should do, as we felt that this could help to increase the children’s social awareness. Using this approach, we felt that the simplest way to convey which shape the directing player had chosen would be to have players choose shapes through posing in simple, visually distinct ways, such as one-armed, static positions adapted from the flag semaphore character alphabet (see figure 4.9). This kind of posing could be easily sensed by the game as well as the robot by attaching the Wiimotes to the children’s upper arms via a thick velcro strap similar to a blood pressure cuff and reading the “pitch” values of their accelerometers.

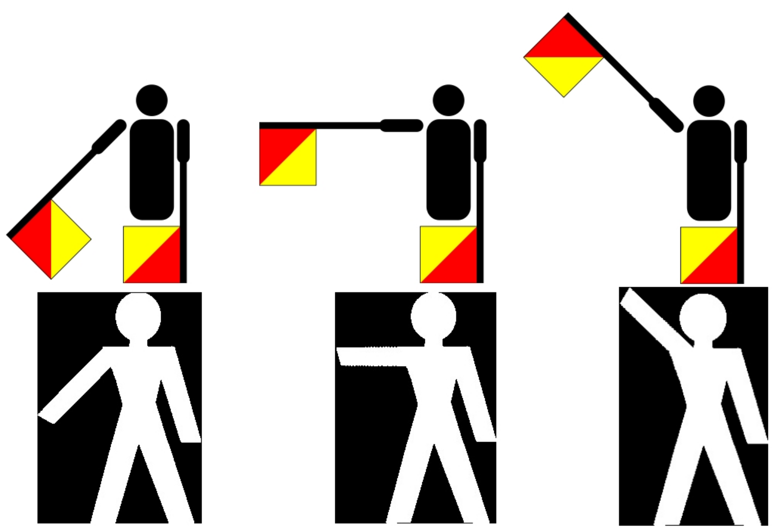


Figure 4.9: **Top row:** The flag semaphore poses upon which we based our game poses. From left to right, they are A or 1, B or 2, and C or 3 or Acknowledge (from *http://en.wikipedia.org/wiki/Flag_semaphore*). **Bottom row:** The icons used in “Copycat” which showed the players how they should pose in order to fill in a given wireframe shape with colour.

In order to make it easier for the children to learn how to play the game and to better reinforce the concept of collaborative interaction, we designed the gameplay in "Copycat" such that the players would have to work together to mimic each other's poses. Initially, one might expect that children with autism could have problems with this particular form of play as it is a well-established fact that children with autism have a difficult time mimicking or imitating the behaviours of others. Specifically, children with autism find it more difficult than neurotypical individuals to imitate the subtle nuances or styles of performing an action [Hobson and Lee, 1999]. Additionally, there is strong evidence to support the idea that autism may be correlated with the inhibited development of a specific class of neurons in the brain's frontal cortex known as mirror neurons, or neurons which become active when people observe and/or mimic others performing precise motions with their hands [Williams et al., 2001]. As such, one might expect that the children would find this game even more difficult to play than they did "Tilt and roll". However, research has also shown that when an adult actively mimics the behaviour of children with autism over the course of multiple sessions, these children will gradually become more likely to be socially responsive toward the adult than if the grown-up had simply played with them without imitating the children's actions [Field et al., 2001]. As such, we designed "Copycat" to require the children to imitate each other's behaviour and to interact with a humanoid robot that would mimic their behaviour to promote better social interaction and engagement among the children at the cost of potentially lengthening their required time to learn the game.

To ensure that each child would be able to play "Copycat" for roughly the same amount of time as every other child and to give a sense of order to the children's collaborative efforts, we decided to include turn-taking in our game. Although children with autism are known to have difficulties with taking turns and will actually perform turn taking less often than other children [Mundy et al., 1986], research has shown that children with autism can successfully play a tabletop collaborative video game which enforces turn-taking. Furthermore, playing this game with computerreinforced rules and technology-based methods of taking turns seemed to promote positive social interaction in some of the children with autism [Piper et al., 2006]. As such, we felt confident that including turn-taking in "Copycat" would benefit the children that played our game.

We only gave one controller to each child for a number of reasons, although we realize that there could be many benefits to each of the children using two controllers (one strapped to each upper arm) to play "Copycat". With two controllers for each child, the number of poses that one could perform in the game would increase from 4 to 10, and the poses themselves could become more complicated since they would require the children to concentrate on how both of their arms were positioned instead of focusing on only one arm. These changes could make the game more interesting for the children. Furthermore, even if the poses did not increase in number or complexity - if each pose now merely required the children to perform an action with both arms instead of only one - the game could still be easier for the children to play. This is because such a design choice would avoid the pitfall which caused minor confusion to a few children when they played "Copycat" with three players for their first time. In this triadic setting, with KASPAR located to their side of both children (i.e. the robot was diagonally across from both children) and facing them, one of the children did not know how to mirror the robot's one-armed pose because doing so would contradict the one-armed pose of the other child, who was also attempting to mirror the robot's one-armed pose (see figure 4.10). Despite the potential benefits of each child using two controllers and therefore two arms to play "Copycat", we did not include this in our game's design because we felt that the children would become tired too quickly if every pose in the game required the children to hold both arms in a specific pose. In contrast, if the game required only one arm for posing and the child's posing arm was fatigued, they could use their other arm to support their posing arm and continue playing. Most importantly, requiring each child to make poses with only one arm left their other arm free to point at the screen or make gestures at the other player(s); by only requiring one arm to play "Copycat", this gave the children the freedom to use their other arm to communicate with others, which is the very kind of behaviour that this experiment is trying to promote.

Figure 4.10: Because each child had a controller strapped to one of their arms, some children were mildly confused during their first time playing "Copycat" triadically with respect to how all of the players should imitate each other. As an exmaple, each child here is attempting to mirror KASPAR's pose and is doing so successfully in a mirroring sense, resulting in the children not imitating each other. More importantly, attempting to mirror KASPAR is causing the child on the left-hand side to pose an arm that does not have a controller strapped to it, meaning that neither KASPAR nor the game "Copycat" can perceive the child on the left's pose. The child on the right is attempting to point out this mistake to the child on the left and is also indicating the arm that the other child should actually be posing with.

4.3.3 Hardware and software used

Our "Copycat" game used the same hardware as "Tilt and roll", in the sense that it required players to strap Wiimotes to one of their arms while it used the data from the controllers' accelerometers (their pitch readings, specifically) to interpret how each player was posing. "Copycat" also used the wiiuse v0.12 open source libraries to interface with the Wiimote hardware. Similarly, the OpenGL v3.2 libraries were used to render impressive-looking 3D computer graphics for the game for the same reasons that they were used in "Tilt and roll".

The "Copycat" game fulfilled its goal of being an enjoyable video game that promoted collaboration and imitation among its players, and both the children with autism involved in our third study and some of their classmates had a lot of fun playing the "Copycat" game whether or not KASPAR was also playing with them. The game's software was designed such that after it successfully connecting to two or more specific Wiimotes and thereby determined what kind of game would be played (dyadic with two children, dyadic with one robot and one child, or triadic with two children and one robot), the game process initialized its variables, reset the number and types of shapes it would display, and entered its main loop. As long as a quit message wasn't returned by a keyboard command inside of this loop, the game process would first check to see if KASPAR sent it a message containing the robot's speech, as this would happen whenever KASPAR said something to the children. Then, it would sense the Wiimotes' pitches, apply a low-pass filter to each in the form of a windowed running average, classify each Wiimote's pitch into each player's pose, and record any changes to the poses in each player's log of gameplay. If the players had not paused the game, the game process would update its display of shapes. In updating its display, the game process would attempt to draw each shape that was still visible, and upon checking if all the players' poses matched the pose associated with a given visible shape, the game would either gradually fill that shape in with an appropriate colour or activate the appropriate sensory rewards, depending on how long the players had held their poses. If the game involved KASPAR, the game thread would then send its game data over to KASPAR for processing. Lastly, provided that the children weren't meant to be resting, the game process would draw the appropriate stick figures for each shape as well as an arrow to indicate whose turn it was and then return to the beginning of its main loop.

4.4 Summary

In this chapter, I first discussed how the arena games used in my first experiment were comprised of simple tasks for the NXT robots to accomplish and how when the children participating in the study successfully programmed the robots to perform these tasks, the arena provided the children with sensory rewards of flashing LEDs and pleasant music. After describing examples of these games and how the arena was constructed as a wooden framework with sensors attached at certain spots with velcro, I explained why I chose to have the robot's tasks gradually become more and more collaborative and why I decided to have the arena serve as a central focus of activity for the children instead of letting them play with the robots in any setting that they wanted. Lastly, I described the specific sensors and interface boards that were used in the arena and the Java programs that used the data from these sensors to give the children sensory rewards.

Next, I discussed the dyadic video game used in my second study, "Tilt and roll". After describing how one child with autism was meant to play either a human or a robot player and stand facing them with the game screen between them, I described how the players were meant to roll and tilt Wiimotes in order to move lines around on a screen and select shapes by synchronizing their actions with their partner. I then discussed why the game's physical layout was meant to promote collaboration among its players, how the cooperative mechanics of the game were meant to promote social interaction and communication, and why the game used minimalistic graphics and intuitive controls to require as little explanation as possible. I then explained how we used the pitch, roll, and button-pressing data from the Wiimotes and the algorithms used by the game's software to entertain its players.

Lastly, I described the dyadic/triadic video game used in my third study, "Copycat", which was meant to be played by two children with autism and occasionally the robot KASPAR as a third player. I explained how the players were meant to strap Wiimotes onto their arms and take turns posing in one of the ways shown by stick figures on a screen and directing the other player(s) to mimic them. After describing how the wireframe shape associated with the chosen pose would fill in with colour and spin around when the children successfully posed like its related stick figures, I then explained why specific design choices were made in this game. Specifically, I went into detail on how the game's focus on mimicry and imitation was meant to encourage more social interaction among the players, and how even though children with autism have difficulties imitating the style in which others perform an action, having their own actions consistently mimicked helps to improve the social engagement shown by a child with autism. Additionally, I discussed how even though turn-taking has been shown to be difficult for some children with autism, research has also shown that including turn-taking in a collaborative game for children with autism can be beneficial for them. Lastly, I discussed how the game used the pitch values from the Wiimote controllers to determine how the players were posing as well as a general overview of how the game operated.

Chapter 5

First study: Using a robotics class and LEGO NXT robots to foster collaboration among groups of children with autism

This chapter describes an exploratory study involving the design of an after-school robotics class for groups of children at the higher-functioning end of the autistic spectrum. The aim of the study was to foster collaboration among the children in the context of a class where they programmed LEGO robots under the guidance of an experimenter. The class took place once a week over several months and used many different measures to assess the children's collaborative behaviours. Detailed analysis of behavioural data is presented, and despite the small sample size, our findings suggest that the number of potentially collaborative behaviours the children displayed during a class is more strongly related to the amount of enjoyment the children derived from the classes than to the number of classes in which the children participated. Parallel-run, free-form drawing sessions conducted before certain classes gave some indication that these behavioural changes partly generalized to a different context. Additionally, many of the children in the class either found their experiences in class to be helpful in other social interactions or expected them to be.

5.1 Introduction

5.1.1 Background and motivation

In addition to being inspired by research on group learning related to robotics, which was discussed in section 2.4.2, and research on social play among children with autism, which was discussed in section 2.5.2, this study's particular approach was also inspired by the idea of using children with autism's stereotyped interests to teach them how to socially interact with their peers [Attwood, 1998] [Greenspan and Wieder, 1998]. Specifically, LeGoff found that children who participated in structured, group-based LEGO therapy displayed positive social behaviours significantly more and negative social behaviours significantly less after the set of therapy sessions concluded [LeGoff, 2004]. Later, in a longitudinal study spanning three years, LeGoff and Sherman found that children who attended a set of LEGO therapy play sessions performed significantly better on standard social behaviour tests than children who attended more traditional autism therapy sessions for the same period of time [LeGoff and Sherman, 2006], although other researchers have found LEGO therapy to be only slightly more effective than traditional therapy [Owens et al., 2008].

This study used designs similar to those used in LeGoff's LEGO therapy sessions, inasmuch as the children in both studies learned positive social interaction skills by cooperatively playing with a single toy or set of toys with other children in a group setting. However, our study focused on the children programming robots that were previously constructed from LEGO Mindstorm kits, as children with autism have a natural fascination with computers and electronic devices [Colby and Smith, 1971] [Moore, 1998] [Powell, 1996]. Furthermore, while LeGoff's LEGO therapy sessions focused on children building structures, children in our study made their robots perform specific tasks and learned how their interactions with the robot changed its behaviour. In this way, the robot became an independent agent with its own goals that the children learned to play with. Furthermore, in addition to collaborating with other members of their own group, children in our study also learned to collaborate with children from other groups when they made all the robots play together to accomplish goals, while LeGoff does not mention having done this. Additionally, our study carried out as part of the Aurora project also compares the children's interactions in the robotics classes to their interactions in three free-form drawing sessions to determine whether any of the children's behavioural changes observed in the first setting would generalize into a different domain. Lastly, while many previous studies have used one or two evaluative methods to determine the amount of collaboration present among a group of children, our study uses multiple assessment methods and compares each one's results against the others.

5.1.2 Research Aims and Expectations: Interacting with robots in a class setting in order to positively impact collaborative behaviour in groups of children with autism, and generalizing these benefits into other settings

As we stated in section 1.2, the primary question of this thesis was whether interacting with an autonomous robot in structured, explicitly collaborative play sessions could promote social interaction and social engagement among children with autism. In the context of this study, such a question was transformed into the aim of *determining whether interacting with robots over an extended period of time in a group-based, collaborative robotics club would result in an increase in social behaviours displayed by the children.* We expected that this aim would be supported by our findings from this study because Robins and Dautenhahn [Robins and Dautenhahn, 2007] as well as Robins, Dautenhahn, te Boekhorst and Billard [Robins et al., 2005] suggested that robots could mediate interactions between children with autism and other people. Additionally, others suggested that group based clubs for children with autism which focused on their stereotyped interests could help foster more social behaviours among the children [LeGoff and Sherman, 2006]. Research on robotics classes for typically developing children also suggested that robotics classes can teach these children about interacting and working together within groups [Nourbakhsh et al., 2004] [Denis and Hubert, 2001] [Järvinen, 1998]. Furthermore, research has shown that play materials involving rules and structured games elicited more fun and more social interaction from a dyad of a typically developing child and a child with autism than did play materials involving construction materials [Dewey et al., 1988]. By combining the findings of these diverse studies, we expected to see that the robots would mediate social interactions among groups of children with autism by increasing the amount of collaborative behaviours displayed at a group-based robotics class.

The second aim of the research in this study is a more specific form of the thesis's secondary question, which asks whether the social skills that children with autism improved by collaboratively playing with an autonomous robot can transfer to another setting without robots. Placed into the context of this study, such a question became the goal of *understanding whether the children would be able to generalize their collaborative behaviours from a robotics class into another, less structured domain which involved interacting only with other children with autism.* Research has shown that children with autism can have difficulties in applying lessons learned from one setting into another [Jordan, 1999]. We expected that playing with robots would affect the children's ability to generalize their behaviours into different settings. To test this, we interspersed three free-form drawing sessions that did not include playing with or interacting with robots among the robotics classes and observed the children's behaviours during them. Similar the robotics classes, the drawing sessions were exploratory in nature. However, it was important for us to include a first attempt at addressing generalization across different contexts, since this is usually absent in the literature on robot assisted play [Werry et al., 2001b] [Robins et al., 2005] [Robins and Dautenhahn, 2006] [Kozima et al., 2005] [Michaud and Théberge-Turmel, 2002] [Robins and Dautenhahn, 2007] [Robins et al., 2004a] [Robins et al., 2006].

5.1.3 Participants from SNAAP club

Working with the St. Nicholas Academy for Autism Project (SNAAP), an after-school computer club for children with ASD who live in the London borough of Barnet, we recruited a number of children to participate in our weekly robotics classes and observed the behaviours of seven who attended more than 60% of the classes (see table 5.1). The children attended the classes on a volunteer basis over a period of four months (see figure 5.1).

Table 5.1: Descriptions of the children who attended nine or more classes. NOTE: detailed diagnostic information was not available for all of the children

Name	Age	Gender	Diagnosis
R	10	Male	Some form of autism
O	8	Male	High functioning autism and severe ADHD
M	9	Male	Borderline Asperger's Syndrome
Sh	8	Male	Some form of autism
C	14	Male	Asperger's Symdrome
S	11	Male	Asperger's Syndrome, developmental language disorder, fine motor dyspraxia, and hyperactivity
B	9	Male	Asperger's Syndrome

The participants were all boys at the higher-functioning end of ASD, and some of them were familiar or friendly with each other from previous interactions in SNAAP. The participants were organized into groups by the heads of SNAAP since they were more familiar with the children than we were. Although the children in each group were matched for temperaments, capabilities, and placements on the autistic spectrum as closely as possible, compromises were made depending on which children attended a given day of class.

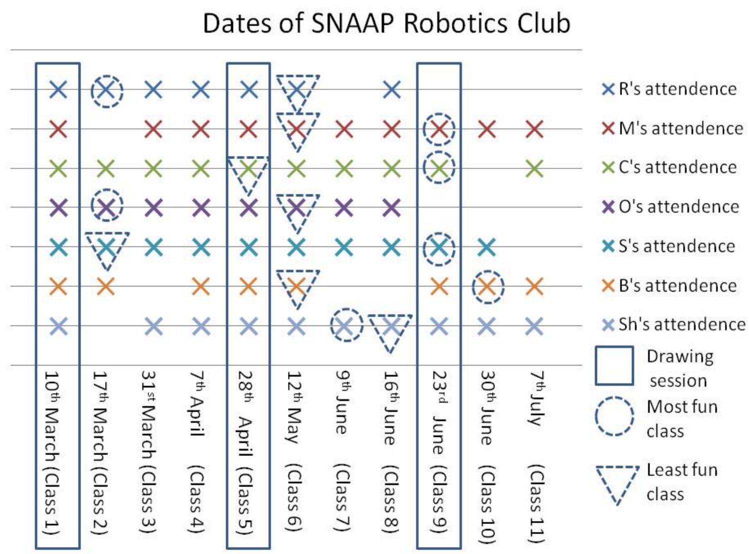


Figure 5.1: The attendance records, as well as the least and most enjoyable (fun) classes, of the children who attended more than 60% of the robotics classes.

5.2 Experiment with SNAAP club : robotics class

5.2.1 Method and procedure

At the robotics classes, each group of participants played with one of three LEGO NXT robots, which we discussed earlier in section 3.1. All of these robots played various collaborative games inside of a sensor equipped arena, which we discussed earlier in section 4.1.

We designed the classes such that in each one, the experimenter would teach a new robotics lesson in the first 15 minutes, and groups of 2-3 children would program and play with the robots to demonstrate what they learned in the remaining 45 minutes. Eleven classes were held which adhered to this schedule, and a twelfth, final class was held during which the children were free to play with the robots in the arena however they wished. This chapter will discuss our findings from the first eleven classes.

During the first class, we observed that the children had difficulties taking turns with their groupmates while playing with their group's robot. Because visual devices are commonly used to inform children with autism about social behaviours [Bondy and Frost, 1994], we designed simple "turn taking wheels" to show how each group member should play with the robot at any given time (see Figure 5.2). We placed these wheels in the classroom and encouraged the children to use these wheels during the 2nd through 9th classes, inclusively. During this period, the children successfully used the wheels to determine how the members of each group should play with the robot. To determine whether or not the children were also learning how to play cooperatively with each other, we removed the turn-taking wheels from the classrooms during the 10th and 11th classes and observed that the children continued to take turns playing with their robots by using roles similar to the ones described on the turn-taking wheels.

5.2.2 Data collection

We used multiple evaluation methods to determine whether our robotics classes affected the amount of collaboration shown among the children participating in our study, including semi-structured interviews, written questionnaires, and video analysis. Using a form of data triangulation, we compared each method's findings against the others to both check the validity of each method's findings as well as to synthesize all of the findings into valid conclusions. Additionally, we use the terms significant, marginally significant, and insignificant in describing the results from our data analysis to say that we used statistical confidence intervals of 95%, 90%, or

Figure 5.2: **Left:** The "turn-taking wheel" the children used. **Right:** The children play with the robots and interact with each other during class

less than 90% (p-values of 0.05, 0.1, and larger than 0.1), respectively, in describing our data.

Questionnaires

Written questionnaires using 7-point Likert scales[1] were administered after each robotics class to both the children participating in our study as well as to their parents or carers. This was done to obtain multiple perspectives of the children's behaviours; a similar technique is used on the Social Skills Rating System, or SSRS [Gresham and Elliott, 1990]. The items on the children's questionnaires asked them to describe how enjoyable each robotics class was, how often they worked with others in their group during each class, and how easy it was to work with other children in their group during each class. The items on the parents'/carers' questionnaires asked them how much their children seemed to enjoy each class, how often their

[1]Electronic copies of these questionnaires will be made available upon request to the authors.

children collaborated with others during each class and how well they did so, as well as how sociably their children behaved outside of each robotics class. For both the parents'/carers' and children's questionnaires, a response of 1 meant the equivalent of "very little" and a response of 7 meant the equivalent of "very much". The differences between children's and parents' responses to various questionnaire items were statistically analyzed using single sample, two-tailed versions of Student's t-test to determine how much the sets of responses differed from each other; two-sample versions of the test were not used because the data in each set of responses varied greatly, and we wanted to determine whether two sets of responses varied in the same ways at the same times.

Video Analysis

We used camcorders to record the children's interactions during class time and taped over 41 hours of video footage. We observed some behaviours among the children which Bauminger described earlier in her studies on social interaction among children with autism [Bauminger, 2002]. Inspired by her coding scheme, we chose to code five behaviours that we felt were potentially collaborative in the context of our robotics classes:

1. **group proxemics**, when groupmates stood within 120 cm, or what Hall describes as the limit of "personal distance" in conversational interaction, of each other [Hall, 1966];
2. **shared gaze**, when groupmates looked at the same object or at each other;
3. **robot-related speech**, how many times the children

   talked about the robotic activities with either the experimenter or their groupmates;
4. **pointing behaviour**, or indicating the robots or computers to either the experimenter or groupmates through pointing at them;

5. **shared positive affect**, how many times the children would laugh or smile with groupmates.

By describing the above behaviours as "potentially collaborative", we mean that we considered the children to be behaving collaboratively only if some instances of these behaviours co-occurred with other behaviours. Specifically, a child would need to exhibit one or more of the last three behaviours (robot-related speech, pointing, or shared positive affect) while they were both close to their groupmates and looking at the same object as them for us to have considered the child as collaborating. Otherwise, the observed instances in question would still be coded in our records, but they would not be considered collaborative behaviours. This was done because studies have shown that when group members are not in close proximity to each other and do not have face-to-face communication, they will have difficulty in collaborating [Kiesler and Cummings, 2002]. Furthermore, our own experiences in the robotics class showed us that the children were more apt to ignore their groupmates' actions if they were not paying attention to them, were not close to them, or both.

To ensure inter-rater reliability, the above behaviours were coded by one of the experimenters as well as a second independent rater who coded 10% of the data. When the independent rater's video codings were compared with the codings of the experimenter to see how well they agreed with each other, the average agreement value was 0.91, which is generally considered to be good. We also examined the above sets of codings for reliability and received an average value for Cohen's kappa of $\kappa = 0.72$. This is acceptable, as having a Cohen's kappa value higher than 0.60 suggests that the agreement observed between the raters is not due to chance alone [Bakeman, 1986][2].

We analyzed the above data for four different classes for each of the seven children that attended over 60% of the classes, which amounted to 25.55 hours

[2] Kappa values of 0.4 - 0.6 have been characterized as fair, 0.6 - 0.75 as good, and over 0.75 as excellent [Anderson et al., 2004]

of data: their first class, their last class (because of the voluntary nature of the classes, the last day of class was not necessarily the same day for each child), and, according to the 7-point Likert scale questionnaires they filled out, the classes with the highest and lowest values for the children's enjoyment, or the children's most and least enjoyable/fun classes, respectively (see Figure 5.1). This was to determine whether the number of classes spent interacting with the same people and robots or the amount of enjoyment from a class affected collaborative behaviour. In order to get as much data as possible, we specifically did not allow the most or least enjoyable classes to overlap with the first or last classes in order to avoid the novelty effect during the first class and to avoid the last class which was very close to the start of the vacation period. This overlap could be avoided easily, since the children whose most or least enjoyable classes overlapped with the first or last ones had multiple classes that they reported as equally most or least enjoyable. In order to select the most or least fun classes from these multiple choices, the parents' ratings for class enjoyability on these days were then used to decide which classes we would analyze. This procedure allowed the selection of the most and least fun classes to not overlap with the first or last classes. This makes sense, since as we will show in section 5.2.3, the answers on the parent's questionnaires were not significantly different from those of their children's.

We used Wilcoxon's signed-rank tests to determine the significance of differences in social behaviours on different days; we could not use paired t-tests because our paired sets of data were not from high enough populations, were not random, and were not normally distributed.

Semi-structured Interviews

A semi-structured interview is a data-gathering method in which an experimenter asks a series of guiding questions to steer an interview with a participant toward specific topics. However, it also allows for additional questions and topics to occur naturally and be followed up during the course of the interview [Rosenthal and Rosnow, 2008]. We conducted a one-on-one, semi-structured interview with each of our study's participants' parents/carers after the last class and used a digital recorder to record what was said. During the interviews, we asked questions about changes in the children's attitudes toward the robotics club, changes in the children's collaborative/social interaction skills in different settings, and the children's diagnoses for ASD. Because we asked guiding questions in the interviews, we used analytic induction to interpret and categorize the answers given by the interviewees.

In addition to the above analyses, we also recorded the behaviours of two of the participants, M and Sh, as a case study evaluation during ten of the fourteen total robotics classes, hereafter referred to as S1 through S10, or the S-classes. While we would have observed them in more classes, the first two of the fourteen robotics classes were too chaotic for us to have gotten any useful data, the fourteenth class was conducted differently as described in section 5.2.4, and neither M nor Sh attended one other class. Specifically, we coded their behaviours according to the previously described coding scheme as well as described their behaviours in a more ethnographic manner.

5.2.3 Results

Questionnaires

To determine how well the children's and parents'/carers' responses on their written questionnaires matched for the same questions on the same days (how enjoyable each class was for a child and how often a child worked with others), we examined the numerical differences between the responses to the two sets of questionnaires. Because an average difference of 0 between the two data sets would suggest identical responses, we performed two-tailed, one-sample t-tests to determine how significantly the differences between the data sets varied from 0. We discovered that there were no significant differences between the two sets of data regarding how enjoyable the children found each class (df=51, t=0.5683, p>=0.2) or how often a child worked with others (df=49, t=0.1074, p>=0.2). We conducted a similar test on the children's responses to how easily they worked with others in each class and the parent's responses to how well their children worked in each class and determined that there was also no significant difference between the two response sets (df=51, t=0.2043, p>=0.2). In addition, we also found no significant difference between the children's own responses for how enjoyable each class was and how easily they worked with others in each class (df=57, t=1.2066, p>=0.2). However, the children's responses to how enjoyable a class was and how often they worked together with others were slightly different (df=57, t=1.8763, p<0.1), and their responses to how often they worked with others and how easily they worked with others on a given day were significantly different (df=57, t=3.266, p<0.05).

Video Analysis

Table 5.2: The behaviours of the children who attended nine or more classes. †- statistically insignificant, * - marginally statistically significant, ** - statistically significant

Increase in ...	From first to last classes	From least to most fun classes
Proportion of class time spent "close while sharing gaze"	Z = -1.527, p = 0.127 †	Z = -1.863, p = 0.063 *
Robot-related speech	Z = -1.859, p = 0.063 *	Z = -2.371, p = 0.018 **
Pointing behaviours	Z = -0.420, p = 0.674 †	Z = -2.023, p = 0.043 **
Average rate of robot-related speech / minute	Z = -2.197, p = 0.028 **	Z = -2.366, p = 0.018 **
Displays of positive affect	Z = -1.581, p = 0.114 †	Z = -2.214, p = 0.027 **

As one of the goals of this study was to determine whether the robots could foster collaboration among the groups of children, when we discuss instances of robot-related speech, pointing behaviour, and shared positive affect, we will only mention cases in which the observed behaviours were considered collaborative. As can be seen in table 5.2, the children spent a marginally greater proportion of class time "close while sharing gaze" during their most enjoyable classes than during their least enjoyable ones. The children also spoke marginally more about the robots in social contexts during their last classes than during their first classes, and spoke significantly more about the robots in social contexts during their most enjoyable classes than during their least enjoyable ones. When the total number of instances of talking about the robots in social contexts was graphed against the proportion of time spent "close while sharing gaze" for all four days, the data fit a quadratic curve best with a correlation coefficient of $r = 0.81$ (see figure 5.3). This shows that instead of speaking about robots at a constant rate regardless of how much time they spent together, the number of times the children talking about robots each minute increased as they spent more time together.

Furthermore, the children also exhibited a significantly higher average rate of robot-related speech per minute (dividing the number of instances of talking about robots in social contexts during a class by the duration, in minutes, of said class) during their last classes than during their first classes, as well as during their most enjoyable classes than during their least enjoyable ones (see figure 5.4:right). The children also exhibited significantly more pointing behaviour, as well as shared displays of positive affect with their groupmates (see figure 5.4:left), during their most enjoyable classes than during their least enjoyable ones.

Case Study

Concerning the case study evaluation of the two children M and Sh, they began playing relatively cooperatively during S1, in the sense that even though they occa-

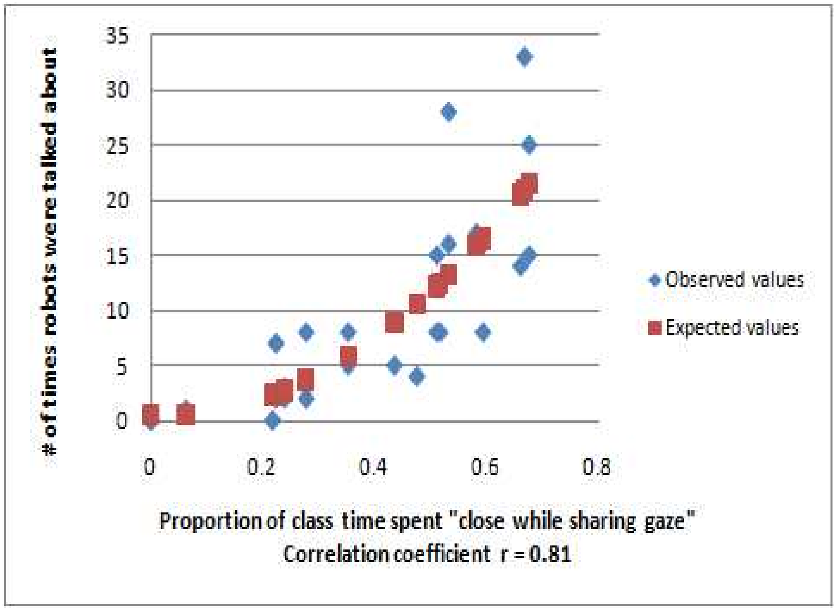


Figure 5.3: The quadratic trend indicates that the children had higher rates of talking about the robots in social contexts on days that they spent more class time around their groupmates

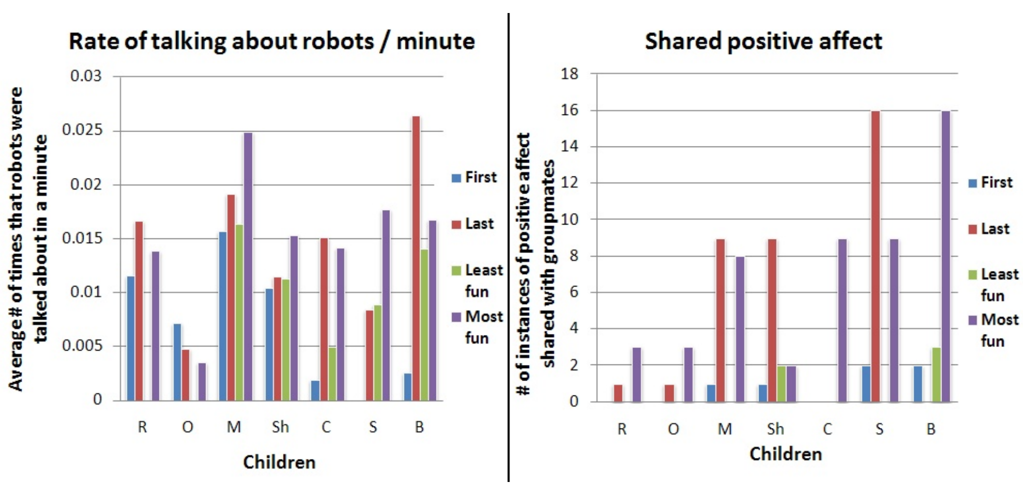


Figure 5.4: **Left:** Our data on the children's rates of talking about the robots displayed per minute. **Right:** Our data on how often the children displayed "shared positive affect".

sionally had arguments that became physical and did not spend much of their time speaking with each other, they showed that they were capable of working together towards a common goal and helping each other out. In this class, Sh exhibits two behaviours that he continues to display during most of the other S-classes; a tendency to sit near the computer and repetitively manipulate items on the screen even when M is somewhere else working on the robot, and a tendency to speak to himself out loud. However, these behaviours seem to be displayed far more frequently and for longer periods of time during S1 than S10. In fact, M and Sh speak to each other in a back-and-forth conversational manner during much of S10; this is something that was rarely done during S1 and was performed with much shorter exchanges when it was.

Additionally, M and Sh seemed to engage in more conversations (when one displayed robot-related speech, the other would often quickly respond with other robot-related speech), seemed more willing to share their perspectives on how they should program the robot (they talked to each other more often about the robot), and seemed to be more joyful (displayed shared positive affect more) during S10 than during S1. It is difficult to determine any potential cause(s) driving these findings, as there are many differences between S1 and S10. Firstly, almost four months, or sixteen weeks, elapsed between the two sessions. Any number of events could have happened to M or Sh outside the scope of the robotics class which affected their behaviour during this time, such as progress made in a therapy program, emotional maturation, or any other similar event(s). Secondly, neither M nor Sh understood how to use the NXT robots' sensors before S1, while both M and Sh had attended our robotics classes and received detailed instructions on how to gather and manipulate all of the NXT robots' sensor data before they attended S10. Because the children displayed less positive affect if they experienced frustration in understanding the behaviour of specific sensors, the disparity between the first and last classes in both M and Sh's knowledge of robotics, as well as their familiarity with the NXT robots in particular, may have also contributed to their changes in attitude. Thirdly, the number of other children present changed dramatically between S1 and S10, from five other children to none, respectively. As the number of other children present decreased, so did the level of background noise as well as the amount of movement in a child's field of view. Because research has shown that too much sensory input can negatively affect the communicative capabilities of some children with autism [Bogdashina, 2005], it is also possible that the ambient noise level may have affected the interactions of M and Sh. Lastly, M and Sh programmed the NXT robots and played together with them during every single instance of the robotics class, so it is also possible that the two children simply became accustomed to each others' personalities and behaviours. As evidence for this, consider table 5.3, which shows how a Wilcoxon's signed rank test performed on M and Sh's potentially collaborative behaviours reveals that significantly more ($p \leq 0.05$) were displayed during S10 than S1. For a more in-depth view of M and Sh's potentially collaborative behaviours during every session, see figure 5.5.

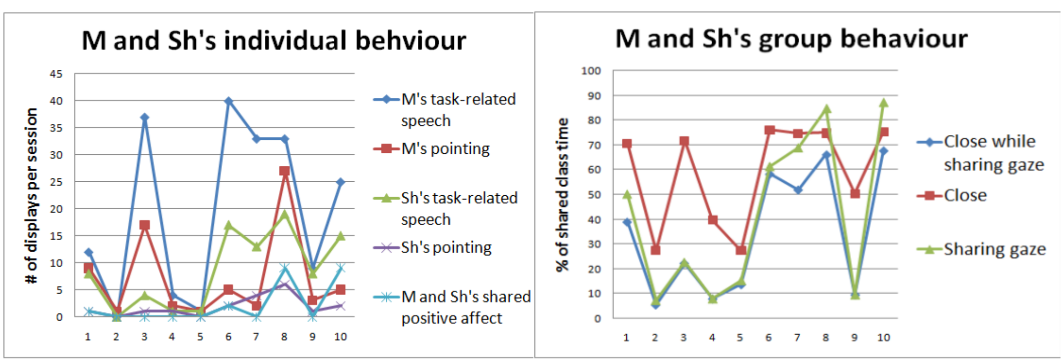


Figure 5.5: M and Sh's potentially collaborative behaviours during the 10 sessions described.

Ethnographic Data

When viewed from an ethnographic perspective, M and Sh also displayed a number of noteworthy behaviours during their time spent at the robotics class. During S3,

Table 5.3: The result of a Wilcoxon's Signed Rank test performed over the behaviours of M and Sh during S1 and S10

	Child	Session 1	Session 10
Proportion (%) of class time spent "close while sharing gaze"	M	0.52	0.68
	Sh	0.52	0.68
Robot-related speech	M	12	25
	Sh	8	15
Pointing behaviours	M	9	5
	Sh	1	2
Freq. of robot-related speech	M	0.0124	0.0191
	Sh	0.0083	0.0115
Displays of shared positive affect	M	1	9
	Sh	1	9
W+ = 6, W- = 49, N = 10 Z = -2.194, $p \leq 0.03$ **Statistically significant**			

the children learn about using their robots' ultrasonic range sensors and using them to make their robots perform different-sized "laps" of the square arena. Although it has never been described as a race, M and Sh perceive it as one in spite of Sh's mother insisting otherwise. Additionally, both M and Sh want to be the first ones to have their robot make a successful "lap" of the arena. This drive to win may have caused some friction between them, since when the robot does not perform as expected, M becomes agitated and loses his temper more easily. Additionally, when Sh thinks M has pronounced his name incorrectly, Sh wearily reminds M of how his name is pronounced, leading M to insult Sh. A small scuffle then breaks out between the two, but their mothers are able to intervene and defuse the situation. This is the only time during all of the classes that this happens between M and Sh, and the two are usually a good deal more cooperative. Afterwards, both M and Sh are eventually able to make their robot be the first one to successfully "lap" the arena.

During S8, M and Sh seem to engage in imaginative play more often than normal. Sh makes certain comments while he codes ("Are you being funny? I don't think so!"), and explicitly says that he's speaking on behalf of the robot. Later, M and Sh pretend that the robot's sensors are actually weapon systems: "It looks like a laser cannon...eat my laser!" "Ahh, oh no! I'm imitating the robot - oh no!" When the robot is in the arena, Sh grabs the robot around its compass sensor and picks it up while its wheels are turning at full speed. Because the compass sensor is a forward-pointing black rectangle mounted on an elevated mast located on the back of the robot and the robot itself is spinning its wheels, M compares the robot to a scorpion and Sh plays along with him:

> M: It's a scorpion, it's trying to bite him! You've got to hold it by its tail!
> [the experimenter explains that scorpions can sting with their tails]
> Sh: No, they can't - look! (places the robot on the ground)

Because engaging in imaginary play is something children with autism have difficulty with, it is very interesting to note that this is the first class in which M and Sh have done so.

Figure 5.6: M and Sh during S10, immediately after Sh pretends to be angry. It is easy to see Sh smiling, and it is important to note he did not frown or speak emotionally at M, which he had done during previous robotics classes when he was actually angry

During S10, M and Sh engage in more back-and-forth conversations than usual, many of which are longer than usual. At the beginning of the class, after M asks Sh to get him a USB cable and Sh does so, M thanks him "Thank you, Sh!", to which Sh responds in the same cadence "You're welcome - see all the good things I do for you?". Later, Sh admonishes M for "being silly" and singing a song about loops in the program, but Sh appears to be joking, as he smiles when he does so and engages in the following exchange (see figure 5.6):

Sh: Say [loop] one more time and I'm going to get mad!

M: OK...loop!

Sh: (in an affected manner and smiling) Arrgh!

M: Thanks. You were like an angry bear.

Sh: I'm not an angry bear...!

M: Everyone's an angry bear.

Because children with autism can have difficulties in using speech for communicative purposes, and particularly because Sh would often speak to himself and might not respond appropriately when others spoke to him, it was interesting to see this exchange take place.

Semi-structured Interviews

After the penultimate class was concluded, we conducted private interviews with the children's parents to hear what they felt about the robotics classes. From the interviews, we found that three of the parents felt that the turn taking wheel was a very successful and helpful tool. In addition, four of the parents felt that the experiences and knowledge from the robotics classes help their children in current social situations or could help them in future social situations; the first said that when her child becomes anxious with children at school, they could be reminded of the behaviour and coping mechanisms used during the robotics classes to help get them through; the second said that her child is now confident enough to approach and help out other children with their programming when they go to Legoland; the third said that the robotics classes have given her child more "normal" topics with which to start conversations when meeting new people; the fourth said that her child has learned about how to take turns and talk with others through programming problems instead of directly taking control of the computer and fixing it without talking.

5.2.4 Discussion

Determining that the questionnaire responses of a child and their parent/carer to the same items on any given day were not significantly different suggests that both observed the same behaviour reliably, which means that the parent/carer's responses can be used as deciding factors when their children describe multiple classes as being equally fun, and that the parent/carer's explanations and insights on their children's behaviour are accurate. Furthermore, the lack of a significant difference between a child's questionnaire responses on how fun a given class was and the ease with which they worked with others in class, combined with our observational findings that a child's display of collaborative behaviour is correlated with the amount of fun they reported in a class, suggest a link between collaborating with others and the perceived ease of doing so. Additionally, the parents/carers reports of some of the children improving their interactions with and collaborations with other children after having participated in the class also suggest that the children either found it fun or easy to continue collaborating/interacting with others after the robotics class ended. However, it is still difficult to understand how these factors interact; while it is possible that the children derived enjoyment from collaborating with others and eventually found it easy to learn how to do so, it is also possible that they grew to find it easy to have fun with others and would behave collaboratively in these cases. More work must be done in the future to tease each aspect apart from the others. These findings contribute to the primary hypothesis of the thesis, but because of the nature of the study and the way its data was analyzed, it is difficult to determine the strength of their support.

An interesting development occurred during the the last robotics class, which did not follow the normal routine. Instead of the children being asked to play with the robots in a specific way that demonstrated the robots' usage of a particular sensor, the children were free to play with the robots however they wanted in an arena programmed to provide sensory rewards proportional to how cooperatively the robots played with each other; if the children made the robots achieve certain goals simultaneously and by working together, the arena would play more sounds and flash more lights than if the robots achieved goals without the help of the other robots. On that day, the children who attended freely agreed to play socially with each other instead of playing alone with their own robots. While it is possible that they were purely motivated by the elaborate sensory rewards they could receive if they played together, the fact that many children reported the last few classes to be more fun than the first few suggests that the children may have learned to enjoy playing together and collaborating. However, it may also be that the children who would attend so many classes that emphasized teamwork and collaboration would also be inherently more willing and able to play cooperatively, and therefore attend more classes, than those that were not; the exit interviews with some parents of the children who attended fewer than nine classes seem to confirm this final hypothesis.

5.3 Experiment with SNAAP club: drawing sessions

5.3.1 Method and Procedure

In addition to the robotics classes, we also asked the children to participate in drawing activities. The use of such activities was inspired by art therapy, which is a form of psychotherapy that uses drawing, painting, sculpting, or any media as a means of expressing strong feelings about a particular subject instead of using words [Evans and Dubowski, 2001]. It is important to point out that using art therapy was never an aim of the study. However, we were inspired by the success of this form of therapy as applied to children with autism, so we designed free-form group drawing activities for the children from SNAAP in order to determine whether they would generalize their collaborative behaviours from the robotics class into a different domain.

On three separate occasions in this study, before the beginnings of the first, fifth, and ninth robotics classes [3] (see figure 5.1), we asked the children participating in the class to also participate in a 10-minute long drawing activity. Before these three sessions, the children were asked to look at monochrome images of robots and make their own versions of the drawings using coloured pencils or crayons (see figure 5.7).

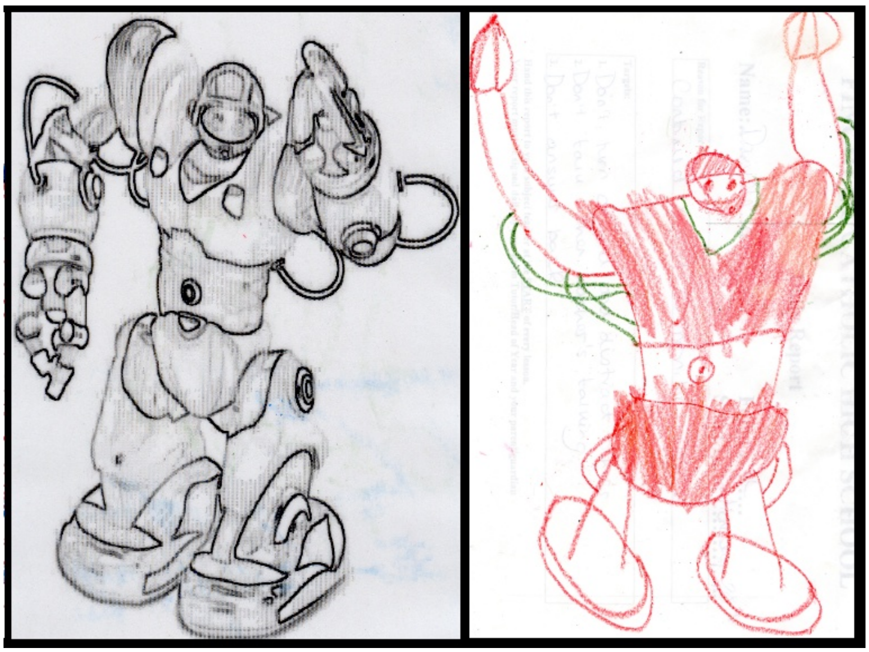


Figure 5.7: **Left:** A monochrome image used for inspiration during the second drawing session. **Right:** A sketch inspired by the image to the left and produced during the second drawing session.

The children were asked to make these drawings while sitting at tables with the same people that they would later play with. At every drawing session, each group was given a single sheet of paper to share and was told to recreate a monochrome drawing of a robot using coloured implements. Each group was given the same set of instructions at every drawing session, and these instructions were designed to have specifically ambiguous phrasing with regard to how a group was

[3] Three sessions were selected to be located at the beginning, middle and towards the end of the study. The ninth class was selected in order to have an opportunity to include all children in the activity, even those who may not attend the very last session.

meant to allocate drawing space on the paper: by addressing each group and telling them to "use [the paper] to make your own version" of the monochrome drawing, it was never made clear whether one drawing or many drawings were meant to be produced by each group. This allowed the groups to decide for themselves how to allocate the space on the paper (see figure 5.8).

Figure 5.8: A group of three children (from left to right they are C, S, and B) make art together on a single sheet of during one particular drawing session.

5.3.2 Data Collection

We used camcorders to record the children's interactions during class time and taped 3 hours of video footage, of which we analyzed one hour's worth. To describe the children's behaviour while drawing, Parten's levels of social play [Parten, 1932] were used as a basis for our own classification system. Although Parten's system was originally developed to describe play among neurotypical preschool children between the ages of 2 and 5, researchers studying the play beheviours of children with autism have customized or modified this scale to assess play in their own studies [Wolfberg and Schuler, 1999] [Anderson et al., 2004]. As can be seen in table 5.4, our version of Parten's classification system is focused around the different behaviours and forms of play that could occur at our previously-described drawing sessions.

Table 5.4: Parten's social play categories and how they were applied in our study

	Parten's definition	This study's definition
unoccupied behaviour	child is apparently not playing or observing any activities that might be exciting, but otherwise moves their body around or glances around the room	child does not talk socially and does not draw
onlooker	child watches other children play from close distance and often talks to them	child talks socially, doesn't draw
solitary independent play	child plays alone and independently with toys different from those used by other nearby children, regardless of what others are doing	child draws a shared or separate drawing, does not talk socially, no one else draws
parallel activity	child plays independently near other children with similar toys, no attempt to engage other children or to influence/modify their behaviours	child draws separately, does not talk socially, and another child draws
associative play	child plays with other children, borrowing and loaning material without coordinating or organizing around 'goals' or materials, each child acts as they like; children are engaged in and may discuss similar activities	child draws separately and talks socially OR child draws shared drawing, talks socially, no one else draws
cooperative/ organized supplementary play	child plays in group organized to achieve some competitive goal, make a product, play a formal game, etc; strong sense of belonging to group; one or two members direct activities of others in order to achieve common goal	child draws shared drawing, as does someone else

To classify the children's behaviours into the categories described in table 5.4, we coded video footage of the children at the drawing sessions. At these sessions, we coded the following behaviours:

1. **drawing:**
    (a) **no drawing:** the child is not placing the point of a pen, pencil, or crayon to the paper
    (b) **separate drawing:** the child is making their own drawing of the robot
    (c) **shared drawing:** the child is contributing to a single, common drawing

of the robot or to someone else's separate drawing

2. **talking:**

   (a) **no talking:** the child is not talking

   (b) **social talking:** the child is talking about the robots, the drawings, or the drawing session to someone else

   (c) **nonsocial talking:** the child is either babbling to themselves or is not talking about the topics listed as "social talking"

3. **demeanor:** the child is using a loud or angry voice and using negative language (no, stop, don't, etc) or using positive language and shared laughter toward another child or their work

The above coding scheme differs from the one used to analyze the children's interactions in the robot classes. These differences seem justified due to the very different natures of a free-form drawing session which produced artwork (see figure 5.7) and a teacher-led, structured, goal-directed robotics class. Since a drawing session is inherently different from a robotics class, if one observes individuals behaving collaboratively in both sets of circumstances, then this may indicate generalization of collaborative behaviour across distinctly different settings.

When we examined the data from the children's drawing sessions to determine how much they collaborated with each other, we compared the amount of time that each child behaved cooperatively, associatively, or as an onlooker in each session. We selected these classifications because in all of them, the child was either talking socially with another individual, working together with another child, or both. These behaviours are very similar to what we looked for in the robotics classes, in which the children were always asked to work together to play with the robots and where one of the collaborative behaviours we coded in our videos was talking about the robots while being near a groupmate and looking at the same object as them. As was stated before, this was done in order to examine whether the collaboration skills learned in the robotics class would generalize to another domain. Furthermore, by testing one's results in multiple settings, one can cross-check their data and give it more meaning.

As before, to ensure inter-rater reliability, the above behaviours were coded by one of the experimenters as well as a second independent rater who coded 10% of the analyzed data. As before, the independent rater's video codings were compared with the codings of the experimenter to see how well they agreed with each other. The average agreement value was determined to be 0.93. We also examined the above sets of codings for reliability and received an average value for Cohen's kappa of $\kappa = 0.74$. As stated before in section 5.2.2, this is acceptable and suggests that the agreement observed between the raters is not due to chance alone and is also considered "good agreement" [Bakeman, 1986] [Anderson et al., 2004].

5.3.3 Results

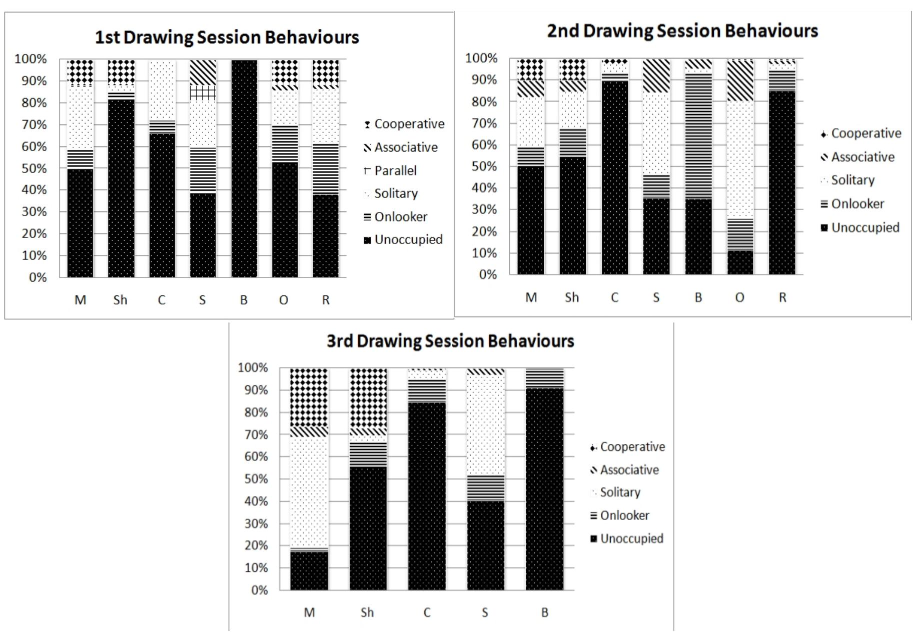


Figure 5.9: The categorized behaviours of the children during the three drawing sessions.

As can be seen in figure 5.9 and table 5.5, the observational video data from the drawing sessions suggest that the children's collaborative abilities increase in a marginally significantly manner between the first and last sessions, but that they do not marginally or significantly increase between consecutive drawing sessions. This may suggest that the changes are too slight to detect on small scales, while it may also suggest that the observed changes are due to factors other than time. This is similar to the observational data gathered from the robotics classes themselves, which suggests that some the children's displays of collaborative behaviour can be marginally affected by the number of robotics classes a child has attended.

5.3.4 Discussion

As observational data from coded videos suggests, some of the children's collaborative capabilities seem to marginally increase over time, both in robotics classes and in the drawing sessions. This suggests that these improvements are not limited to a single, specific domain but can be generalized to others, as well. Furthermore, these domains do not need to be particularly similar, as our data shows similar trends in both the rule-based, structured, teacher-led setting of the robotics classes, in which the children programmed the robots to act in specific ways, as well as the unconstrained, open-ended, drawing sessions in which the children created their own interpretations of pictures of robots. While this is encouraging, as most children with autism have difficulties in generalization, i.e. in applying skills from one setting into another, because this study did not gather data on the children's behaviours before taking part in our class, it is difficult to confirm whether the children's behaviours have improved from before they ever interacted with NXT robots in a group setting. Further investigations on larger samples of children must also be conducted in order to both to verify these results and identify explanations for the findings. Studies must also be conducted to determine whether similar findings would result from other regularly-scheduled group-based interactions or whether these results are par-

Table 5.5: The results of Wilcoxon's Signed Rank tests performed over children's time spent (in seconds) playing cooperatively, associatively, or as onlookers during the drawing sessions

Child	**1st session**	**2nd session**	**3rd session**
M	58s	122s (2m 2s)	111.5s (1m 51.5s)
Sh	43s	129.5s (2m 9.5s)	140s (2m 20s)
C	14s	18s	51s
S	80s (1m 20s)	75s (1m 15s)	66s (1m 6s)
B	0s	172s (2m 52s)	41s
1st vs 2nd sessions: W+ = 13, W- = 2, N = 5 $Z = -1.483$, $p \leq 0.14$	Statistically insignificant		
2nd vs 3rd sessions: W+ = 6.5, W- = 8.5, N = 5 $Z = -0.271$, $p \leq 0.79$	Statistically insignificant		
1st vs 3rd sessions: W+ = 14, W- = 1, N = 5 $Z = -1.753$, $p \leq 0.08$	Marginally significant		

ticular to robot-related activities. In short, these findings marginally support the secondary hypotheses of this study and of this thesis, but they would support it even more if we had data on how the children behaved before we began our study.

5.4 Summary

This chapter shows our findings from a voluntary after-school class on robotics for groups of children with autism. The results from this exploratory study suggest that the amount of enjoyment a child had at a given class was more strongly related to the amount of potentially cooperative behaviours they exhibited than was the amount of time a child spent with a given group, but the amount of time a child spent in a given group still affected their collaborative behaviours. This marginally addresses the primary aim of this study, determining whether interacting with robots over an extended period of time in a group-based, collaborative robotics club would result in an increase in the children's displays of social behaviours, as well as gives evidence to affirmatively answering the primary question motivating this thesis, whether interacting with an autonomous robot in structured, explicitly collaborative play sessions could promote social interaction and social engagement among children with autism. Similar changes in behaviour were also seen when the children interacted in a more free-form setting and were asked to draw on group-shared pieces of paper, suggesting that the children generalized their behaviours from the robotics classes to another, different domain. This supports the secondary aim of this study, understanding whether the children would be able to generalize their collaborative behaviours from a robotics class into another, less structured domain which involved interacting only with other children with autism. This also gives evidence to affirmatively answer the secondary question behind this thesis, whether the social skills that children with autism improved by collaboratively playing with an autonomous robot can transfer to another setting without robots . In addition, many of the children's parents reported that attending the class helped or would help their children in social situations. Furthermore, the fact that our different methods of data gathering and data analysis show similar results gives increased support to our findings.

This first study taught us a great deal about the benefits and limitations of its experimental design. Because this study did not collect data on the children's behaviours around other people before they first interacted with the autonomous robots in our club, it was difficult to determine how much the children's social behaviours actually improved because of their group-based interactions with the robots. This motivated us to gather data in our future studies on how the children interacted without robots in the presence of other people, whether typically developed or autistic. The first study's use of having many different collaborative games allowed us to observe the children's social behaviours in many settings that were slightly different from each other, but it did not allow us to draw any solid conclusions about changes in the children's social behaviours over time. As such, our future studies each focused on one collaborative game in order to allow us to track the changes in each child's social behaviours over time while knowing that any behavioural trends would be due to the children's changing abilities to interact with others instead of their changing knowledge of each game's play mechanics. Additionally, having many children interacting with each other in the same room did not allow us to clarify how each child's actions affected the behaviour of any other child; with so many events and behaviours taking place one after another in a classroom setting, it became difficult to point out which event affected any other subsequent event, to say nothing of the fact that having so many different noises and conversations filling the air at any given time must have made it difficult for the children to focus on any given activity. Our future studies needed to have one or two children in a room at any given time, both to allow the children to properly concentrate and to allow observers to determine the causal relationships between different events and behaviours more accurately and more easily. In short, we needed to conduct additional studies which used more controlled environments and cleaner, more streamlined experimental designs in order to address the abovementioned issues. This is why our later studies seem more constrained and structured when compared to the complexity of our first study, and we describe how we conducted our second study in the following chapter.

Chapter 6

Second study: Using an autonomous version of the humanoid robot KASPAR to promote cooperative, dyadic play among children with autism

In this chapter, I describe a pilot study in which children with autism alternated between playing a cooperative, dyadic video game with an adult human and playing the same game with an autonomous humanoid robot, KASPAR. The purpose of the study was to determine whether the children, all of whom had difficulties communicating and engaging in social play with others, would display more collaborative behaviours when playing with an adult after playing and interacting with the humanoid robot. Based on our analysis of the children's behaviours while participating in our study, our findings suggest that the children were more entertained, seemed more invested in the game, and collaborated better with their partners during their second sessions of playing with human adults than during their first. One possible explanation for this result is that the children's intermediary play session with the humanoid robot had an impact on their subsequent play session with the adult. Additionally, while the children saw the robotic partner as being more interesting and entertaining, they played more collaboratively and cooperated better with the human adult.

6.1 Introduction

6.1.1 Background and motivation

Research has shown that humanoid robots can stimulate dyadic imitative free-form play among children with autism, whether the humanoids are remotely-operated robotic "puppets" or robotic toys programmed to dance to pre-recorded music [Robins et al., 2005]. Additionally, triadic interactions can be fostered among a child with autism, a humanoid robot, and a human experimenter [Robins and Dautenhahn, 2006]. Such behaviours are necessary in order for children to engage in social play, a form of play in which children with autism have significant difficulty participating due to the social impairments that are characteristic of their disorder [Howlin, 1986]. Although previous work has shown that children with autism can engage in free-form, unstructured forms of social play known as associative play, it has not been shown whether they can engage in a more organized and complex form of social play, known as cooperative play, with robots. Furthermore, it has not been shown whether playing cooperatively with humanoid robots has any effect on collaborative play skills among children with autism. This chapter presents a study which examined whether having children play collaboratively with a humanoid robot affected the way the same children would play collaboratively with a typically-developed adult.

This study incorporated ideas from the many different research areas in addition to background information on humans and robots collaborating as equals, which was discussed in section 2.4.1, and on assistive technology used to help children with autism to play more cooperatively, which was discussed in section 2.5.2. Specifically, because studies have shown that there are specific social behaviours that children with autism will perform less often than non-autistic children due to their impairments in interacting and communicating with others, this study utilized the frequency with which these behaviours are displayed to determine the change in social engagement between a child and their play partner over the course of different play sessions. One of these play partners was the autonomous humanoid robot KASPAR which also reacted to specific forms of communication, as research shows that children with autism are particularly socially engaged when interacting with robots that respond to the children's behaviour. The play sessions focused on social, cooperative play among two individuals at a time, as studies have shown that the particular difficulty which children with autism have with this style of play may further hinder their development of basic social skills. Furthermore, the robot's behaviours, its role in the play sessions, and its degree of expressiveness were designed according to findings from related research on successful collaboration between humans and robots.

6.1.2 Research Aims and Expectations: Playing collaboratively with a humanoid robot in order to change a child with autism's social behaviour in a subsequent play session with a human partner

The primary goal of this study was a recontextualized form of the secondary question of this thesis, which is whether the social skills that children with autism improved by collaboratively playing with an autonomous robot can transfer to another setting without robots. In the context of this study, this has become the goal of *using objective measurements to determine whether dyadically collaborating with a humanoid robot while playing an explicitly cooperative game would change a child with autism's collaborative dyadic interactions with a human in the same context.* This is a novel and interesting goal for a number of reasons.

Firstly, previous research has shown that when used as social mediators, robots can help children with autism to interact in novel ways with other people, including other children with autism [Feil-Seifer and Matarić, 2011] [Robins et al., 2009] [Robins et al., 2005] [Robins and Dautenhahn, 2006] [Werry et al., 2001b]. These earlier studies compared the children's interactions in the contexts of the experiments with second-hand reports of the children's earlier interactions in different settings. In addition, such studies have mainly focused either on single children with autism interacting dyadically with a robot or on single children triadically interacting with a robot as well as their parent or carer. However, no studies before this have used the same experimental setting to compare dyadic interactions of single children with autism and a human adult with the dyadic interactions of the same children and a humanoid robot.

Secondly, the abovementioned earlier studies examined how children with autism interacted and played in open-ended, exploratory settings with robots. According to Parten's research on play [Parten, 1932], we can classify some of the forms of play in these studies as parallel (two children with autism play in their own ways with the same robot at the same time, either without acknowledging each other or by acknowledgment without communication [Robins et al., 2009] [Werry et al., 2001b]), some as associative (a child with autism imitates a robot and communicates with its human adult controller [Iacono et al., 2011] [Robins et al., 2010] [Robins et al., 2009] [Robins et al., 2005] [Robins and Dautenhahn, 2006]), and on a few occasions, cooperative (two high-functioning children with autism spontaneously interact and communicate to organize a game together with a reactive robot [Werry et al., 2001b], or a child with autism plays a two-player game with an experimenter while interacting minimally with them [Iacono et al., 2011]). In these studies as well as others, there have been few cases of the children participating in cooperative play. This is not surprising, as that specific form of play requires frequent communication and interaction among its participants, and by definition, children with autism have great difficulty with these social activities. However, this study is novel because it asked children with autism to participate in cooperative play by continually communicating and interacting with both a human and a robot. Additionally, although almost all of the previous studies involved children with autism playing with robots in semi-organized ways without any specific goals, this study asked multiple children with autism to play in an organized, collaborative manner with a robot to achieve a specific, common goal.

Because children with autism have difficulties with generalizing behaviour and skills between settings [Gaylord-Ross et al., 1984], we wanted to design the interactions of the children with autism among both the robot and the human adult to be as similar as possible in order to ensure the highest likelihood of skill transference between the two settings. To this end, we used KASPAR [Dautenhahn et al., 2009] and programmed it to play "Tilt and roll", a game we described in section 4.2, with a child with autism according to the ways we described in section 3.2. Drawing upon the deliberately strong similarities between the behaviours of the human and the robot as well as earlier studies' claims of children with autism's increased displays of social engagement with robots, we expected that, in our study, the children's social engagement and displays of positive affect during a play session with KASPAR would partially tranfer over into a subsequent play session with a human adult. Furthermore, we also expected that such objective measurements during a subsequent play session with a human adult would be greater and more frequent than those during a play session which preceded playing with KASPAR; in short, the children would play more collaboratively with a human partner after having played with the robot than they did beforehand.

Table 6.1: Descriptions of the children who participated in this study.

Name	Age	Sex	Speaking ability according to P-scale	Listening ability according to P-scale
D	6	Male	P4	P4
HT	6	Male	P5	P5
T	7	Female	P4	P5
HW	6	Male	P6	P8
M	8	Male	P4	P4
B	6	Male	P5	P4

6.1.3 Participants from Southfield School

Six children with autism participated in this study from Southfield School in Hatfield, a school for children with special needs; none of these children had interacted with KASPAR or played our collaborative game before. We specifically did not include a group of neurotypical, or non-autistic, children as a controlling factor in our study. This is because we did not want to distinguish or contrast neurotypical children and children with autism, as our research group is more interested in studying robot-assisted play as a tool for autism therapy than studying autism as a psychological disorder. The participants consisted of five boys and one girl (see Table 6.1), and although we did not have access to the children's individual diagnoses for autism, we received confirmation from their head teacher that each child had previously been diagnosed with autism by a medical professional. Furthermore, we were given access to each child's degree of communicative competency according to the P-scale (performance scale). This is a set of performance criteria used by all schools in the UK for children with special needs working below level 1 of the UK's national curriculum. These criteria rate the children's listening and speaking skills on a scale from one (being briefly aware of interactions with familiar people) to eight (linking up to four key-words in sentences while demonstrating an understanding of causality, or listening and responding appropriately to questions regarding causality) [Qualifications and Authority, 2009]. The study took place over a period of three weeks, and all but one of the six participants played one game session per day on four days during this period; one of the children played only three video game sessions. Additionally, all the participants' parents signed consent forms on behalf of their children before the study began.

6.2 Experiment

6.2.1 Method and Procedure

This study was carried out with the approval of the Faculty Ethics Committee of University of Hertfordshire's faculty of Engineering and Information Science. In this study, each child played two game sessions with the same human partner, **H**, and two sessions with the humanoid robot KASPAR, **K** (see figure 6.1). **H** had been trained to interact the same way with every child according to a well-rehearsed script, and **K** had been programmed to interact the same way with every child according to a specific set of inputs. When each child played the game, the only other people in the room were the child's carer, who would remind the children of the game rules or keep the children focused on playing the game if they became distracted; the experimenter, in order to record their own impressions about each interaction and help out if KASPAR did not operate correctly; and **H**, who would inobtrusively operate the recording equipment when not acting as a human partner for the children.

Because none of the children knew **H** or **K** before they played with them, each child's behaviour could not be affected by any previous experiences with them. As such, the interactions themselves became standardized and we were able to compare each child's interaction with a particular partner to those of every other child with the same partner; in contrast, had each child's human partner been a family member

Figure 6.1: Left: One of the children plays the collaborative game with **H**. Right: The same child plays with **K**.

or friend, each child's game-playing experience could be different and would be difficult to compare with those of the other children.

We based the order in which the children would play with **H** and **K** on a method from behavioural analysis known as a reversal, withdrawal, or ABAB, design. According to this method, participants alternate between two experimental phases: a phase in which a baseline of behaviour is tracked for some period of time ("A", or playing with **H**) and a phase in which an experimental intervention is implemented while the same behaviours are tracked ("B", or playing with **K**) [Rosenthal and Rosnow, 2008]. Each phase in our experiment consisted of a single play session on a single day, and by adding a number suffix to distinguish whether it was each child's first or second time playing the collaborative game with a human or robotic partner, we wrote the partner ordering as **H1 - K1 - H2 - K2**. Each child played only one game session on a given day, and although the sessions lasted for up to 25 minutes, the children were free to stop playing earlier if they were bored or uncomfortable. By having every child alternate between playing partners and by using the same standardized methods for describing the collaboration in both, we were able to determine whether the children would play more collaboratively during their second play session with the human partner (**H2**) than during their first (**H1**), or whether any behavioural changes that occurred during the first intervention phase

(**K1**) would disappear during other conditions. It is important to note that having each phase consist of a single play session did not allow us to determine whether a change in a child's collaborative behaviours between **H1** and **H2** was due to the intermediary session with KASPAR (**K1**) or to familiarization with **H** from repeated play sessions. However, because it allows for exploring the effects of inserting an intervention phase after a baseline (as well as a baseline after an intervention), allows each child to act as their own control group, and is a potent method when dealing with small sample sizes, the reversal design was considered appropriate for this study's aims.

Although we considered other experimental designs, it was decided that they were not suited for accomplishing the goals of this study. For example, a multiple baseline design would have allowed us to determine whether children with autism would play more cooperatively only when they started their intervention phase (playing with KASPAR), or whether similar results would occur after a certain amount of consecutively-scheduled baseline sessions (play with a human partner). However, such a design would not allow for alternating between the two phases, meaning that we would not be able to determine whether any changes in the children's behaviour were reversible. Similarly, a between-subjects design would have allowed us to compare and contrast the effects of many different experimental conditions (e.g., types of play partners), with each child only playing with one kind of partner. However, in addition to not allowing us to either determine whether any changes in the children's behaviours were reversible, this design also would have required a much larger number of participants in order for us to draw useful conclusions from the results due to the high degree of variability among the diagnoses, personalities, and idiosyncrasies of children with autism. In short, the reversal, withdrawal, or ABAB design was the best experimental design to allow us to investigate whether dyadically collaborating with a humanoid robot while playing an explicitly cooperative game would change a child with autism's collaborative dyadic interactions with a human in the same context.

6.2.2 Data collection

To measure how the children collaborated and interacted with their partners, whether human or robotic, we used two camcorders to videotape the children's play sessions and used the video game itself to record and timestamp both players' in-game actions. The behaviours which were manually coded from the videotapes and automatically recorded in the game's log files include:

1. **prompting** - a question or suggestion, verbalized by the child's partner or carer, directed toward making the child choose a shape;

2. **choosing** - one of the players expresses their desire, verbally or through pushing a button, to select a specific shape and for the other player to move their part of the crosshair to the said shape;

3. **successful shape selection** - the two players agreed to choose a particular shape, moved the crosshair near it, and pressed the trigger buttons on their Wiimotes simultaneously;

4. **unsuccessful shape selection** - the child presses the trigger button on their Wiimote when the crosshair is not near a shape, when their partner hasn't done the same, or both;

5. **gaze and gaze shift** - what the child looked at while playing the game, as one of the core deficits of autism is impaired gaze patterns [American Psychiatric Association, 1994]. The children's gazes were coded while looking at the game itself, the other player, the carer, the experimenter, or something in the environment unrelated to the study;

6. **positive affect** - the child laughed or smiled while playing the game (see Figure 6.2).

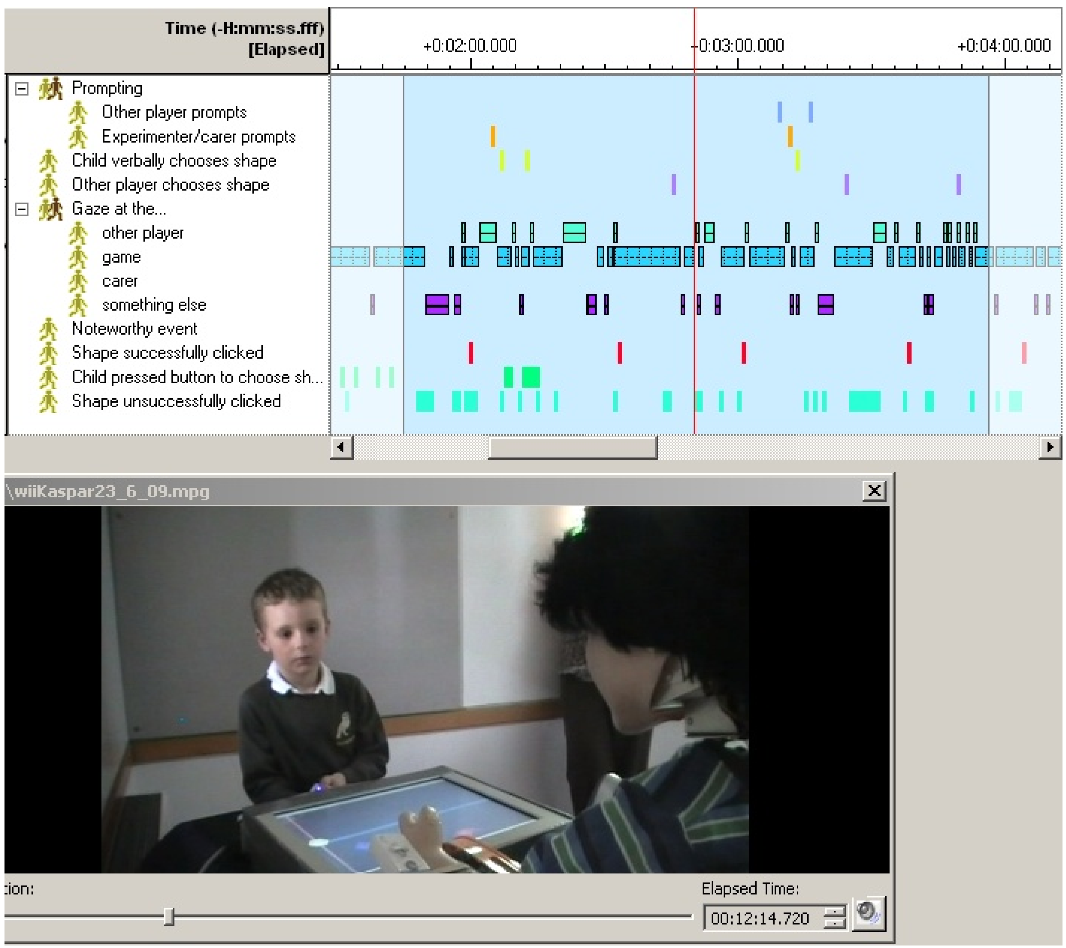


Figure 6.2: An example of one child's coded behaviours represented on both a graphical timeline (top) as well as a movie player (bottom) in Noldus's Observer software package. Both the timeline's large red vertical bar and the movie player's position box represent our current position in time.

While some of the above behaviours are inherently social activities, such as communicating one's choice to another individual, some of these behaviours are only social in the context of the collaborative game. For example, while performing a successful action in a video game would not be considered inherently social, it becomes both social and cooperative in the context of this study's collaborative game since it requires two players to coordinate their actions spatially (i.e. moving each player's part of the crosshair to a specific shape) as well as temporally (i.e. synchronizing the pressing of buttons on their respective controllers) towards a common goal of selecting shapes. Furthermore, the players had to communicate with each other to coordinate how, when, and where these actions would be performed in real time. Since all of these actions are collaborative / cooperative in nature [Malone et al., 1990], the game behaviours that accomplish them are therefore also collaborative.

To ensure inter-rater reliability, the above behaviours were coded by the experimenter as well as a second independent rater who coded 10% of the data. When the two sets of codings were analyzed for similarity, the average agreement value was 0.80, which is generally considered to be good. We also examined the codings for reliability and received an average value for Cohen's kappa of $\kappa = 0.74$. This is acceptable, as having a Cohen's kappa value higher than 0.60 suggests a good agreement between the raters [Bakeman and Gottman, 1997].

6.2.3 Analysis and Results

Our paired sets of data had small sample sizes and abnormal distributions, so instead of using paired t-tests, we used Wilcoxon's matched pairs signed-rank tests to determine which game session pairs had statistically significant differences ($p < 0.05$) regarding how often certain behaviours occurred. Additionally, we used the Mann-Whitney U test to evaluate a hypothesis regarding children having different gaze patterns and displaying positive affect while playing with different partners.

Table 6.2 shows whether there were significant differences in certain be-

Table 6.2: The results of Wilcoxon's signed rank tests comparing the children's behaviours during each play session. ✘ - statistically insignificant, **?** - marginally statistically significant, ✔ - statistically significant

	H1 vs **K**1	**K**1 vs **H**2	**H**2 vs **K**2	**H**1 vs **K**2	**H**1 vs **H**2	**K**1 vs **K**2
Total time spent interacting with partner	Z = -2.023 p = 0.043 ✔ (**H**1<**K**1)	Z = -0.943 p = 0.345 ✘	Z = -0.135 p = 0.893 ✘	Z = -0.943 p = 0.345 ✘	Z = -0.944 p = 0.345 ✘	Z = -0.944 p = 0.345 ✘
Proportion of total time spent gazing at other player	Z = -2.201 p = 0.028 ✔ (**H**1<**K**1)	Z = -2.201 p = 0.028 ✔ (**K**1>**H**2)	Z = -2.023 p = 0.043 ✔ (**H**2<**K**2)	Z = -2.023 p = 0.043 ✔ (**H**1<**K**2)	Z = -0.943 p = 0.345 ✘	Z = -0.674 p = 0.500 ✘
Proportion of total time spent gazing at game	Z = -2.201 p = 0.028 ✔ (**H**1>**K**1)	Z = -2.201 p = 0.028 ✔ (**K**1<**H**2)	Z = -2.023 p = 0.043 ✔ (**H**2>**K**2)	Z = -2.023 p = 0.043 ✔ (**H**1>**K**2)	Z = -0.314 p = 0.753 ✘	Z = -0.405 p = 0.686 ✘
Proportion of total time spent gazing at something else	Z = -2.201 p = 0.028 ✔ (**H**1<**K**1)	Z = -2.201 p = 0.028 ✔ (**K**1>**H**2)	Z = -2.023 p = 0.043 ✔ (**H**2<**K**2)	Z = -2.023 p = 0.043 ✔ (**H**1<**K**2)	Z = -0.943 p = 0.345 ✘	Z = -0.135 p = 0.893 ✘
Avg # of gaze changes per minute	Z = -2.201 p = 0.028 ✔ (**H**1<**K**1)	Z = -2.201 p = 0.028 ✔ (**K**1>**H**2)	Z = -2.023 p = 0.043 ✔ (**H**2<**K**2)	Z = -2.023 p = 0.043 ✔ (**H**1<**K**2)	Z = -2.201 p = 0.028 ✔ (**H**1<**H**2)	Z = -0.405 p = 0.686 ✘
Avg # of gaze changes from/to game per minute	Z = -2.201 p = 0.028 ✔ (**H**1<**K**1)	Z = -2.201 p = 0.028 ✔ (**K**1>**H**2)	Z = -2.023 p = 0.043 ✔ (**H**2<**K**2)	Z = -2.023 p = 0.043 ✔ (**H**1<**K**2)	Z = -2.201 p = 0.028 ✔ (**H**1<**H**2)	Z = -0.674 p = 0.500 ✘
Avg # of gaze changes from/to other player per minute	Z = -2.201 p = 0.028 ✔ (**H**1<**K**1)	Z = -2.201 p = 0.028 ✔ (**K**1>**H**2)	Z = -2.023 p = 0.043 ✔ (**H**2<**K**2)	Z = -2.023 p = 0.043 ✔ (**H**1<**K**2)	Z = -1.363 p = 0.173 ✘	Z = -0.135 p = 0.893 ✘
Avg # of gaze changes between other player and game per minute	Z = -2.201 p = 0.028 ✔ (**H**1<**K**1)	Z = -2.201 p = 0.028 ✔ (**K**1>**H**2)	Z = -2.023 p = 0.043 ✔ (**H**2<**K**2)	Z = -2.023 p = 0.043 ✔ (**H**1<**K**2)	Z = -1.363 p = 0.173 ✘	Z = -0.135 p = 0.893 ✘
Proportion of session time child displayed positive affect	Z = -1.461 p = 0.144 ✘	Z = -0.674 p = 0.500 ✘	Z = -0.677 p = 0.498 ✘	Z = -1.214 p = 0.225 ✘	Z = -2.023 p = 0.043 ✔ (**H**1<**H**2)	Z = -1.826 p = 0.068 ?
Avg # of shapes children chose per minute	Z = -2.201 p = 0.028 ✔ (**H**1>**K**1)	Z = -2.201 p = 0.028 ✔ (**K**1<**H**2)	Z = -2.023 p = 0.043 ✔ (**H**2>**K**2)	Z = -2.023 p = 0.043 ✔ (**H**1>**K**2)	Z = -1.572 p = 0.116 ✘	Z = -1.753 p = 0.080 ?
Avg # of shapes children chose per minute while gazing at game	Z = -2.201 p = 0.028 ✔ (**H**1>**K**1)	Z = -2.201 p = 0.028 ✔ (**K**1<**H**2)	Z = -2.023 p = 0.043 ✔ (**H**2>**K**2)	Z = -2.023 p = 0.043 ✔ (**H**1>**K**2)	Z = -1.153 p = 0.249 ✘	Z = -1.214 p = 0.225 ✘
Avg # of shapes children chose per minute while gazing at other	Z = -1.153 p = 0.249 ✘	Z = -0.105 p = 0.917 ✘	Z = -0.674 p = 0.500 ✘	Z = -0.405 p = 0.686 ✘	Z = -0.734 p = 0.463 ✘	Z = -0.944 p = 0.345 ✘
Avg # of times per minute children took initiative in choosing shape	Z = -1.992 p = 0.046 ✔ (**H**1>**K**1)	Z = -2.201 p = 0.028 ✔ (**K**1<**H**2)	Z = -2.023 p = 0.043 ✔ (**H**2>**K**2)	Z = -1.214 p = 0.225 ✘	Z = -2.201 p = 0.028 ✔ (**H**1<**H**2)	Z = -1.826 p = 0.068 ?
Avg # of times per minute children successfully selected shapes	Z = -1.782 p = 0.075 ?	Z = -2.201 p = 0.028 ✔ (**K**1<**H**2)	Z = -2.023 p = 0.043 ✔ (**H**2>**K**2)	Z = -1.483 p = 0.138 ✘	Z = -2.201 p = 0.028 ✔ (**H**1<**H**2)	Z = -0.674 p = 0.500 ✘

haviours between various phases of the experiment. We expected that the children would both display positive affect more often and spend more time interacting with KASPAR than with the human player because they would want to spend more time with an enjoyable partner, so we were surprised to find that there were no significant trends regarding total time spent interacting. We anticipated that the children would have different gaze patterns and frequencies depending on whether they played with KASPAR or the human player, since research has shown that for many children with autism, robots can trigger more social interaction and more interest than people. We expected that the children would be more interested in playing the game while with KASPAR than with the human, but we were surprised that they did not also play the game more effectively while playing with the robot; by "play...more effectively", we mean that the children would select more shapes, take the initiative in choosing shapes more, and perform other game-related activities that would require social engagement and social interaction. Most importantly, we expected that playing and collaborating with KASPAR would make the children collaborate better with the human player. We describe whether our results supported our expectations in the following paragraphs.

As figure 6.3 shows, gaze changes regarding the game and the other player were significantly higher when playing with KASPAR. Most times (80% of gaze switches) that a child looked away from the other player, the child would then look toward the game, and such focus changes between the two would occur significantly more when playing with KASPAR. In addition, we found that the children changed what they gazed at significantly more when playing with the robot, but that they also changed what they looked at more often during **H2** than **H1**. Furthermore, the proportion of time the children spent looking at the game screen or controller ("the game") was significantly lower and the other player significantly higher when playing with KASPAR (see Figure 6.4).

The average number of shapes the children chose (verbally or by pressing

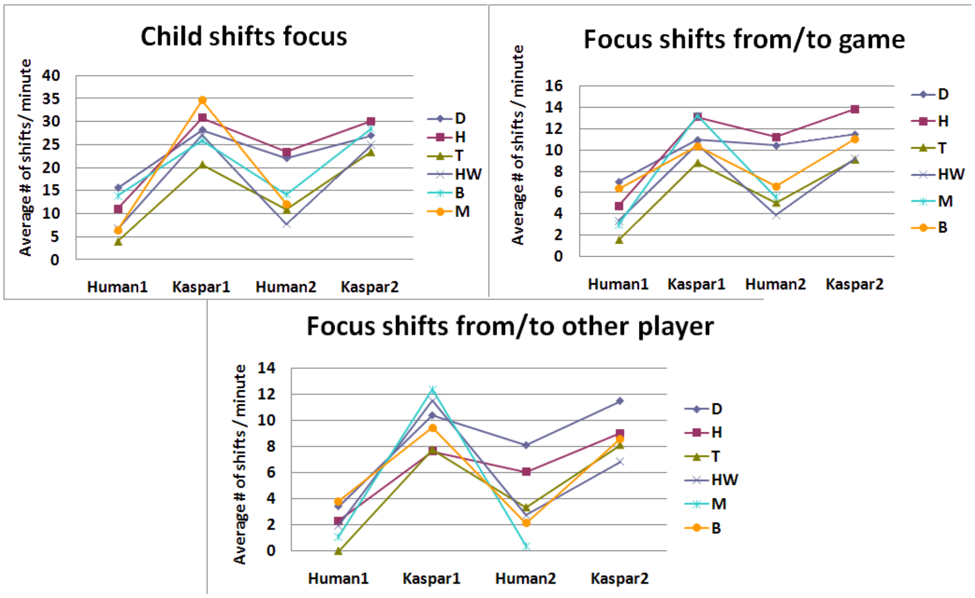


Figure 6.3: The children's eye gaze shift trends.

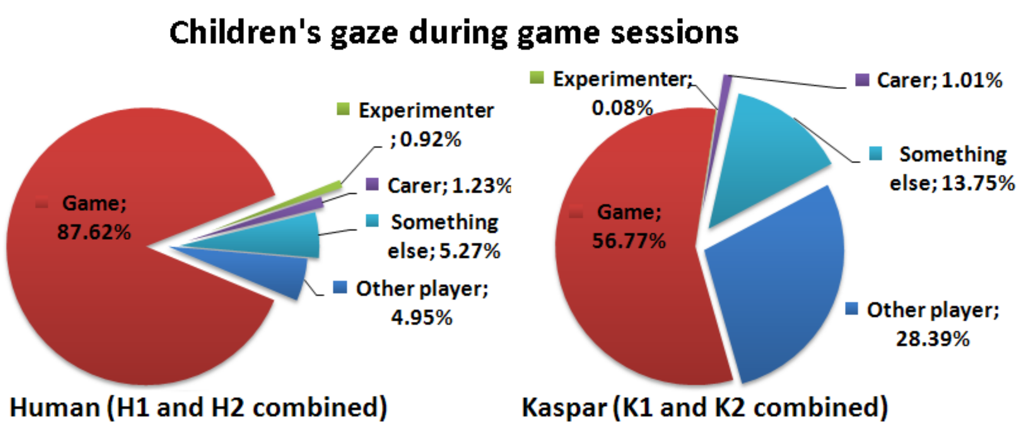


Figure 6.4: The children's eye gaze while playing with either partner.

a button on their Wiimotes) per minute was significantly lower while playing with KASPAR, and while the children chose significantly fewer shapes while looking at the game and playing with KASPAR than with a human, there was no significant difference in choosing shapes while looking at the opposite player. The children also took the initiative in choosing shapes (chose without external prompting to do so) instead of following another's lead (choosing after being prompted or selecting a shape chosen by the other player) more during **H2** than **H1**. Additionally, the children successfully selected shapes through cooperating with the other player significantly more during **H2** than **H1** (see Figure 6.5).

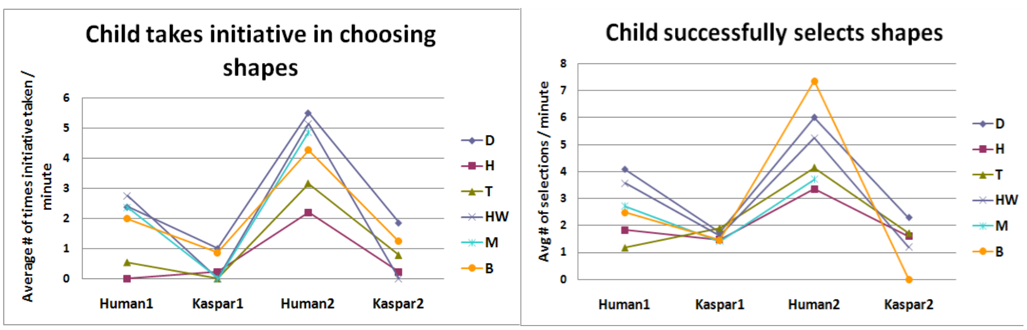


Figure 6.5: The children's trends on taking the initiative in choosing shapes and cooperatively selecting them.

The proportion of time for which the children displayed positive affect during each session did not follow any significant trends, but when we only examined the data during the sessions in which the children did exhibit positive affect, it was found that they usually looked at either the other player or the game itself. In these cases, while displaying positive affect, the proportion of time spent looking at the other player was significantly more ($Z = -2.511$, $p = 0.012$) and the game significantly less ($Z = -3.24$, $p = 0.001$) when playing with the robot (see Figure 6.6).

After we conducted our final game session, we met with the children's teacher to learn more about how the children behaved outside of our experimental setting and to understand certain sporadic behaviours we observed in some of the children.

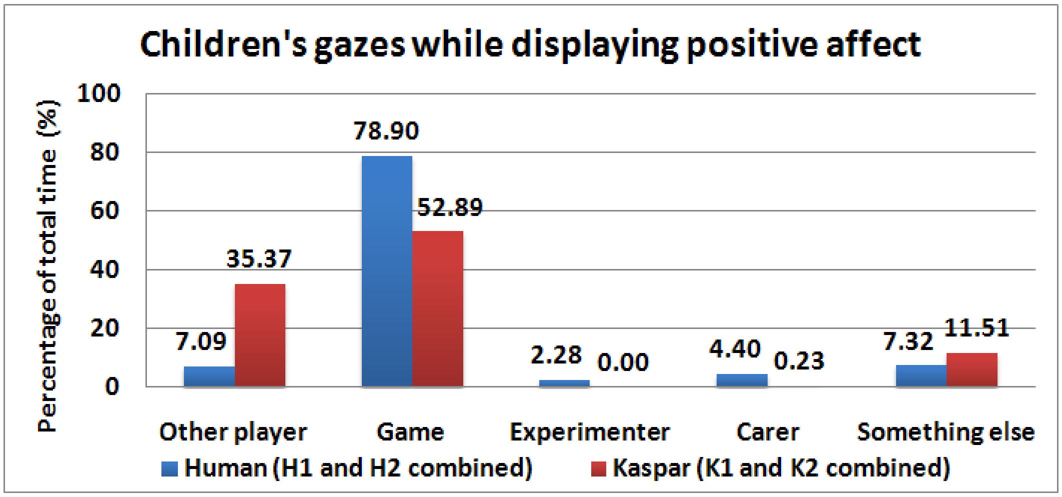


Figure 6.6: The children's eye gaze trends while displaying positive affect.

All of the children participating in our study were described as having difficulties playing with other children of similar ages; while a few were able to play by themselves near others, some could only play while separated from other children, and some had no interest in most toys. However, all were reported as having problems with turn-taking, sharing, and playing synchronously with other children. Therefore, while it is interesting that all of the children participating in our study were capable of playing the dyadic video game with an adult human, the fact that they were also capable of playing the game with a child-like robotic partner is particularly noteworthy. Additionally, some of the children would mimic KASPAR's facial expressions, gestures, or vocal phrases while playing with the robot, but would not mimic their human partner's behaviours or phrases; these same children were described by their teacher as fond of mimicking actions or phrases from television and computer games. Furthermore, some of the children's reactions to KASPAR or the game were considered by the teacher to be very rare. For example, one child found it very enjoyable and funny to make KASPAR change what it was saying in mid-sentence by choosing shapes at specific times. Another, who had no play skills and was normally uninterested in any sort of play, willingly played with KASPAR and **H** in addition to expressing positive affect while playing with and looking at the robot. Though not representative of all children, these instances show that interacting and playing with KASPAR can be a singular experience for some children with autism.

6.3 Discussion

The most noteworthy results of this study are the increases in the children's actively collaborative behaviours (switching gaze focus, taking initiative in choosing shapes, and successfully selecting shapes) between the first and second sessions of playing with the human partner compared to the lack of significant changes in such behaviour between the first and second sessions of playing with KASPAR. This shows that the children only grew more interested in playing the game or more capable of collaborating when playing with the human partner, while they did not show these trends when playing with the robot. Because the two sessions of the children playing with the human partner were separated by a single session playing with KASPAR, this might mean that the children learned about collaboration through interacting with the robot and applied this knowledge to their subsequent interactions with the human player. In turn, this would support the hypothesis of this experiment as defined in section 6.1.2 as well as the secondary hypothesis of the thesis. However, it is also possible that the increases in the children's actively collaborative behaviours across two play sessions with the human partner could be due to the children becoming more comfortable interacting with the human partner over time. To better investigate this issue, another study would have to be conducted that would involve sets of repeated, contiguous play sessions with both partners; interacting with robots could then be more strongly shown to improve the collaborative behaviours of children with autism if findings similar to this study were only found between sets of human-partnered play sessions which took place before and after a set of robot-partnered play sessions.

The study also supports the findings of previous research by showing that the children played with the human partner and KASPAR in distinctly different ways. Because the children both looked at KASPAR more and would switch their gaze between it and the game more than they would while playing with the human, we can infer that the children found KASPAR to be a more interesting game partner. Furthermore, the children also found KASPAR to be more fun and enjoyable than the human since when they would display positive affect, they would look more at KASPAR than at the human. This could be said to support the primary hypothesis of this thesis.

There are also certain findings from this study that were surprising and/or not easily explained. Specifically, the children did not collaborate more or better with KASPAR, as they instead chose fewer shapes and passively followed the robot's suggestions instead of taking the initiative in choosing shapes. This suggests that the children were neither as engaged in the game nor as able to perform cooperative actions when interacting with KASPAR as often as they could when interacting with the human player. Additionally, the children who would mimic actions and speech from different forms of media would also freely and happily mimic KASPAR's actions and speech, despite the fact that doing so did not apparently help them either to interact with KASPAR or to play the game. One child was observed performing actions that, instead of being helpful for selecting shapes, served only to make the robot act in an amusing manner. These phenomena suggest that although the children from our study saw the robot as more entertaining than the video game, they also seemed to pay less attention to the content and meaning of KASPAR's speech than to the fact that KASPAR spoke to them at all.

At first glance, the data suggesests that the children perceived KASPAR as a source of humor and interest instead of an entity with which they could communicate and play; this might be due to the novelty of the children interacting and playing with a humanoid robot. Specifically, because none of the children had interacted with a humanoid robot before, much less played a game with one, they may have found the experience of KASPAR interacting with them to be so interesting that they wanted to observe the robot and its behaviours instead of actually communicating with it. As such, future studies involving KASPAR should focus on using the robot's interactions with the children as rewards in and of themselves. Specifically, researchers should limit the frequency or duration of the interactions if the children either do not play cooperatively or passively fixate too much on KASPAR's actions and speech instead of actively playing the game and communicating with KASPAR.

It is also possible that these data trends are not due to the novelty effect but are instead artifacts of the ways in which the children communicated with KASPAR. Since the children were taught to communicate with the robot through pressing buttons while speaking and tilting their Wii controllers, it is possible that performing all of these behaviours correctly was too complex for the children to learn. It is important to note that this was the same way that the children were taught to communicate with the adult human partner, with whom they communicated more effectively. One possible reason for such a discrepancy is that since both the human partner and the child's carer could understand the children's speech, they would also occasionally remind the children about correct choosing procedures when they vocalized their choices without also pressing the correct button on their Wii controller or tilting it correctly, or any permutation for an incorrect action. In contrast, the robotic partner had neither the sensors nor the programming required for understanding speech, so if the child chose a shape only by speaking to it, the robot would not remind the child to also press the correct button. Instead, only the carer would correct the children's occasionally incorrect methods of communication in these circumstances. Perhaps if the children were instead taught to use simpler means to communicate in the context of the game (e.g. removing button-pushing from the equation and relying only on words and simpler physical gestures instead) or if KASPAR could sense speech and other natural, more noisy forms of communication, then the children would communicate more while interacting with the robot.

6.4 Summary

This chapter presents our findings from a study in which children with autism alternated between playing a collaborative, dyadic video game with a human partner and playing the same game with a humanoid robot in an *ABA* setting. The results from the study suggest that the children were more entertained, seemed more interested in the game, and collaborated better with a partner during their second sessions of playing with a human than their first; in contrast, there were no significant differences when comparing how the children played in their first and second sessions with the humanoid robot. The changes in the children's social behaviour with the human player may be due to the children's intermediary play session with the robotic partner, which would support this study's goal to use objective behavioural measurements to determine whether dyadically collaborating with a humanoid robot while playing an explicitly cooperative game would change a child with autism's collaborative dyadic interactions with a human in the same context. Additionally, this would also affirmatively answer the second question of this thesis, whether the social skills that children with autism improved by collaboratively playing with an autonomous robot can transfer to another setting without robots. However, there is also a chance that the changes in the children's behaviour might also occur after enough repeated interactions with a human adult, without any child-robot interaction whatsoever. Similarly, the lack of change in the children's social behaviours with the robotic player may be due to the novelty effect of playing and interacting with an autonomous robot. Furthermore, while the children seemed to see their robotic partner as being more interesting and more entertaining than their human partner, they seemed to solve problems collaboratively and worked together better with people. This phenomenon might be due to a combination of the novelty of interacting with a robot overtaking the desire to interact productively with it, the method of communicating with the other player being difficult for the children to master, and the adult human player being more flexible in communicating with the children than KASPAR the robot.

Because this experiment was more controlled and better designed than our previous study, we were able to interpret out data much more effectively than before. Specifically, by using a reversal design and gathering data on the children's behaviour both before and after they interacted with KASPAR, we came up with multiple explanations for the improvements in some of the children's key social behaviours while playing with the adult. These are:

- repeatedly practicing the collaborative game;
- familiarizing themselves with the typically developed adult;
- and interacting with KASPAR.

In order to determine which of these explanations, if any, best fit our findings, we needed to conduct a similar study with an improved experimental design. Specifically, we needed multiple play sessions in each phase to tease apart the effects of improving in behaviour due to practicing gameplay from improving social behaviour due to previous interactions with a robot. We also needed multiple human partners to tease apart the effects of becoming familiarized with a particular person's behaviour, particularly a person trained to act well with children with autism, from the effects of becoming familiarized with the behaviours of many other people who have not been specially trained and have also been diagnosed with autism.

Additionally, although this experiment used a single collaborative video game throughout the course of the entire study and involved an autonomous humanoid robot which communicated with the children and followed the children's in-game commands, the game and the robot's behaviours had room for improvement. With respect to the game, we felt that its play mechanics could have been simplified even further, as well as be made to include aspects of imitation and increased collaboration to make its play even more social. Additionally, its controller interface could be made even more intuitive so as to not require any button-pressing or guesswork on proper controller usage. With respect to the robot's behaviours, we felt that some of them were not designed to adequately fit the interests of children with autism; specificlaly, because the robot prompted the children every 6 seconds during the second study, some of the children quickly learned that they did not need to play the game in order to make the robot look at and communicate with them. As such, these children almost stopped actively engaging with the robot and tried to exploit additional flaws in the robot's programming. Furthermore, the method of communicating with the robot could also have been made more similar to methods of communicating with other people - instead of having to press a special button on the controller to command the robot (which is not done while communicating with people), the children could just perform the same actions that they would while playing with a person and the robot would automatically understand their in-game commands. This is why we conducted a third study and designed a new game for it, the former of which is described in the following chapter.

Chapter 7

Third study: Using KASPAR the robot to autonomously facilitate collaborative, imitative play among pairs of children with autism

In the following chapter, I discuss a study in which pairs of children with autism switched between multiple sessions of playing a cooperative, imitation-based video game with each other and multiple sessions of playing the same game with each other as well as an autonomous humanoid robot, KASPAR. In doing so, I wanted to determine whether the children, all of whom were impaired in participating in social play and communicating with others, would exhibit more collaborative actions after participating in a set of triadic, imitative play sessions with both the humanoid robot and another child with autism than they did beforehand. To determine whether there was any change in the children's displays of collaborative behaviour, we had the children participate in a set of dyadic play sessions with another child with autism both before and after the triadic sessions and then compared the behaviours in the first set of dyadic interactions to the behaviours in the second set. Our analyses of the children's behavioural data indicated that the children paid more attention to the other child playing with them, were more socially engaged with the other child, showed more enjoyment and tried to share their enjoyment more often with the other child, were more communicative, and tried more often to coordinate their cooperative actions with the other child during their second sets of dyadic play than during their first sets of dyadic play with the same children. Furthermore, the trends in the data suggest that the children's unique interactions in the intermediary set of triadic play sessions involving the autonomous robot instead of the children's familiarization with each other and the collaborative game were responsible for the change in social behaviours between the two sets of dyadic play sessions involving pairs of children with autism.

7.1 Introduction

7.1.1 Background and motivation

Experiments conducted by Robins, Dautenhahn, and others have shown that humanoid robots have helped to stimulate dyadic, free-form imitative play with individual children with autism as well as triadic interactions among the robots themselves, a child with autism, and a human experimenter [Robins et al., 2004a], [Robins et al., 2005], [Robins and Dautenhahn, 2006]. My earlier research involved an autonomous version of the humanoid robot KASPAR and showed that children with autism displayed more social behaviours when playing a collaborative, dyadic game with a human adult only after having played the same game with a robot, but because of the study's limited duration, this finding might also indicate that the children's social behaviours gradually improved over time regardless of their play partner [Wainer et al., 2010]. Iacono, Lehmann, Marti et al examined how children with autism played dyadic imitative and turn-taking games with a remotely-operated version of KASPAR and with the autonomous IROMEC robot, respectively, and their findings suggest that the children communicated and interacted better after participating in the study [Iacono et al., 2011].

This chapter presents a study which examined whether having pairs of children with autism play a imitative, collaborative game with a humanoid robot affected the way these children would play the same game without the robot, and it incorporated ideas from many different research studies. Specifically, most studies on using robots to help children with autism through playing with them have used human controllers to remotely operate their robots. Such research can produce very engaging interactions between the robot and the children, but this design approach can depend too much on the human operator's skill in handling the robot and their familiarity with the moods and behaviours of the children with whom they are interacting. As such, the study in this chapter used an autonomously-operated humanoid robot in order to demonstrate that any improvement in the children's behaviour would be entirely due to the robot's presence and actions instead of those of a human operator. Furthermore, much of the research on social robotics for children with autism has mainly focused on the social interactions either between the children and a robot or between the children and another human in a robot's presence. These studies have described novel and significant social interactions among children with autism when robots are present, but by focusing on the time spent with the robot, such research can overlook data on the lasting effects of the robot's influence. As such, the study described in this chapter had the pairs of autistic participants alternate between playing with each other and playing with other as well as a humanoid robot in order to prove that the novel social behaviours displayed by the children in the presence of the robot would carry over into later into subsequent interaction sessions that did not include the robot's presence.

7.1.2 Research Aims and Expectations: Changing the social behaviour exhibited by pairs of children with autism while playing an imitation-based, collaborative video game change by making them interact with a humanoid robot facilitator/partner

The primary goal of this study was a modified form of the secondary question of the thesis, which is whether the social skills that children with autism improved by collaboratively playing with an autonomous robot can transfer to another setting without robots. In this case, such a question has been altered to the goal of *using objective measurements to determine whether the social interactions between a pair of children with autism who played an imitative, collaborative game would change after the pair triadically collaborated with a humanoid robot in the same context.* This is a novel and interesting goal for a number of reasons.

Firstly, although a fair amount of research has shown that robots can help children with autism to interact in novel ways with other people, including other children with autism, when they are used as social mediators [Feil-Seifer and Matarić, 2011], [Robins et al., 2009], [Robins et al., 2005], [Robins and Dautenhahn, 2006], [Werry et al., 2001b], [Wainer et al., 2010], these earlier studies compared the children's interactions in the contexts of the experiments with second-hand reports of the children's earlier interactions in different settings. Furthermore, very few of these studies have used a repeated measures design to accurately tease apart the gradual effects of familiarization and the sudden effects of a robotic intervention on the changing behaviour of a child with autism. In addition, such studies have mainly focused either on single children with autism interacting dyadically with a robot or on single children triadically interacting with a robot as well as their parent or carer. However, no studies before this have used multiple, repeated encounters in the same experimental settings to compare dyadic interactions of pairs of children with the triadic interactions of the same children and a humanoid robot, much less to determine whether interacting with the robot affected the children's interactions with each other.

Secondly, although robots have often playfully imitated the actions of children with autism while being remotely operated [Robins et al., 2004c] [Robins et al., 2005] [Robins et al., 2009] [Duquette et al., 2008] [Iacono et al., 2011], it is rare for robots to mimic the actions of children with autism while controlling themselves autonomously [Dautenhahn and Billard, 2002]. Furthermore, no studies to the author's knowledge have shown that the playful behaviour of an autonomous humanoid robot can impact the subsequent behaviour of children with autism in settings that do not include robots. As such, it is both novel and interesting that this chapter describes a study in which a humanoid robot both successfully imitated simple poses and behaviours of children with autism while operating autonomously and improve the children's subsequent social interactions with other children.

7.1.3 Participants from Southfield School

Our experiment's six participants came from Southfield School in Hatfield, a school for children with special needs. All of our participants had been previously diagnosed with varying degrees of autism by medical professionals, and all children had issues with speech, language, and communication. We received information from Southfield School on each child's degree of communicative and social competency based to the P-scale (performance scale), a set of performance criteria used by all schools in the UK for children with special needs working below level 1 of the country's national curriculum (see table 7.1). These criteria rated the children's listening, speaking, and social awareness skills on scales from one to eight, with the meanings of the numeric ratings ranging from being briefly aware of interactions with familiar people while focusing their attention on sudden sensory stimuli, to linking up to four key-words in sentences while demonstrating an understanding of causality, listening and responding appropriately to questions regarding causality, and participating in a wide spectrum of social activities while understanding which code of social conduct is appropriate and beneficial to everyone in a given situation, respectively [Qualifications and Authority, 2009]. Although half of these children had already played with KASPAR during an experiment of ours from the previous year [Wainer et al., 2010], their teacher vouched for the fact that these children were very unlikely to have their current interactions be influenced by their earlier interactions with KASPAR because of the year-long intervening period. The children in our study consisted of five boys and one girl between 8 and 9 years of age, and all of the participants' parents signed consent forms on behalf of their children before the study began in order to allow their children to participate in our study as well as to allow their likenesses to be shared with the scientific community. The study took place over a period of 10 weeks between May 7^{th} and July 16^{th} of 2010.

Table 7.1: Descriptions of the children who participated in this study.

Name	Age	Sex	Speaking ability according to P-scale	Listening ability according to P-scale	Personal and social skills according to P-scale
R	9	Male	P7b	P7b	P7c
M	9	Male	P6a	P5a	P5b
T	8	Female	P6c	P6c	P4a
H	8	Male	P8c	P8b	P7c
Cl	9	Male	P6c	P6b	P5a
C	8	Male	P6a	P7c	P5a

7.2 Experiment

7.2.1 Method and procedure

This study was carried out with the approval of the Faculty Ethics Committee of University of Hertfordshire's faculty of Engineering and Information Science. In our experiment, pairs of children with autism alternated between playing a set of imitative, collaborative video games dyadically with each other and playing the same game triadically with each other as well as KASPAR the robot (see figure 7.1). In this study, the robot was been programmed to play the collaborative game "Copycat", which was discussed in section 4.3, in a similar manner as the children themselves and to interact with the children, as was discussed in section 3.2. Every child was taught how to play the collaborative game during their first game session, and every child practiced the game's mechanics by themselves in order to refresh their memories at the beginning of every game session. The children played during each game session for as long as they liked and stopped playing whenever they wanted. The game sessions took place in the teacher's lounge of Southfield School which was well-lit in order to allow the children to easily see each other, KASPAR, and the game screen. In addition, we closed the doors of the room and closed its shades in order to limit the number of trivial things that could distract each child from playing the game and interacting with the other players. Other than the children, the only other person in the room was a human carer who was familiar with the children as well as the game. Their role was to keep the children focused if they became distracted and to calm the children down if they became too excited or agitated during a session. The carer was asked to usually be silent and remain a few feet away from the children while they played in order to not interfere too much with the children's collaborative and communicative efforts, but they were allowed to move closer and speak to the children if they were clearly in need of assistance. Although the experimenter set up all of the equipment and was the person who greeted and said goodbye to the children during every session, they did not remain in the room while the children played together in order to prevent the experimenter's presence from influencing the children's interactions and behaviours. Instead, the experimenter observed every game session by sitting at a desk in an adjacent rooom and watching a laptop-based video feed from a small, unobtrusive security camera which was set up in the teacher's lounge only for the duration of each game session and trained on the children.

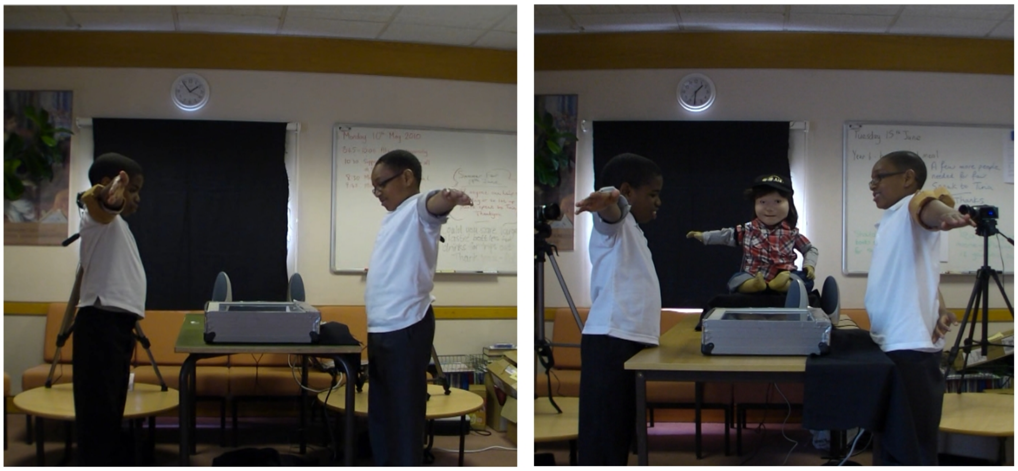


Figure 7.1: **Left:** Two children with autism, M and C, play "Copycat" dyadically with each other. **Right:** The same two children, M and C, play "Copycat" triadically with each other and KASPAR.

The experimental design was based on a *reversal* or *ABA* design, in which the participants alternate between two phases; in one phase known as phase "A", a baseline of behaviour is tracked for some period of time, and in the other phase known as phase "B", an experimental intervention is implemented while the same behaviours are tracked [Rosenthal and Rosnow, 2008]. By switching between these phases, researchers can determine whether participating in an experimental intervention will affect the baseline behaviours of a set of subjects. In this experiment, the observed behaviours were the children's interaction styles with respect to patterns of gaze, speech, and displays of positive affect. Furthermore, the baseline behaviours of phase "A" consisted of every unique pairing of children playing dyadically with each other, while the experimental intervention of phase "B" consisted of KASPAR the robot playing triadically with every possible unique pairing of children. In our experiment, the children first participated in the original iteration of phase A (known as phase A_1), followed by a familiarization phase "F" in which each child interacted dyadically with KASPAR for three sessions on three distinct days. This was done so that the children would become accustomed to the robot's unique manners of movement and speech instead of being startled by them, thus making KASPAR a familiar interaction partner and decreasing the power of the novelty effect in the children's later interactions. After phase F, the children participated in the original iteration of phase B (known as phase B_1), followed by a second iteration of phase A (known as phase A_2) and a subsequent second iteration of phase B (known as phase B_2). As such, the ordering of the phases was:

$$A_1 - F - B_1 - A_2 - B_2$$

Every single child was paired once in a play session with every other child in each iteration of the A and B phases. Since there were six total participants, the number of unique pairings of the participants, or number of sessions, per A/B phase was :

$$\binom{6}{2} = \frac{6!}{2!(6-2)!} = \frac{6*5*4*3*2}{2*(4*3*2)} = \frac{6*5}{2} = \frac{30}{2} = 15$$

With fifteen unique sessions that took place in each of the four iterations of the A or B phases and the three pairings per child that took place during phase F, there were a total of (15 * 4) + (3 * 6) = 78 sessions that took place in our study. To switch perspective from the number of sessions in the whole study to the number of sessions in which each individual child participated, with every child taking part in five play sessions per iteration of the A or B phases (in order to play with every other child once during each phase) and three play sessions during phase F, every child took part in 5 * 4 + 3 = 23 total sessions.

We decided to use a reversal design for our experiment with repeated measures in each phase because we anticipated having very few children available to participate in our study, and such a design allows each subject to act as their own control group. Furthermore, we wanted to be able to determine whether the children's behaviour during our study would be influenced by the novelty of interacting with a humanoid robot, the novelty of playing a fun video game during school hours, the learning which took place during the collaborative interactions with other children, or the learning that took place by imitating the robot's behaviour and being imitated by it. As such, gathering multiple data points for every child during each phase of our study allowed us to distinguish between the overlapping infuences of each effect on the children's behaviours. Additionally, by having each child interact with every other child once per experimental phase, we were able to obtain a complete, balanced picture of every child's interaction history and collaborative abilities; if we had never changed the pairings of the children and made each child only interact with one other child for the course of the whole experiment, there is a very good chance that we would have had one or more pairs of children who could not have worked well together due to conflicting personalities/preferences. Naturally, such an occurrence would have greatly reduced the effective size of our participant pool and dataset, to say nothing of the significance of any findings from our study.

7.2.2 Data collection

To measure how the children collaborated and interacted with their partners, whether human or robotic, we used three camcorders to videotape the children's play sessions and used the video game itself to record and timestamp both players' in-game actions. The behaviours which were manually coded from the videotapes and automatically recorded in the game's log files include:

1. **prompting to choose** - a question or suggestion which was verbalized by a child, the carer, or the robot, and aimed at making the directing child choose any shape provided that said child had not already done so;

2. **urging to comply** - a question or suggestion which was verbalized by a child, the carer, or the robot, and directed toward making a non-directing

player comply with the choice of (pose like) the directing player provided that they had not already tried to do so;

3. **other forms of talking** - one of the children or KASPAR verbally selected a specific shape, congratulated another player, gave advice on how to play that was neither considered prompting nor urging, talked about anything else, or made a series of sounds with the intent to communicate which were not repeating another's speech verbatim;

4. **successful shape selection** - all of the players agreed to pose in a certain way to choose a particular shape and held identical poses for a long enough period of time;

5. **pose** - how a player held the arm on which they wore a Wiimote. The poses were classified as "upward", "outstretched", "angled downward", "at rest", and "moving too quickly to be classified".

6. **gaze and gaze shift** - what the children looked at while playing the game, as one of the core deficits of autism is impaired gaze patterns [American Psychiatric Association, 1994]. The children's gazes were coded while looking at the game itself, the other child playing, or KASPAR;

7. **positive affect** - one of the children laughed or smiled while playing the game (see. figure 7.2).

While some of the above behaviours are inherently commuicative activities, such as any form of speech, and some combinations of the above behaviours are intrinsically social, such as smiling while looking at another person, some of these behaviours are only social in the context of the collaborative game. For example, while neither performing a successful action in a video game nor posing one's arm would not be considered inherently social acts, such behaviours become social,

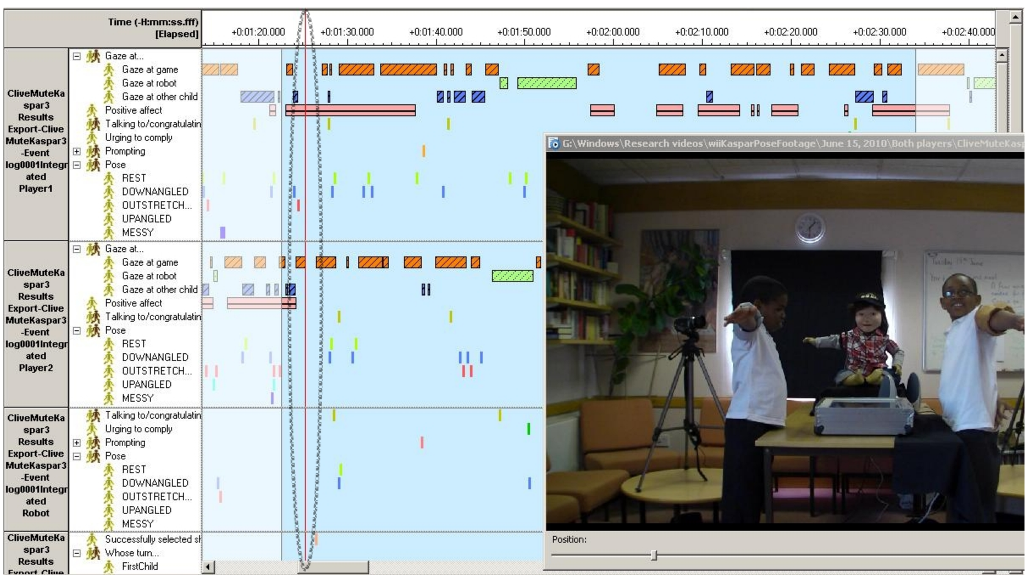


Figure 7.2: An example of the coded behaviours of two children and KASPAR represented on both a graphical timeline (left) as well as a movie player (right) in Noldus's Observer software package. Both the timeline's large red vertical bar (outlined in a checkered oval) and the movie player's position box represent a timeslice of the session.

cooperative, and indicative of successful imitation in the context of this study's collaborative game. This is because successfully selecting a shape required multiple players to mimic another player's pose at the same time, and since none of the actions in any given session were decided beforehand, it was up to the players to communicate with each other in order to coordinate how, when, and where these actions would be performed in real time. Since all of these actions are collaborative / cooperative in nature [Malone et al., 1990], the game behaviours that accomplish them are therefore also collaborative.

Because of the many play sessions involved in our study, the variable lengths of the sessions (average length of 6 minutes, standard deviation of 2 minutes 43 seconds, maximum length of 15 minutes), the amount of time required to manually code a given length of video for each child's various behaviours, and the amount of time available to us, we decided to manually code three minutes out of every play session. By coding such a sample from every session, we were able to complete coding all of the videos in a reasonable amount of time while also obtaining a balanced and accurate portrayal of each session. Each sample was comprised of the three contiguous minutes between the one minute mark and the four minute mark of each session. We did not code the first minute of each play session because our observations informed us that during this time, the children were usually still coping with changing between social activities and attempting to concentrate on the game. As such, their behaviours during the first minute of any session were not likely to be indicative of their behaviour for the rest of that session. One fifth of the play sessions had durations of less than four minutes total, and in these cases we coded from the end of the session's first minute until the end of the session itself.

To ensure inter-rater reliability, the above behaviours were coded by the experimenter as well as a second independent rater who coded 10% of the data. When the two sets of codings were analyzed for similarity, the average agreement value was 0.71, which is generally considered to be good. We also examined the codings for reliability and received an average value for Cohen's kappa of $\kappa = 0.66$. This is acceptable for exploratory studies, as having a Cohen's kappa value higher than 0.60 suggests a good agreement between the raters and is not due to chance alone [Bakeman and Gottman, 1997].

7.2.3 Analysis and Results

Because our datasets had abnormal distributions and subsequently failed Kolmogorov-Smirnov tests of normality, we used Wilcoxon's matched pairs signed rank tests instead of paired t-tests to determine which phases of the experiment had statistically significant differences between their observed behaviours. We understand that Wilcoxon's test measures the ranked and signed magnitudes of the differences between pairs in its dataset, as compared to the paired t-test measuring the difference between the means of the pairs in its dataset. Since the calculations for Wilcoxon's test do not account for either the size of the sample or the standard deviation of its data, the test results are particularly subject to the influence of small percentages of outlying pairs in their datasets that possess differences of large magnitudes. However, because our datasets did not have sufficiently normal distributions, we could not use t-tests in our analyses.

Before we conducted our first game session with the children, our general expectations were that the study's participants would be more socially communicative and more socially engaged with each other only after interacting with KASPAR the robot. Specifically, we expected to find that each child would speak more, both in terms of general speech as well as game-directed advice, would display more positive affect, and would look more at the other child playing with them only after interacting with the robot. During the sessions that involved playing with the robot, we predicted that each child would display more positive affect and would focus more attention on KASPAR than on the other child playing with them because of the robot's predictability, its repetitive actions, and its ability to fascinate and engage the children. Furthermore, although we expected that the children would speak more after interacting with KASPAR and that some of them would be slightly more communicative with the other children, we felt that most of the children's speech would be directed toward their carers instead of the other child playing with them. We expected this to happen because the carers were typically-developed individuals with whom the children were very familiar and were also likely to be very proactive and socially persistent in their day-to-day interactions with the children outside of our experimental setting. In contrast, because all of the children involved in our study were diagnosed with autism, although we felt it likely that each child would try to initiate more interactions with the other child playing after having played with KASPAR, we felt that the children's abilities to understand and appropriately respond to social stimuli would not develop as much. Furthermore, we also expected that the children would select fewer shapes while playing triadically with KASPAR than while playing dyadically with another child for two reasons - it would require more time and effort to coordinate collaborative efforts among three players than it would among two, and the children in our study would likely be more focused on enjoying KASPAR's speech and behaviours than they would on playing the game successfully.

Table 7.2 lists different forms and combinations of the children's social behaviours and indicates whether the frequency or duration of these behaviours changed over the course of the experiment. Although some behaviours were clearly performed more during certain phases than others, none of the behaviours increased over time throughout all of the phases. Because none of the graphs below show upward-sloping linear trends over the course of the study, we can infer that none the changes in the children's behaviours are due to their increasing familiarity with the experimental setting or the children's continued practice with our collaborative game.

As expected, each child looked at the other child playing with them significantly more after they interacted with KASPAR (phase A_2) than they did before-

Table 7.2: The results of Wilcoxon's signed rank tests comparing the children's behaviours during each phase of play sessions. ✘ - statistically insignificant, ? - marginally statistically significant, ✔ - statistically significant

	$\mathbf{A}_1$ vs $\mathbf{B}_1$	$\mathbf{B}_1$ vs $\mathbf{A}_2$	$\mathbf{A}_2$ vs $\mathbf{B}_2$	$\mathbf{A}_1$ vs $\mathbf{B}_2$	$\mathbf{A}_1$ vs $\mathbf{A}_2$	$\mathbf{B}_1$ vs $\mathbf{B}_2$
Total time each child spent gazing at the other child	Z = -1.347 p = 0.178 ✘	Z = -2.643 p = 0.008 ✔ $(\mathbf{B}_1 < \mathbf{A}_2)$	Z = -1.368 p = 0.171 ✘	Z = -2.972 p = 0.003 ✔ $(\mathbf{A}_1 < \mathbf{B}_2)$	Z = -3.939 p = 0.000 ✔ $(\mathbf{A}_1 < \mathbf{A}_2)$	Z = -1.738 p = 0.082 ?
Total time each pair of children spent engaging in mutual gaze	Z = -2.442 p = 0.015 ✔ $(\mathbf{A}_1 < \mathbf{B}_1)$	Z = -2.556 p = 0.011 ✔ $(\mathbf{B}_1 < \mathbf{A}_2)$	Z = -1.533 p = 0.125 ✘	Z = -3.067 p = 0.002 ✔ $(\mathbf{A}_1 < \mathbf{B}_2)$	Z = -3.010 p = 0.003 ✔ $(\mathbf{A}_1 < \mathbf{A}_2)$	Z = -1.477 p = 0.140 ✘
Total time each child spent gazing at other child or KASPAR	Z = -4.741 p = 0.000 ✔ $(\mathbf{A}_1 < \mathbf{B}_1)$	Z = -4.165 p = 0.000 ✔ $(\mathbf{B}_1 > \mathbf{A}_2)$	Z = -3.980 p = 0.000 ✔ $(\mathbf{A}_2 < \mathbf{B}_2)$	Z = -4.782 p = 0.000 ✔ $(\mathbf{A}_1 < \mathbf{B}_2)$	Z = -3.939 p = 0.000 ✔ $(\mathbf{A}_1 < \mathbf{A}_2)$	Z = -0.998 p = 0.318 ✘
Total # of gaze changes between the game and the other child	Z = -0.585 p = 0.559 ✘	Z = -2.798 p = 0.005 ✔ $(\mathbf{B}_1 < \mathbf{A}_2)$	Z = -1.954 p = 0.051 ?	Z = -1.584 p = 0.113 ✘	Z = -3.230 p = 0.001 ✔ $(\mathbf{A}_1 < \mathbf{A}_2)$	Z = -1.245 p = 0.213 ✘
Total # of instances of positive affect	Z = -2.218 p = 0.027 ✔ $(\mathbf{A}_1 < \mathbf{B}_1)$	Z = -0.899 p = 0.369 ✘	Z = -0.487 p = 0.626 ✘	Z = -1.675 p = 0.094 ?	Z = -2.849 p = 0.004 ✔ $(\mathbf{A}_1 < \mathbf{A}_2)$	Z = -0.453 p = 0.651 ✘
Total time spent displaying positive affect	Z = -0.154 p = 0.877 ✘	Z = -1.759 p = 0.079 ?	Z = -1.244 p = 0.213 ✘	Z = -0.010 p = 0.992 ✘	Z = -1.594 p = 0.111 ✘	Z = -0.010 p = 0.992 ✘
Total # of instances of mutual displays of positive affect	Z = -2.297 p = 0.022 ✔ $(\mathbf{A}_1 < \mathbf{B}_1)$	Z = -1.451 p = 0.147 ✘	Z = -1.314 p = 0.189 ✘	Z = -1.383 p = 0.167 ✘	Z = -2.576 p = 0.010 ✔ $(\mathbf{A}_1 < \mathbf{A}_2)$	Z = -0.31 p = 0.975 ✘
Total time spent in mutual displays of positive affect	Z = -1.136 p = 0.256 ✘	Z = -1.874 p = 0.061 ?	Z = -1.533 p = 0.125 ✘	Z = -0.426 p = 0.670 ✘	Z = -1.817 p = 0.069 ?	Z = -0.057 p = 0.955 ✘
Total time spent displaying positive affect while gazing at the other child	Z = -0.607 p = 0.544 ✘	Z = -2.746 p = 0.006 ✔ $(\mathbf{B}_1 < \mathbf{A}_2)$	Z = -2.047 p = 0.041 ✔ $(\mathbf{A}_2 > \mathbf{B}_2)$	Z = -2.335 p = 0.020 ✔ $(\mathbf{A}_1 < \mathbf{B}_2)$	Z = -3.815 p = 0.000 ✔ $(\mathbf{A}_1 < \mathbf{A}_2)$	Z = -0.524 p = 0.600 ✘
Total # of instances of displaying positive affect while gazing at the other child	Z = -0.920 p = 0.357 ✘	Z = -2.142 p = 0.032 ✔ $(\mathbf{B}_1 < \mathbf{A}_2)$	Z = -0.952 p = 0.341 ✘	Z = -1.436 p = 0.151 ✘	Z = -3.084 p = 0.002 ✔ $(\mathbf{A}_1 < \mathbf{A}_2)$	Z = -0.356 p = 0.722 ✘
Total # of instances of speaking (talking, urging, or prompting)	Z = -0.877 p = 0.381 ✘	Z = -1.020 p = 0.308 ✘	Z = -0.130 p = 0.897 ✘	Z = -0.033 p = 0.974 ✘	Z = -0.241 p = 0.810 ✘	Z = -1.289 p = 0.197 ✘
Total # of instances of children conversing, or speaking responsively	Z = -1.305 p = 0.192 ✘	Z = -1.750 p = 0.080 ?	Z = -0.251 p = 0.802 ✘	Z = -1.123 p = 0.261 ✘	Z = -0.720 p = 0.471 ✘	Z = -1.770 p = 0.077 ?
Total # of instances of speaking while gazing at the other child	Z = -2.103 p = 0.036 ✔ $(\mathbf{A}_1 < \mathbf{B}_1)$	Z = -1.675 p = 0.094 ?	Z = -0.976 p = 0.329 ✘	Z = -3.199 p = 0.001 ✔ $(\mathbf{A}_1 < \mathbf{B}_2)$	Z = -3.291 p = 0.001 ✔ $(\mathbf{A}_1 < \mathbf{A}_2)$	Z = -1.402 p = 0.161 ✘
Total time spent not posing like the "directing" player	Z = -0.298 p = 0.766 ✘	Z = -1.306 p = 0.192 ✘	Z = -0.216 p = 0.829 ✘	Z = -1.512 p = 0.131 ✘	Z = -1.347 p = 0.178 ✘	Z = -0.648 p = 0.517 ✘
Total # of successfully selected shapes	Z = -3.417 p = 0.001 ✔ $(\mathbf{A}_1 > \mathbf{B}_1)$	Z = -2.890 p = 0.004 ✔ $(\mathbf{B}_1 < \mathbf{A}_2)$	Z = -3.115 p = 0.002 ✔ $(\mathbf{A}_2 > \mathbf{B}_2)$	Z = -3.428 p = 0.001 ✔ $(\mathbf{A}_1 > \mathbf{B}_2)$	Z = -0.905 p = 0.365 ✘	Z = -0.178 p = 0.859 ✘
Percentage of shapes successfully selected without player being urged to comply	Z = -2.531 p = 0.011 ✔ $(\mathbf{A}_1 > \mathbf{B}_1)$	Z = -3.672 p = 0.000 ✔ $(\mathbf{B}_1 < \mathbf{A}_2)$	Z = -2.941 p = 0.003 ✔ $(\mathbf{A}_2 > \mathbf{B}_2)$	Z = -1.482 p = 0.138 ✘	Z = -1.512 p = 0.131 ✘	Z = -0.714 p = 0.475 ✘
Percentage of shapes successfully selected without player being prompted to choose	Z = -3.693 p = 0.000 ✔ $(\mathbf{A}_1 > \mathbf{B}_1)$	Z = -3.901 p = 0.000 ✔ $(\mathbf{B}_1 < \mathbf{A}_2)$	Z = -3.595 p = 0.000 ✔ $(\mathbf{A}_2 > \mathbf{B}_2)$	Z = -3.305 p = 0.001 ✔ $(\mathbf{A}_1 > \mathbf{B}_2)$	Z = -1.360 p = 0.174 ✘	Z = -0.675 p = 0.499 ✘

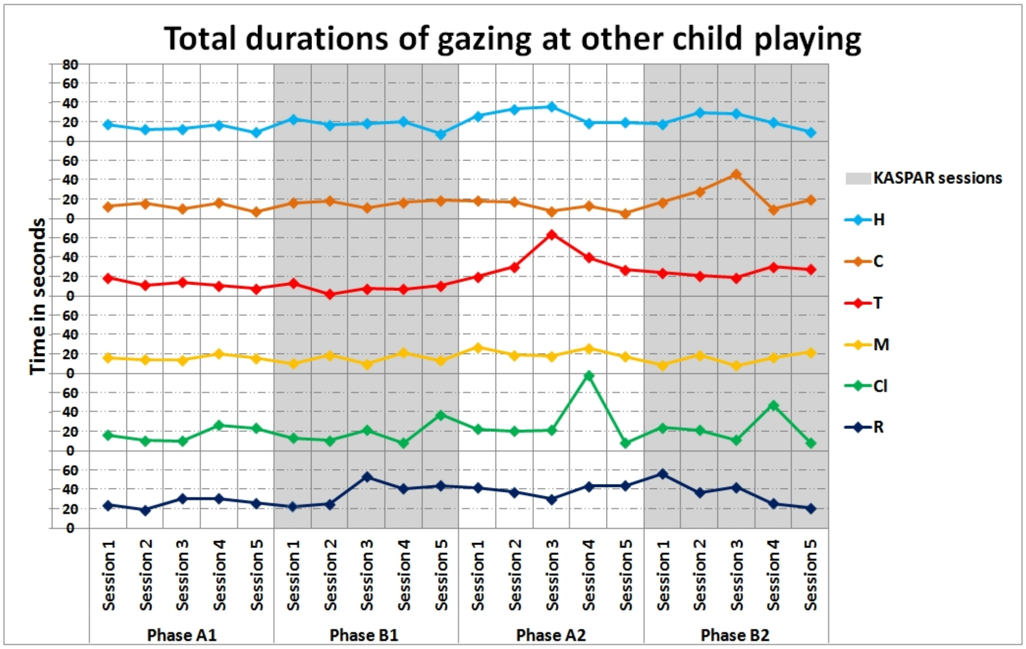


Figure 7.3: The amount of time each child spent looking at the other child playing the collaborative game with them during each session of this experiment.

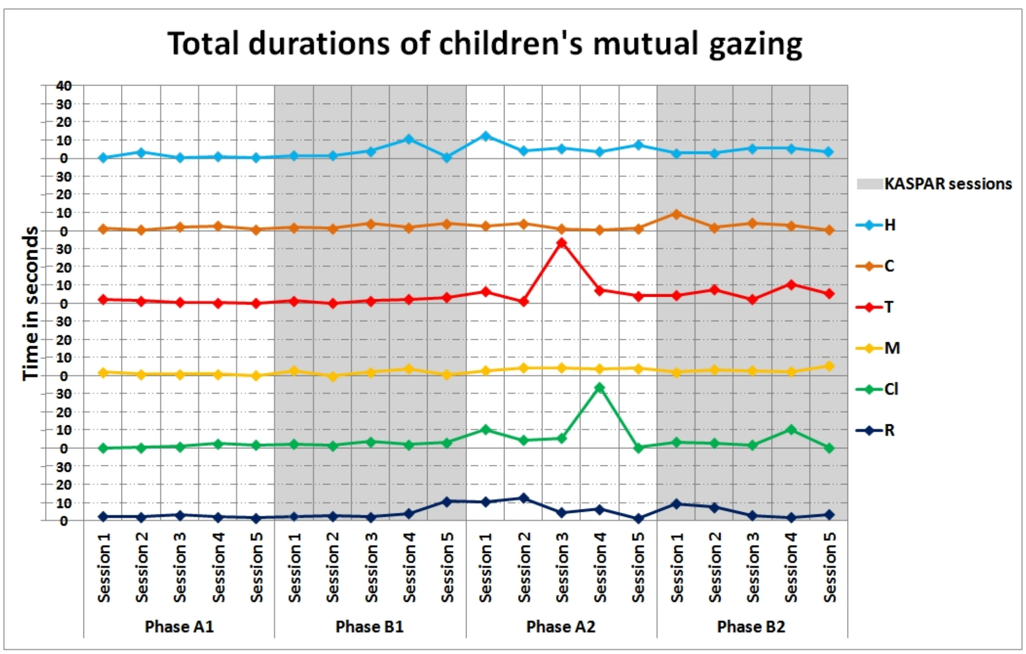


Figure 7.4: The amount of time each child and their partner spent looking at each other at the same time during each session of this experiment.

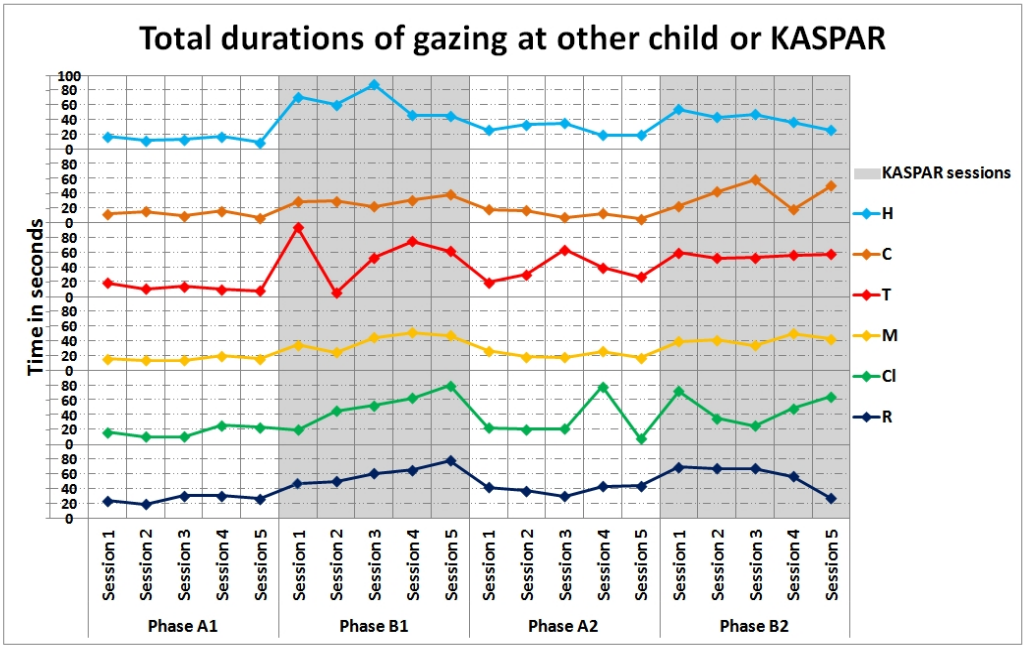


Figure 7.5: The amount of time each child spent looking at the other child or KASPAR the robot during each session of this experiment.

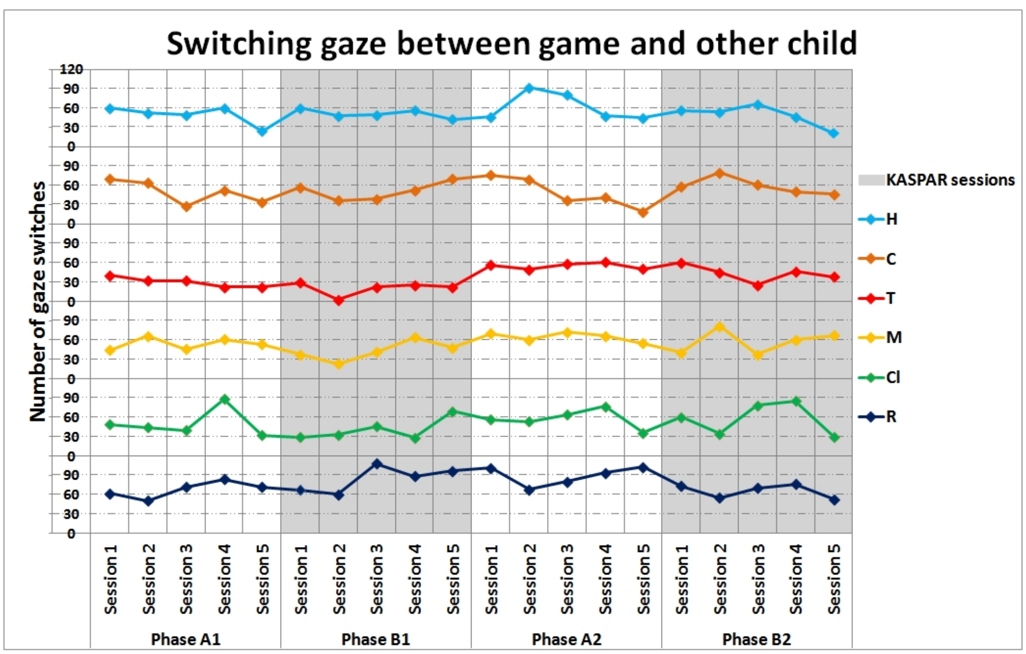


Figure 7.6: The number of times that each child alternated between looking at the game and looking at the other child during each session of this experiment.

hand (phase A_1). However, we were surprised to find that each child also looked at the other player significantly more during the last phase of play which involved KASPAR, phase B_2, than they did during their first phase of play without it, phase A_1 (see figure 7.3). Furthermore, we were pleased to find that the children also looked at each other at the same time significantly more often after their first set of interactions with KASPAR than they did beforehand (see figure 7.4). To get a more balanced perspective on how the children observed the other individuals playing the game, we also examined how much time each child spent looking at the other child as well as KASPAR during every phase of the experiment. We found that each child spent significantly more time looking at the other child as well as the robot while playing with KASPAR than they did looking at the other child during the sessions without the robot, which is what we expected (see figure 7.5). Additionally, each child switched between looking at the game and looking at the other player significantly more often after playing with KASPAR than they did beforehand. Surprisingly, there were no consistent differences of gaze switching between phases involving playing with KASPAR and those only involving play with another child; although one would expect that giving children with autism the opportunity to pay attention to an interactive humanoid robot would mean that they would switch their gaze between the game and the other child significantly less in favour of switching their gaze between the robot and either the game or the other child, we only found a significant difference in such gaze switching between phases B_1 and A_2 as well as a marginally significant difference between phases A_2 and B_2 (see figure 7.6).

Although we expected that the children would display positive affect more while playing with KASPAR than while only playing with another child, and would also display more positive affect after having played with KASPAR than they did beforehand, our data only supported some of our predictions. Specifically, although we did not find any significant differences between any of the phases for the total

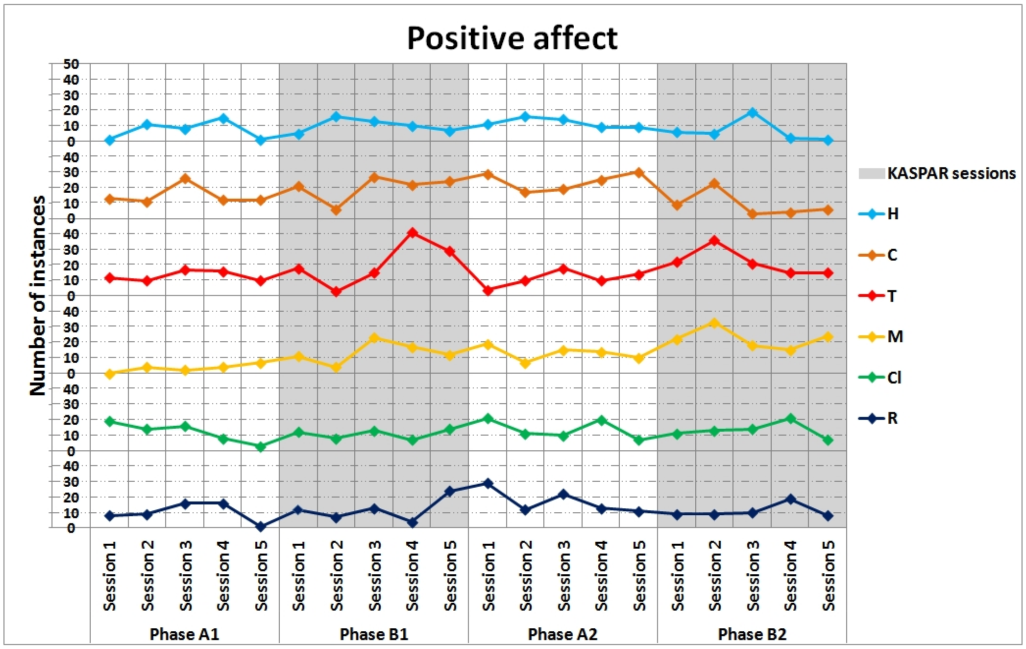


Figure 7.7: The number of times each child spent displaying positive affect during each session of this experiment.

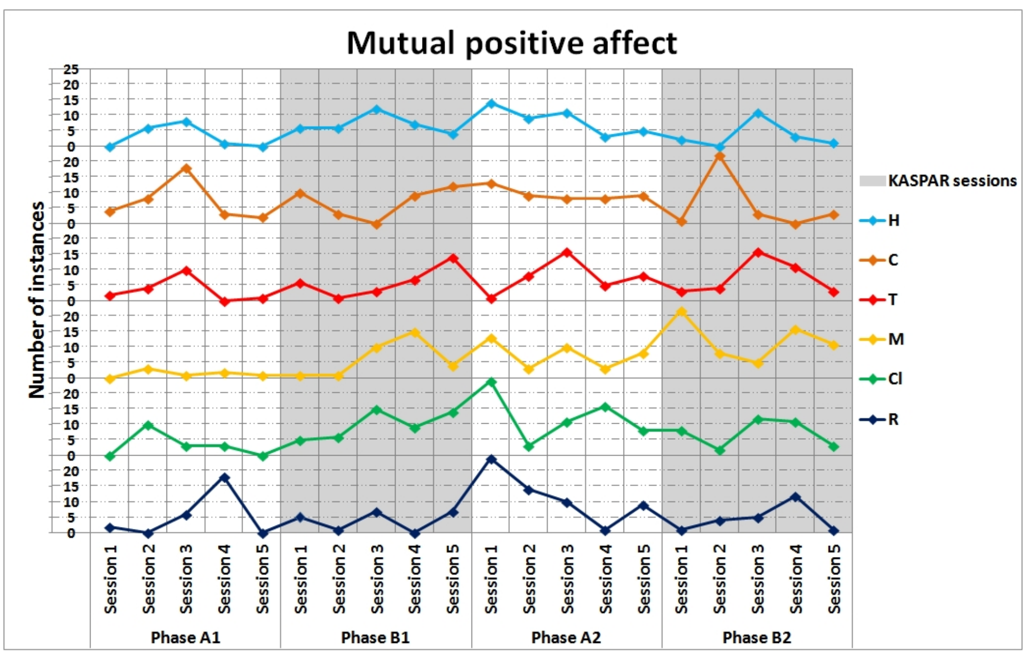


Figure 7.8: The number of times each child displayed mutual positive affect with the other child during each session of this experiment.

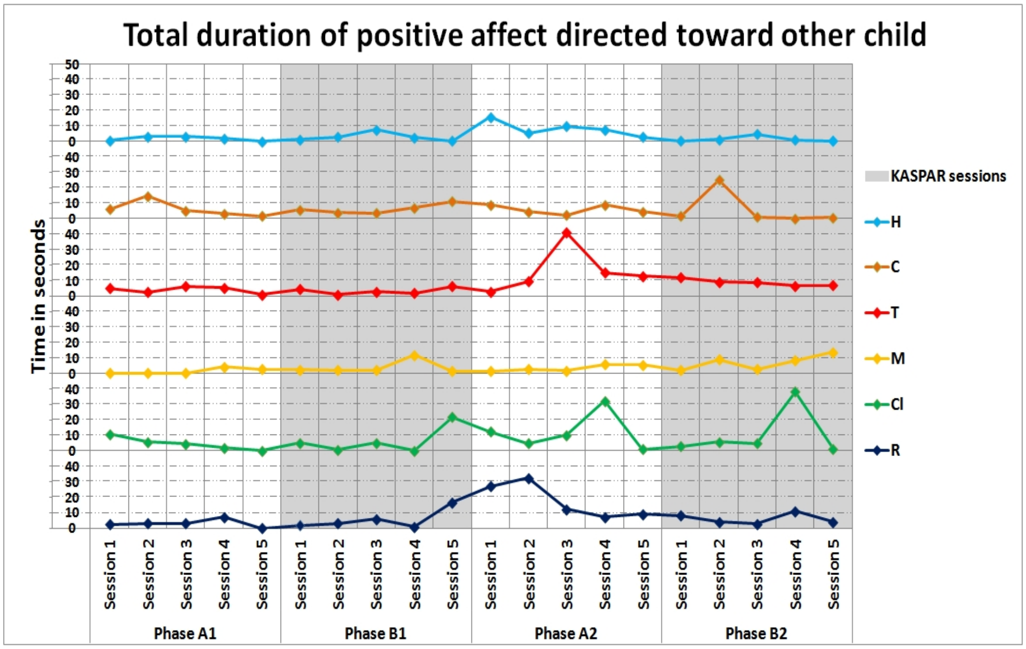


Figure 7.9: The amount of time each child spent displaying positive affect while looking at the other child during each session of this experiment.

time the children spent displaying affect, the children did have significantly more instances of displaying positive affect during phase A_2 than they did during phase A_1. Furthermore, our data also did not show that the children had more instances of displaying positive affect while interacting with KASPAR than they did while only interacting with each other (see figure 7.7). Interestingly, we found that the children had significantly more instances of displaying mutual positive affect - positive affect displayed by both children during the same time - during phase A_2 than during phase A_1 (see figure 7.8), but we did not find any significant trends among the other phases regarding the total time spent displaying mutual positive affect at the same time. We also found interesting trends with respect to how often each child displayed positive affect while looked at the other child playing with them, which suggests that the children came to find more enjoyment from socially interacting with other people in the context of a collaborative game. Specifically, the children spent significantly more time directing their positive affect at the other child playing with them during phase A_2 than during phase A_1, and also that they spent significantly more time displaying positive affect at the other child during phase A_2 than either of the phases involving KASPAR (see figure 7.9).

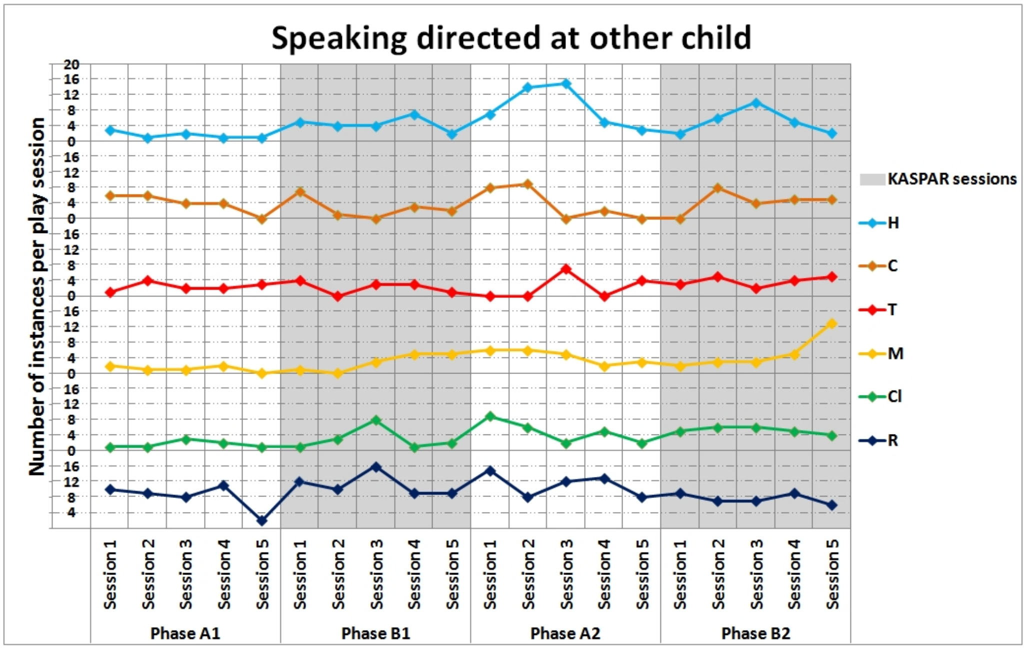


Figure 7.10: The number of times each child spoke while looking at the other child during each session of this experiment.

While we predicted that the children would communicate more after having interacted with KASPAR, our data did not strictly show this. Specifically, there were no significant differences between any of the phases with respect to the total number of times the children spoke (talking, prompting, or urging) during each session, nor were there significant differences in the number of times that the children talked responsively with anyone (within 2 seconds of another child's speech, or following KASPAR's or the carer's speech within 2 seconds). However, we found that the children spoke significantly more while looking at the other child playing with them (or preceding periods of looking at the other child by no more than 2 seconds) during phase A_2 than they did during phase A_1; in fact, the children spoke while looking at the other player significantly less often during the first phase, A_1, than during any other phase (see figure 7.10). This was particularly interesting, as we predicted that although some of the children might speak more after interacting with KASPAR, most of the children's speech would probably be directed towards their carers instead of toward the other child playing with them.

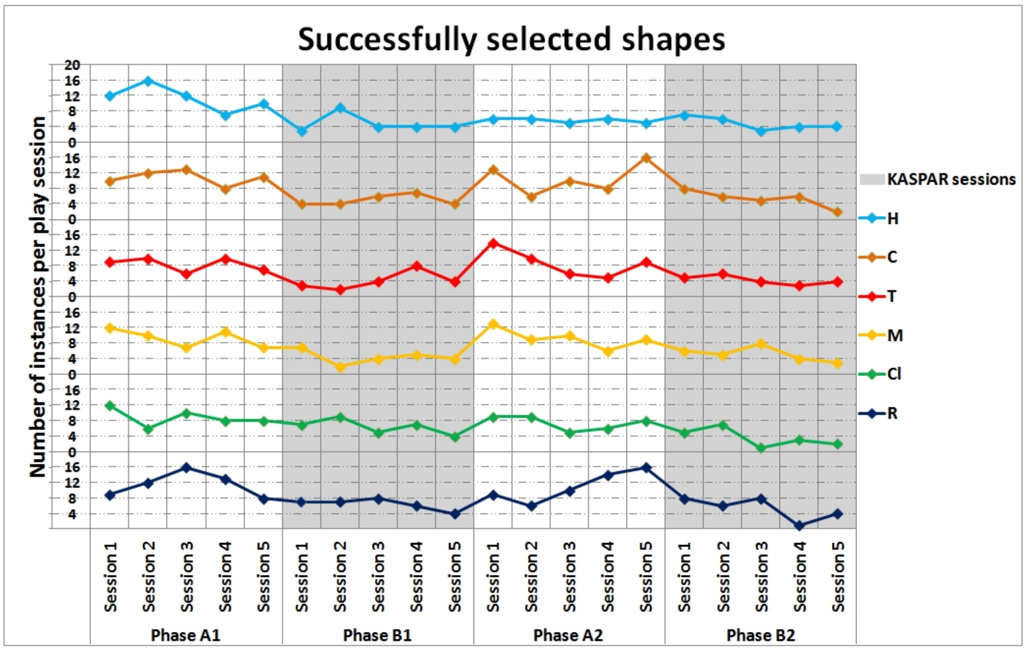


Figure 7.11: The number of shapes successfully selected during each session of this experiment.

We predicted that the children would not play as successfully and select fewer shapes while playing triadically with KASPAR than while playing dyadically with another child, and our data confirmed our expectations (see figure 7.11). We did not find any significant differences between the phases for the amount of time that each child did not pose like the directing player, but we did find interesting results for how well the children played without having to be verbally coerced into playing a certain way. Specifically, our data shows that between consecutive phases in our experiment, the percentages of rounds that the children played successfully without having to be urged to comply with the directing player's choice were significantly different; unfortunately, this trend did not extend to a full distinction between dyadic

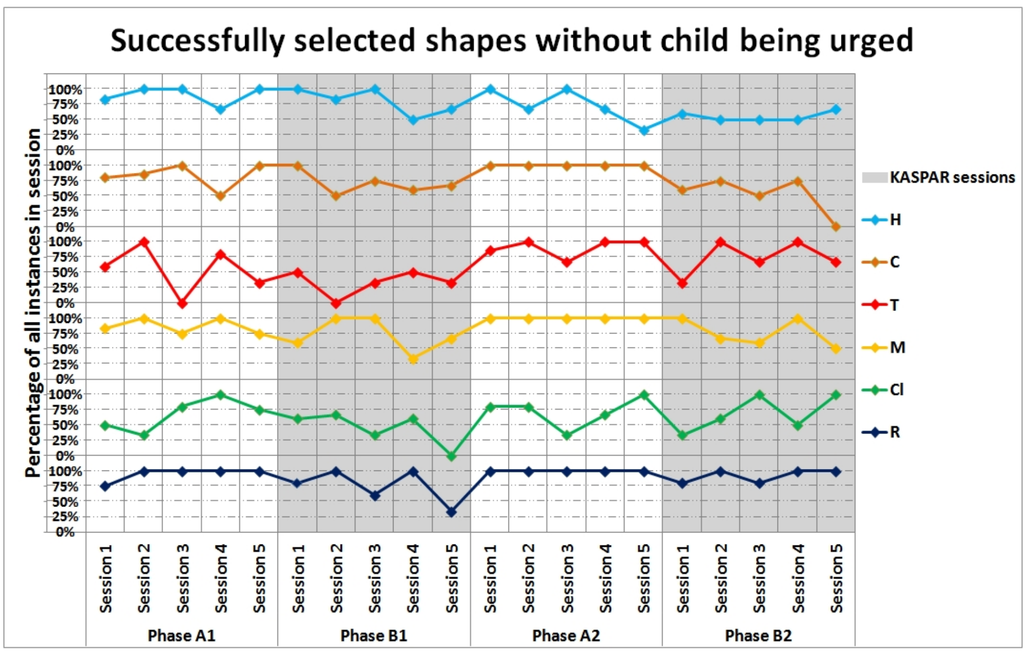


Figure 7.12: The percentage of shapes successfully selected without having to be urged to comply with the directing player's choice during each session of this experiment.

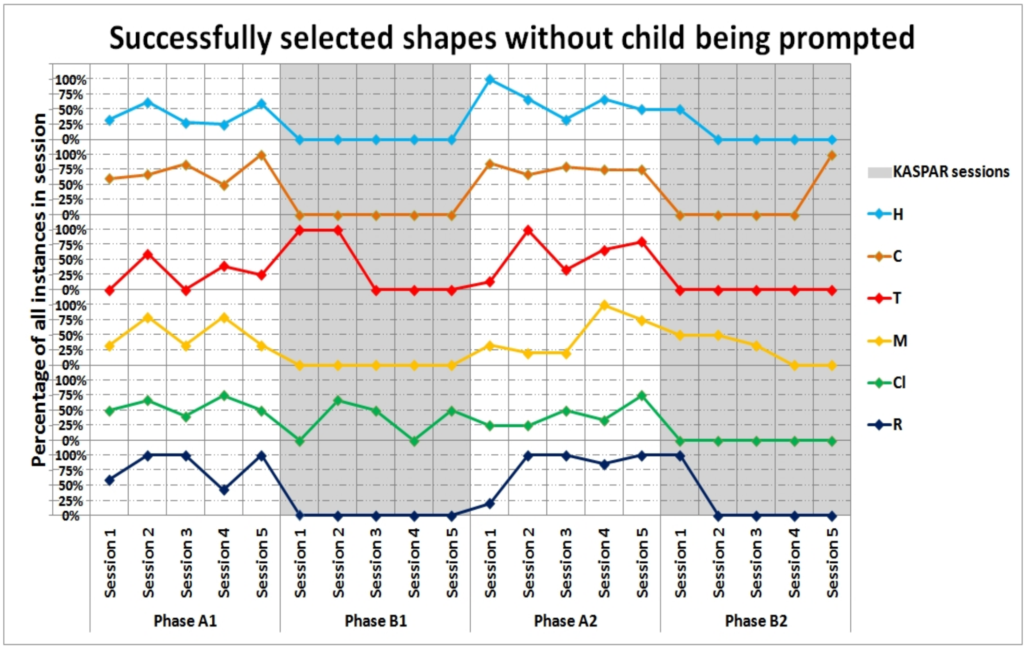


Figure 7.13: The percentage of shapes successfully selected without having to be prompted to choose a shape during each session of this experiment.

and triadic play because there was no significant difference between how the children played in phases A_1 and B_2. Additionally, there was no significant difference between how the children played before or after interacting with KASPAR (see figure 7.12). Additionally, our data shows that the children successfully played a significantly higher percentage of rounds without someone - whether the other child, the carer, or the robot - prompting them to choose a shape as long as they played dyadically with another child; when they played triadically with KASPAR, there were many more instances of someone having to prompt the directing child to choose a shape. Unfortunately, there was no significant difference in how the children played before or after interacting with KASPAR (see figure 7.13). As such, the children's behaviours which dealt with the number of shapes they selected did not seem to be affected by whether the children had or had not yet played with KASPAR.

After we conducted our last play session in this experiment, we met with the children's teacher to learn more about the children's personalities and whether their dispositions and behaviours during our experiment were typical for them. Each of the children in our study had their own preferences and styles of play; T and Cl preferred to usually play by themselves away from others and needed adult supervision to play in close proximity to other children, H, M, and C needed supervision only for actively engaging in play with other children, and R, who possessed one of the highest P-scale scores for personal and social skills (see table 7.1 in section 7.1.3), had a regular group of children with whom he could cooperate and play socially without adult supervision. However, all of the children were described as having difficulties with key elements of social play, such as taking turns in a game and maintaining their concentration to accomplish a cooperative task. As such, it is important to note that all of the children were able to play our collaborative game for extended periods of time as well as make significant improvements in their displays of social behaviours after they interacted with KASPAR. Additionally, half of the children correctly used mannerisms and figures of speech during phase A_2 which they originally heard from the robot, and these phrases were appropriately understood by the other children playing with them. These children did not repeat phrases that were unique to the other children that they played with, which shows that the imitating children were particularly fascinated by KASPAR. Furthermore, some children unwittingly and intermittently exhibited tendencies which seemed to diminish their own enjoyment or the enjoyment of others from playing the collaborative game; Cl would sometimes try to elicit emotional reactions from the children that they played with, T would occasionally become overly excited while playing the game, and C occasionally had a negative attitude towards playing the game and interacting with others. At the recommendation of the children's teacher, we asked the carer present at each play session to be alert for these unpleasant behaviours and try to both limit their occurences and ameliorate the situations that developed from them. The carers did their best to do so, and it is interesting to note that in spite of these occasional rough patches in the children's behaviour, the children still managed to display more social behaviours and more social engagement while participating in our study.

7.3 Discussion

7.3.1 Interpretation of behaviour improvements between phases A_1 and A_2

The fact that the participants of this study displayed certain social behaviours more during phase A_2 than during phase A_1, or more after playing with KASPAR than they did beforehand, suggests many interesting things. Firstly, the fact that each child both gazed more at the opposite child in addition to switching their gaze between the game and the other child means that each child paid more attention to the partner with whom they played. Such trends would be noteworthy even if they were the only ones found in our study, as children with autism have marked deficiencies in looking at the other person with whom they are interacting, even when they are in a one-on-one interaction with an adult carer in a naturalistic setting [Volkmar and Mayes, 1990]. However, when coupled with the fact that the children experienced increases in their duration and frequency of looking at each other at the same time, the children's previously mentioned gaze trends become indicative of improved social communication. This is because mutual gaze is an important form of nonverbal communication that plays an important role in synchronizing actions and regulating turn-taking in both speech and behaviours [Kleinke, 1986]. As such, having pairs of children with autism who were playing a collaborative game together and increased their durations and frequencies of gazing at each other at different times as well as at the same time suggests that these children were more socially engaged with their partners.

Secondly, the fact that the children showed more displays of positive affect suggests that they enjoyed phase A_2 more than phase A_1. By itself, this would be worth noting because children with autism display positive affect in social settings less often than other children [Dawson et al., 1990]. The children also displayed positive affect more while looking at the other child playing with them, which is also interesting by itself because children with autism tend to direct displays of positive affect at other people less often than other children [Kasari et al., 1990]. However, considering that the children increased displays of positive affect, positive affect directed at the other child playing, simultaneous displays of positive affect, and gaze switches between the game and the other child, it is also possible that the children may have wanted to share their happiness or enjoyment with the other child playing with them more often. From our viewings of the experiment's footage, the children's behaviours and body language would support this claim. Finding an increase in displays of shared enjoyment between pairs of children with autism interacting together would be quite interesting because one of the hallmarks of autism is a deficiency in spontaneous displays of shared enjoyment [American Psychiatric Association, 1994].

Thirdly, the fact that the children directed more of their speech (combining urging, prompting, and general talking) at the other child playing with them shows that the children were more communicative with their partners in phase A_2 than in phase A_1. This alone would be quite interesting as children with autism tend to have impairments in social communication [American Psychiatric Association, 1994]. However, seeing as how the children also increased their gaze switches between the game and the other child playing in addition to the amount of mutual gaze between each other, it is possible that the children were making more efforts to actively coordinate their cooperative actions while playing together. This would have required children with autism to perform a number of potentially difficult social behaviours at the same time, such as having one or more parties visually focusing on each other at the same time and understanding another person's intentions or goals, and our viewing of the experimental footage would support this interpretation. This would be a very intriguing finding as it was one of the overarching aims of the experiment.

It is important to note that although the abovementioned behavioural increases were found between phases A_1 and A_2, none of the behaviours that we examined had any significant changes in duration or frequency between phases B_1 and B_2. This suggests that although there were certainly behavioural differences between successive different phases, the children's triadic interactions with KASPAR and another child in B_1 and B_2 were not significantly influenced by anything during the intervening dyadic phase with another child, A_2. Instead, only the children's behaviours during dyadic phases involving another child, A_1 and A_2, were significantly influenced by their interactions during the intervening triadic phase with KASPAR and another child B_1. Additionally, not every successive phase (one which chronologically followed after another) featured increases in a behaviour's duration or frequency when compared to an earlier phase; on the contrary, some behaviours showed decreases between certain successive phases, some behaviours showed decreases between some phases and increases between others, and some behaviours did not show any significant changes between different phases. This suggests that the changes observed in the behavioural data were due to changes in the children's play settings (dyadic with another child vs triadic with a robot and another child) instead of the children becoming increasingly familiar and/or skilled in playing the collaborative game. In short, these findings support the idea that the behavioural changes observed between the two dyadic phases of interaction, A_1 and A_2, were unique and due to the intervening triadic session B_1 involving KASPAR. Specifically, we believe that the children's improvements in social interaction, social communication, imitation, and collaboration through playing with KASPAR helped them to socially interact better and more frequently with other children. This would both contribute to the goal of this study as well as strongly support the secondary hypothesis of this thesis.

7.3.2 Interpretation of behavioural differences between dyadic and triadic sessions

There were also several behavioural trends that differentiated between the children playing dyadically with each other and triadically with each other as well KASPAR. Firstly, the children spent more time looking at the other child playing and KASPAR during the triadic sessions than they did just looking at the other child playing during the dyadic sessions. This is hardly surprising given the findings from previous research on assistive robotics for children with autism described in section 2.3, as well as the findings from chapter 6, all of which show that children with autism are fascinated by robots and will look at them for long periods of time. While this concept also holds true for this study, there is another possible reason for this finding which is unique to the children's interaction setting in this study. Earlier research either involved children with autism interacting with an adult who was meant to support and encourage each child's playful explorations with a robot [Robins et al., 2004c] [Robins et al., 2004d] [Robins et al., 2009] [Iacono et al., 2011], or two children exploring different forms of play together with a robot [Werry et al., 2001b] [Robins et al., 2009]. The robots in these earlier studies were the main focus points for the children, and the play that developed between the children and the robots was unstructured and exploratory. Therefore, although the robot helped to foster communication and interaction between the child and either the other child or the human adult, it is not surprising that the children spent most of their time looking at the robots in these studies. On the other hand, the play in this study was structured around a specific game and was meant to be explicitly collaborative between all of the players; everyone, including the robot, received a turn to pose in a specific way while the other players had to imitate the directing child's pose in order to receive a reward. This meant that each child had to check to make sure that they were posing the same as the other players, regardless of whose turn it was. As such, whenever a child played with KASPAR and another child, they had to spend more time looking at the other two players to make sure that everyone was posing identically than they did while playing with only one other child for the simple reason of having more players to check up on during the triadic sessions than during the dyadic sessions. This means that the difference in time spent gazing at the other players between the dyadic and triadic sessions was also influenced by the number of other players in each phase in addition to the children's fascination with robots.

Secondly, there were fewer shapes selected during the triadic sessions involving KASPAR and the children than there were during the dyadic session only involving the children, and there are a number of reasons for this. As we described in the preceding paragraph, some of the children in our study were fascinated by KASPAR to such an extent that they would look at him for longer periods than they would look at another person. During these periods of intense gaze, the children would stop paying attention to what anyone said, even when KASPAR itself spoke. The children could be made to refocus on playing the game by the carer calling out to them, but these periods of the children being "hypnotized" by KASPAR meant that the children took longer on average to select a shape. Additionally, even if some children were not "hypnotized" by KASPAR, some of them either had difficulties holding their arms steady or did not pose the way that they intended to while looking at KASPAR. In the first case, KASPAR could not understand which pose the children were trying to make if their arms were too unsteady, while in the second case it could understand the children's pose and mimic them, but the children would then realize that their own arms were not posed the way that they intended and would consequently have to reposition their arms while waiting for KASPAR to recognize their new pose. Naturally, both of these outcomes also contributed to more time being spent selecting a single shape and fewer shapes being selected overall. Even if none of the above scenarios occurred, the mere act of coordinating the same pose among the players often took longer with three players than it did with two because of the children's confusion or social misunderstandings. In short, all of these factors contributed to both more time being taken to select a single shape as well as fewer shapes selected overall during the triadic sessions than during the dyadic ones.

Thirdly, there were more promptings before a player chose a shape during the triadic sessions than during the dyadic ones, and there is a specific reason for this. Namely, KASPAR was programmed to first prompt the appropriate child if they hadn't already chosen a shape within 6 seconds of the start of the player's turn and held that pose steady for 2 seconds. Many of the children took more time than that to:

- realize that it was their turn,
- state or point to their choice of shape, and...
- hold that shape's pose for 2 seconds or more.

The carers were meant to take over for KASPAR's role during the dyadic sessions and had been instructed to prompt the appropriate child to choose a shape if the same amount of time had passed without the child making a selection, but many of the carers either gave the children slightly more time to choose or did not prompt the children when they hadn't yet chosen a shape because they knew that the children were about to choose by looking at their body language or hearing their speech. However, because KASPAR had no visual or audio sensors and could only determine that the children had chosen a shape by sensing that they were holding a valid pose for more than 2 seconds, the robot ended up prompting some of the children when they were on the verge of choosing a shape or were in the process of doing so.

Lastly, the data trends show that the children spent significantly more time engaged in mutual gaze with the other child, looking at the other players (human or robotic), and had significantly more instances of speaking while gazing at the other child during phases B_1 and B_2 than during phase A_1, but not A_2. Additionally, there were no significant differences in displays of social behaviours between phases B_1 and B_2. One possible explanation for this is that by interacting with KASPAR and another child during phase B_1, the children's improvements in the abovementioned social behaviours endured throughout the rest of the study regardless of who else they played with. While such an explanation would support the primary hypothesis of this thesis, it would be better supported if one of following two things were true:

- A_2 were also shown to have significantly fewer displays of social behaviours than both of the triadic phases, since this would then mean that displays of such social behaviour were significantly higher while playing triadically than while playing dyadically;

- another, similar study on collaborative play with autonomous robots were conducted which used a multiple baseline design and showed that regardless of the length of the first phase of dyadic play, all of the children with autism irreversibly improved their displays of certain social behaviours after their first phase of playing triadically with an autonomous robot.

7.3.3 Noteworthy anecdotal observations

In addition to significant behavioural trends, there were also a number of interesting situations in which their true significance was not properly captured by coding their behaviours. One such example took place while Cl and M played together with KASPAR in phase B_1. Throughout this play session, M had been playfully trying to convince others that it was his own turn to choose a shape even when the arrow on the screen was clearly pointing at someone else. During one of Cl's turns, after he had finally convinced M that it was not his turn, Cl tried to pose like a shape on the screen but KASPAR never recognized this because his pose was not as steady as it should have been. KASPAR finally realized that Cl was posing steadily and validly when the child held his arm downward to keep it from getting too tired, and the robot then urged M to pose in such a way even though Cl was not trying to "choose" such a

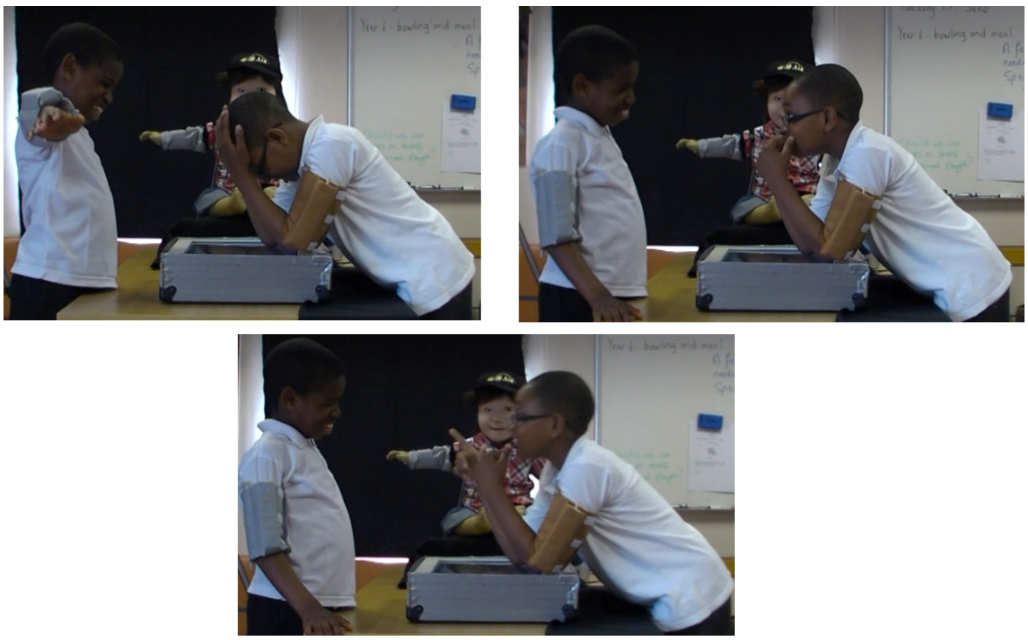


Figure 7.14: **Top left:** Cl is feeling exasperated because of recent events and puts his face in his hands while M is mischievously amused at the situation. **Top right:** Cl glares at M in an unbelieving manner, while M is still very amused as he looks at Cl. **Bottom middle:** Cl admonishes M to play properly and points his finger as a warning while M still finds the whole situation to be hilarious.

pose. Cl then put his head in his hands out of exasperation, glared at M (who seemed particularly amused by Cl's reaction), and then Cl admonished the other child to play correctly in a warning manner while pointing at them (see figure 7.14). This situation was particularly interesting, as Cl rarely spoke to the other player while pointing at them, much less displayed exasperation in such a clearly-understood way without being overly emotional. Additionally, the expressions of both children throughout this exchange imply that they were reacting to and feeding off of each other's emotions. If this is true, then it was an unusually impressive display of social understanding for both children when one also considers their diagnoses of autism and subsequent social impairments; whenever the children had differing emotional reactions at other points in time, the differences were typically due to developments in the game instead of the other player's emotional responses.

Figure 7.15: H, on the left, appears to be tired and sits on a nearby couch while C, on the right, eagerly tells H to continue playing through addressing him by name.

Another example of an interesting development was when C and H played together in phase A_1. In this session, H was not as eager to play as he typically was and seemed to want to stop playing earlier than usual (his teacher later explained that he was eager to attend a cooking class that was meant to start either during his session or shortly afterward). At one point, H seemed tired and sat down on the couch nearest to him which made the carer suggest that he continue playing. C seconded this opinion by happily saying “Come on, H”, which was interesting for a number of reasons (see figure 7.15). Firstly, although C said “Come on” in a number of different situations, he hardly ever addressed anyone by name while doing so. Moreover, he rarely called someone else by name without someone else first saying the other child’s name. In this case, however, C addressed H by name without copying anyone else’s use of the name. Secondly, C was known to be sullen as well as reluctant to play at the starts of sessions during the latter half of the experiment. As such, having him happily suggest to another child that they continue playing and addressing the child by name was a particularly interesting event for C when viewed in hindsight.

Figure 7.16: M, on the right, points at T, on the left, and prompts her to choose a shape.

Yet another interesting observation concerns the way the children understood how to play "Copycat" with three players. While playing with two players proved to be fairly straightforward to the children, in the sense that each player mirrored the poses of both the stick figures on the flatbed screen and the actions of the other child standing directly across from them, playing with three players (Kaspar being one of them) resulted in slightly different play circumstances. Firstly, because the three players formed a sort of ring or triangle around the flatbed screen and Kaspar stood diagonally aside from each child instead of directly across from either one, the children now had to imagine rotating Kaspar by 90 degrees in order to understand how to mirror the robot's pose. Secondly, because only one arm was used to play "Copycat" and because of Kaspar's unique positioning in the 3-player scenario, only one child could think of themselves as mirroring Kaspar's pose if they faced the robot head-on, while the other child had to think of themselves as performing the opposite pose of Kaspar if they faced the robot head-on. One would think that these issues would present difficulties for any two children playing "Copycat" with three players, but the children in this experiment seemed to grasp these concepts relatively quickly. Only three of the children seemed confused about which arm to use for poses (T, C, and M) while playing triadically with other players in phase B_1, and these children only showed difficulties in posing correctly and required someone to correct them at the beginnings of each of their first two sessions of triadic play; in fact, in two instances in which a child expressed confusion over which arm to use for posing, the other child with autism helped correct the confused child instead of the carer doing the correcting! Because most of the children were not initially confused by the new configuration of players in triadic play sessions and all of the children quickly learned how to play properly with three players, this suggests that playing in phases A_1 and T helped most of the children with autism learn the rules of "Copycat" in terms of the poses of the stick-figures on the flatbed screen, instead of merely in terms of the players' orientations with each other in a room. This is particularly noteworthy, as children with autism are known to have difficulties with both transferring skills from one set of circumstances to another as well as coping with changes to a known routine.

A final interesting example occurred while M and T played together during phase A_2. At one point during this session, it was T's turn to direct the other players and she did not seem to be looking at the game, much less on the verge of choosing a specific pose, so M prompted T to choose a shape by saying that it was her turn and pointing at her (see figure 7.16). Although this might not sound remarkable, this is interesting for a number of reasons because of M's history of behaviour. Firstly, M was a particularly passive player and rarely prompted any other player to choose a shape of his own free will - in fact, M only prompted 3 separate times during the course of the whole experiment. Moreover, much of M's speech was comprised of him repeating what someone else had recently said in an echolalic manner. As such, the fact that M prompted someone else at all is an interesting phenomenon. Secondly, M would occasionally point at shapes on the screen but never pointed at any other person, so the fact that he pointed while he prompted someone else to choose is particularly noteworthy. In short, this incident was an especially active and communicative moment for M.

7.4 Summary

This chapter presents our findings from a study in which pairs of children with autism alternated between playing sets of an imitative, collaborative video game dyadically with each other as well as triadically with each other and an autonomous humanoid robot, KASPAR, in an *ABA* setting. The results from the study suggest that the children performed many activities more often during the second phase of playing dyadically with another child than during their first phase of doing so, such as paying more attention to the other child playing with them, being more socially engaged with the other child, showing more enjoyment, trying to share their enjoyment more often with the other child, being more communicative, and trying more often to verbally coordinate their cooperative actions with the other child playing. Because these trends appear most apparently between the two dyadic phases, are occasionally reversed or not as significant when compared to the triadic phases, and were neither constant nor continuing in the same upward direction over the course of the many sessions of this study, this suggests that these improvements are due to the children's intervening phase of playing triadically with KASPAR instead of them becoming more familiar with their partners and the game's mechanics over time. This finding both strongly contributes to the study's main goal of using objective measurements to determine whether the social interactions between a pair of children with autism who played an imitative, collaborative game would change after the pair triadically collaborated with a humanoid robot in the same context. This also seems to affirmatively answer the secondary question of the thesis, which is whether the social skills that children with autism improved by collaboratively playing with an autonomous robot can transfer to another setting without robots.

In contrast, there were no significant differences when comparing how the children played between their first and second phases of playing triadically with KASPAR. Because each child participated in a familiarizing phase involving them playing dyadically with KASPAR before playing triadically with KASPAR and another child, this would indicate that the lack of changes in the children's social behaviours between the first and second phases of triadic play are not due to the novelty effect of playing and interacting with an autonomous robot.

Additionally, the children spent more time looking at the other players, selected fewer shapes, and were more likely to be prompted before choosing a shape during the triadic play sessions than the dyadic ones. While the first two changes are likely due to the increase of play partners, the last distinction between the play phases is probably due to KASPAR's specific behaviours and sensing modalities.

Chapter 8

Conclusions and future work

8.1 Limitations

This thesis covered a number of different issues related to autonomous robots promoting collaboration among children with autism. Although each of the experiments described within addressed this topic in different ways and yielded interesting results, the experiments also contained a number of limitations which are described below.

8.1.1 Number of participants

Although each of the experiments were able to yield very compelling findings, they all suffered from having very few participants; the first experiment involved seven children and both the second and third experiments each involved only six. While the validity and statistical significance of any study's findings can be improved by drawing upon a larger pool of participants, this is especially true when dealing with children diagnosed with autism, as any group of such children will tend to have a wide range in the types of diagnoses (e.g. classic autism disorder, Asperger's syndrome, PDD-NOS) as well as their severities (e.g. low functioning, high functioning), with each child exhibiting a very specific set of autistic behaviours and symptoms with highly idiosyncratic manifestations. This has given rise to a common saying in the autism community which was first said by Dr. Stephen Shore: "If you've met one person with autism, you've met one person with autism" [usa, 2012]. As such, if my experiments had a larger group of participants, this would have resulted in better applicability of our findings due to both a wider variety of representations of autism as well as greater statistical significance of our results.

8.1.2 Duration of experiments

While each of my experiments involved multiple sessions for each participant and were conducted over extended periods of time, they could have involved many more sessions over even longer periods of time; my longest study consisted of 23 sessions for each child and was conducted over a period of 10 weeks. This is because one the one hand, it is particularly difficult to develop research-grade robotic technology that is sufficiently bug-free and suitably designed for long-term usage; on the other hand, the scheduling and logistics involved in organizing and running a long-term experiment are quite formidable. This is unfortunate, as the nature of autism is such that children diagnosed with it require much more time and training than usual to understand and master skills of social interaction and social communication. Therefore, in order to demonstrate that a specific robotic technology can truly help children with autism instead of merely showing that the developed technology works or is well-received by the autism community, one must conduct long term studies involving many sessions for each participant. By doing so, one can determine whether the technology can produce enduring changes in the children's behaviour, whether children can grow to excessively depend on it and what the consequences of that would be, the true shape of children's learning curves when using the technology, and whether the technology can still be useful despite the many issues that can affect the disposition of a child with autism over a long period of time. As such, if my experiments had been conducted over longer periods of time and with more sessions for each participant, this would have resulted in richer data and more helpful suggestions on future designs of our robotic technologies.

8.1.3 Experimental design considerations

Despite the fact that our experiments yielded useful data, our findings could have benefitted from slight changes to the experiment design methodologies that we used. Specifically, because our first experiment was a description of a robotics class and the second and third experiments used reversal designs to determine whether interacting with a robot would affect children's later interactions with people, none of our experiments compared their results against those of control groups of children with autism who did not interact with robots. Specifically, our first study could have benefitted from an additional group of children with autism who participated in a group-based after school club focused on something other than robots, such as constructing buildings out of LEGOs, to determine whether specifically interacting with robots affected the children's social behaviours, as well as an additional group of children who did not attend any after-school clubs at all to determine whether interacting with robots in a group-based setting affected the children's social behaviours more than inactivity or solitary play. Similarly, our second and third studies could have also found more interesting results by utilizing two additional groups of children with autism, one of whom who only played our collaborative video games with other people instead of KASPAR, and another who neither played our collaborative games nor interacted with KASPAR. By comparing our results from the original group of children with those of the children who only played the collaborative video games, we could determine whether interacting with an autonomous robot in a collaborative play setting produced different behaviours in children with autism than merely collaborating with other people in a collaborative play setting; furthermore, comparing the results from the original group of children with a control group could show whether interacting with an autonomous humanoid robot in the context of playing a collaborative video game produced different behaviours in children than inactivity. Most importantly, using control groups in any of our experiments would also require different criteria for observable behaviour. While we observed the behaviours of children only in the controllable contexts of our experiments and operated under the logic that the children's displays of specific social behaviours during our studies were indicative of more generalizeable social trends, the use of control groups requires taking measurements and observing behaviours that can be found in any sort of context. Furthermore, using control groups would require us to ensure that the two groups in each experiment were matched with respect to many different criteria, such as autism diagnoses, mental ages, and communicative capabilities. Therefore, in order for our experiments to gather comparable results from all of the different groups, we would need to collaborate with a psychologist who specialized in autism to administer clinically-approved autism behavioural tests to all children before, during, and after the experiments; examples of such tests include ADOS (autism diagnostic observation schedule), SRS (social responsiveness scale), and GARS2 (Gilliam autism rating scale, 2nd edition). Furthermore, we would need to redesign our experiments or implement new behaviour testing phases in order to analyze social behaviours that the children could exhibit regardless of whether they interacted with a robot or participated in a collaborative, group-based setting.

Although a reversal design attempts to overcome the limitation of not having a separate control group by using each participant as their own control and comparing findings from their baseline phases with those of the intervention phases, the members of an ideal control group are never meant to receive any intervention or treatment at all. Instead, the role of such a group is to help determine whether the results from another experimental group are uniquely due to their specific form of intervention or are reproducible without any intervention at all. Unfortunately, because the participants assigned to a control group need to be just as representative of their source population as the participants in the other experimental group(s), this would require having a very large group of total participants due to the naturally heterogeneous and diverse nature of people diagnosed with autism. As we previously discussed, this was infeasible for all of our studies due to the small number of participants in each experiment.

Additionally, because each of our experiments used a single group assigned to a single experimental treatment (i.e. method of interacting with a robot), we had no other experimental groups against which we could have compared our findings; although it seemed otherwise, our third experiment's use of a training phase involving a child interacting with KASPAR directly before a phase of triadic interactions involving two children with autism and KASPAR did not actually overcome this limitation. This is because our results could have been confounded by the order in which the children experienced the different interactions or the different durations / number of sessions in each phase. Similarly, we could not directly compare any of our experiments' results with those from another experiment that used a different treatment method (i.e. form of robot interaction) on their experimental group(s) because the studies' different conditions, populations, and design methods would have rendered such comparisons invalid. If we had instead used multiple experimental groups with different treatments, we would have been able to validly compare the results of one experimental treatment against another, thereby determining whether some methods of robot interaction would help better than others or whether one method would be better suited to children with specific diagnoses of autism. Like the use of a control group, however, using many different experimental groups would also require a large group of total participants for the same reasons which were described in the preceding paragraph. As such, future experiments could yield richer, more valid data if they used a larger group of participants and slightly different experimental designs than we did.

Although our experiments had many commonalities ranging from aims to means of observation, the first experiment had a distinctly more complex and open-ended approach than the simplified and structured second and third experiments. This is primarily because the first experiment was the result of capitalizing on a teacher's request for a robotics demonstration/information session for an parent-organized group of children with autism which met after school hours, while the second and third experiments were the end products of brainstorming, background research, focus meetings with advisors, and extensive planning. Although the progression of experimental designs from a free-form beginning to a more organized end result suggests a clear demonstration of learning about scientific methodology and provided an education on a variety of methods for data analysis, it is possible that a more focused first experiment could have resulted in initial results that were more interpretable, as well as a more profound overall understanding of the subject matter. Similar comments can be made for the increasingly removed role of the investigator in this thesis's three experiments. In this case, the transition from the first experiment's usage of the investigator as involved educator of the children and hands-on mediator of the robotics club to the third experiment's presentation of the investigator as background organizer and behind-the-scenes observer suggests a growing understanding of the psychological influence of a researcher's presence on the behaviour of an experiment's participants as well as a change of scientific perspective from "researcher as therapist" to "researcher as unseen observer". While this exposure to many different scientific perspectives has given us a better appreciation for various methodological approaches, perhaps the experiments in this thesis would be more repeatable and the results more easily replicated if all of the studies featured the researcher in the role of a removed and invisible observer.

Autism is a spectrum disorder, and while we were not always able to obtain written evidence about our participants' specific diagnoses, the children for whom we did have documentation were diagnosed with many different forms of it; while some had high-functioning forms of autism such as Asperger's syndrome, other children were diagnosed with more moderate forms of the disorder and had more pronounced social impairments. Because our experiments featured small groups of participants and because the participants' diagnoses were so heterogeneous (when they were known at all), despite the impressiveness and significance of our findings, they were not specific enough to focus on the robot's effects on children with particular autism diagnoses. To do this, we would have needed to accomplish one of two difficult feats; we would have needed either to obtain a much larger group of participants for each experiment and a current diagnosis for each child in order to draw conclusions about the impacts of the robot's behaviours on children with specific diagnoses of autism, or we would have needed to cherry pick a comparably-sized group of children with one specific diagnosis of autism from a much larger pool. While such specificity could have helped reveal specific insights about autism as a disorder and increased the validity and significance of our findings, the generality of our findings is also a good thing; because our experiments produced such interesting social behaviours from the children regardless of their autism diagnoses and despite the uniqueness of every child with autism, this might suggest that our findings are more likely to be repeatable and generalizeable among children with a variety of autism diagnoses. The heterogeneity of our participants and our lack of information about some of our participants' diagnoses is attributable to many factors, such as the challenge of finding a psychologist specializing in autism who has been trained in administering autism diagnostic tests and is willing to collaborate, the difficulty of finding large groups of children with autism who are ready and willing to participate in scientific studies, the amount of labour and organizational expertise required to design long-term experiments around the shifting schedules of large numbers of children, and many others. In short, although the fact that our participants had a wide variety of autism diagnoses means that although we could not compare the ways that our robot affected children with specific diagnoses of autism, it also suggests that our experimental findings could be generalized to children with many different severities and diagnoses of autism.

8.1.4 Sensory limitations of robots

Although the robots used in our experiments were equipped with hardware and software that allowed them to sense different aspects of their environments, they could have been given better sensing capabilities. Firstly, each LEGO NXT robot used in our first experiment had the sensory ability to avoid obstacles, turn more accurately, grab onto objects, and sense when they passed over differently-coloured sections of the floor. However, because they did not have the sensory capability to actively seek out and track objects, the children had to interfere with the robot's environments in clever ways (i.e. putting white pieces of paper in the robot's path) in order to direct the robots towards specific objects or locations. If each robot had been equipped with a low resolution colour camera with blob-tracking capability, they would have been able to automatically locate and track many different kinds of object without as much need for the children to intervene. This would have made the robots seem even more autonomous to the children and could have made their interactions even more fun. Although such a camera was not widely available at the time of our first experiment, its use should be included in any later studies that involve NXT robots and children with autism.

Secondly, both versions of KASPAR the robot received each Wiimote's angle tilt data and used this to infer what the children wanted to do in the context of each collaborative game. Furthermore, whenever KASPAR spoke to a child, the robot turned its head to a specific pre-programmed angle calculated according to where each child should have been during each experiment. However, the footage from each experiment showed us there were numerous occasions where the children tried other means to choose shapes (i.e. speaking, pointing, tapping) despite KASPAR's lack of response to their choices, and if the children moved too much from their specified locations, KASPAR would appear to speak to empty space. If KASPAR also received 3D point cloud data describing the children's locations from a Microsoft Kinect motion sensing device, face-tracking and face-identifying data from KAS-

PAR's eye-based cameras or a high-resolution camera mounted on his hat, voice data from microphones on the children's shirts, and/or 2D tactile data from the display screen's touch-sensitive surface, then the robot could have been much more interactive and responsive to the children. Specifically, it could have turned to look directly at each child and focused on their face while speaking to them as well as better understood when the children selected a shape by detecting their vocalizations and inferring which shape they tapped on the touchscreen. However, Kinect motion sensing devices were not available and touch-screens were not widely available at the time of either the second or third experiments. Furthermore, so much time was devoted to testing, programming, and debugging the collaborative games as well as KASPAR's behaviours and interactive protocols that no time was left over to implement either face-tracking algorithms or speech detecting software, as both of these sensing modalities would have required extensive programming and tweaking to work in our experiments' noisy environments. However, similar or better technologies should be included in later studies involving KASPAR and children with autism.

8.2 Review of research questions

This thesis dealt with how autonomous robots can help children with autism to play more collaboratively with each other. Because it has drawn inspiration from many different areas of research, it has contributed to such diverse fields as human-robot interaction, robot-assisted play, assistive robotics, and autism research. In doing so, this thesis has addressed its two fundamental questions, which were described in section 1.2, slightly differently in each experiment.

8.2.1 Collaborative play with autonomous robots promotes social interaction among children with autism

Question 1: Will interacting with an autonomous robot in structured, explicitly collaborative play sessions promote social interaction and social engagement among children with autism?

This question was addressed in slightly different ways in each experiment. In my first experiment involving an after-school robotics club for children with autism, the participants worked together in groups and rotated though different roles of play in order to program LEGO NXT robots and make them autonomously perform different functions during each session. We could not compare the children's behaviours while they interacted with each other to their interactions which involved other children and LEGO robots because this study did not gather data on the children's behaviours before they participated in the robotics club. However, we were able to examine their behaviour during every session of the club. By observing and coding the video footage from the experiments and comparing it with results from questionnaires that the children filled out after each session, we found that the amount of enjoyment that the children reported during a given session mattered more with respect to displays of collaborative behaviour than did the chronological ordering of a given session. Specifically, the children had more instances of robot-related speech, more pointing behaviours, more shared displays of positive affect, and higher average rates of robot-related speech per minute during the children's most fun sessions than during their least fun ones. In contrast, the children only showed a higher average rate of robot-related speech per minute when comparing their last sessions to their first ones. Furthermore, we discovered a positive correlation with an coefficient value of $r=0.81$ between the number of times that the children talked about robots and the proportion of the session that the children spent close to their partners while looking at the same object.

The results from my second experiment also answered this question in a similar way. This study had children with autism alternate between playing a dyadic collaborative video game with a typically-developed adult and playing the same game with an autonomous humanoid robot KASPAR until they had played with each partner twice. In this study, the children looked at the other player more and switched their gaze between the game and the other player more often while playing with KASPAR than they did while playing with the adult. Furthermore, the children also spent more time looking at KASPAR while displaying positive affect than they did looking at the adult and displaying positive affect. Although the children selected fewer shapes and took the initiative less often while playing with KASPAR than while playing with the adult, we believe that this is because the children were so fascinated by looking at KASPAR that they did not respond to other people's speech as often. Furthermore, KASPAR's programming only allowed it to determine whether a child chose a shape when the child moved an in-game cursor; it could not hear the children speaking or see when they tapped or pointed at the screen. In any case, because gazing and displaying positive affect at the individual with whom one is interacting are behaviours that children with autism typically have difficulties displaying in social settings, the fact that these behaviours were displayed more often with KASPAR supports the abovementioend hypothesis. Specifically, it suggests that the children were more socially engaged, if not more collaborative, while playing with the robot.

My third experiment's findings were also supportive of an affirmative answer to this research question. In this study, pairs of children with autism switched between phases, which were comprised of repeated sessions, of playing a collaborative imitative game dyadically with each other and playing it triadically with KASPAR. The results showed that the children spent more time engaged in mutual gaze during both sessions of playing triadically with KASPAR than during the first phase of playing dyadically with each other (but not both phases of dyadic play), and the children also each spent more time looking at the other players while playing triadically with KASPAR than while playing dyadically with each other. Furthermore, the children had more instances of speaking while gazing at the other child during both of their triadic play phases with KASPAR than during their first dyadic play phase (but not both phases of dyadic play). Like the second experiment, this experiment also featured a trend in which the children both selected fewer shapes and selected fewer shapes without having to be prompted while playing triadically with KASPAR than while playing dyadically; we believe that part of the issue is still KASPAR's programming, but also due to the fact that playing collaboratively with three players requires more coordination and organization than only playing with two. This study supports the abovementioned hypothesis in that the phases which involved triadic play with KASPAR featured children that were more socially engaged and socially communicative with each other than they were during their first phase of playing dyadically with each other, if not both phases of dyadic play. This suggests that the children might have improved some forms of social interaction from imitatively playing with KASPAR and that these improvements stayed with the children for the remainder of the experiment, but this would have to be backed up either with significant improvements in both phases of triadic play compared to both phases of dyadic play, or with another study involving a multiple baseline design which showed a similarly irreversible improvement in certain social behaviours after the children first interacted with an autonomous robot.

8.2.2 Social skills that children with autism learned from cooperative play with autonomous robts can be generalized

Question 2: Will the social interaction skills that children with autism have learned by playing collaboratively with an autonomous robot transfer over to the children's subsequent collaborative play sessions, which are only with other people?

This question was also addressed slightly differently in each experiment. The first experiment involving a collaborative robotics club also featured three separate free-form drawing sessions which immediately preceded the robotics club's usual activities and were evenly spaced throughout the experiment. These drawing sessions required the children to collaborate as much or as little as they wanted but did not feature structured play or robots that the children could play with. Furthermore, we also conducted semi-structured interviews with the children's parents to determine whether the children's behaviour had changed outside of the robotics class. In order to determine how well the children's social skills, which they were meant to learn during the robotics club's normal activities, transferred over into robot-free settings, we compared the parents' accounts of their children's behaviour outside of the club and the children's social behaviours during the club's drawing sessions to their behaviours during the robotics classes. From reading over the interviews, we found that most of the parents said that their children were able to use social techniques that they learned from the robotics clubs in other settings such as classrooms, family outings, and general conversations. By analyzing the children's behaviours during the drawing sessions, we found a marginally significant increase between the first and last drawing sessions in the amount of time that the children spent engaged in cooperative play, associative play, or exhibiting onlooker behaviour. In short, the data from this experiment would seem to support the second hypothesis, inasmuch as the data suggests that some of the children were able to transfer the social skills that they learned by interacting with robots into other social settings which only involved other people and which also had fewer rules. However, it is difficult to make this claim because we did not have any data regarding the children's social behaviours in robot-free settings from before they interacted with NXT robots in the robotics club.

The second experiment involved children with autism alternating between playing a dyadic collaborative video game with a typically developed adult and playing the same game with an autonomous version of KASPAR the humanoid robot. By comparing the first and second times that the children played with adults, we determined whether the children transferred the social skills that they learned from interacting with a robot into another interactive setting which did not feature robots. We could do this because when the children first played with an adult in the context of this experiment, they had never interacted with a robot before. However, the second time that the children played with an adult in this experiment immediately followed their first interaction with a robot. As such, if the children learned something from this robot interaction session and transferred these skills into the subsequent interactions which involved an adult, then this second adult interaction session would be significantly different from the first adult interaction session. When we examined all of the children's behaviours in the two sessions, we found that the children displayed positive affect for a significantly greater proportion of time, took the initiative in choosing shapes significantly more often, and selected significantly more shapes during their second time interacting with the adult than during their first. These are significant findings because successfully selecting shapes requires both coordination and collaborative work, and displaying positive affect in a public setting is something that children with autism do not do frequently. Although it is likely that these changes indicated that the children were able to generalize the social skills that they learned through interacting with KASPAR the robot into another setting that did not involve robots, it is also possible that such changes were either due to the novelty effect of the children playing a collaborative video game during school hours or their gradually increasing familiarity for playing with the adult.

The third experiment involved pairs of children with autism switching between repeated sessions of playing an imitative collaborative game dyadically with each other and repeatedly playing the same game triadically with each other as well as KASPAR the humanoid robot. In this setting, we inferred whether the children were transferring social skills that they originally learned from interacting with a robot into a child-only social setting by comparing the first phase of the children dyadically playing the collaborative game together with their second phase of doing so. We were able to do this because in addition to the children not playing with a robot in the past year before their first phase of dyadically playing with another child, the second phase of children dyadically playing together immediately followed a triadic phase of pairs of children playing with KASPAR. Therefore, if the two phases of dyadic play had significant differences between them, this would probably be due to the intervening session of triadic play involving the children playing with a robot. When we compared the children's behaviours in the two phases of dyadic play, we found that there were many significant differences between them. By grouping different behavioural trends together, we inferred that the children were more socially engaged with each other (increased gaze at other child, increase gaze switching between game and other child, increases in duration and frequency of children looking at each other at the same time), displayed their enjoyment more and tried to share their enjoyment more often with the other child (increased frequency of positive affect, increased frequency of positive affect directed at other child, increased simultaneous displays of positive affect of both children, increased gaze swtiching between game and other child), and made more efforts to actively coordinate their cooperative actions (increased speech directed at other child, increased gaze switches between game and other child, increases in duration and frequency of children looking at each other at the same time). These are all very interesting behavioural changes for children with autism and were likely due to the intervening triadic phase of playing with KASPAR. Furthermore, because each phase contained five sessions of play for each child, it is unlikely that these trends were due to the novelty effect of playing a new collaborative video game during school hours.

8.3 Speculation

In the course of conducting all of the work associated with this thesis and discussing the findings from it with others, one cannot help but reflect on unresolved issues in their field of study and consider other explanations for trends in their data. As such, below are some alternative interpretations of the data contained in this thesis and musings on what issues have yet to be addressed in social robotics as applied to children with autism.

8.3.1 Different meanings of experimental data

In our first experiment involving the group-based after school robotics class affiliated with the after-school autism group known as SNAAP, our findings indicated that the children in the class increased their displays of social behaviours while they interacted with robots over an extended period of time. We found that incrases in the children's social behaviours were marginally correlated to the number of sessions that they cumulatively spent interacting with the other children, and attritubted this to the children becoming more familiarized with each other in the presence of the robots. However, it is also possible that our findings were largely due to a selection/sampling bias caused by drawing participants for our experiments from the after-school group SNAAP, to say nothing of our experiment's sampling bias in only analyzing data from children who attended many sessions of the robotics club; because the children voluntarily attended SNAAP, which is a social group for children with autism, it is possible that the children participating in our study either were already naturally familiar with and interested in being social around other children (particularly while playing with robots), or they have parents who contantly urged them to be more social. If the children were already naturally interested in being social, then the robotics club simply gave them a venue to interact with others who were also interested in similar topics, which means that increased socializiation was both naturally easier and inevitable for these children. On the other hand, if the children had parents who were always urging them to be more social, it is possible that the parents's urgings became particularly intense when they heard about the robotics club and became increasingly so during the course of our experiment. However, the fact that our latter two studies found similar results suggests that this alternative explanation of our data's trends is not mutually exclusive to our original explanation.

Our second and third experiments found that in the context of playing a collaborative video game, children with autism displayed more social behaviours with other people after they played and interacted with an autonomous robot, with the third experiment using repeated measures to confirm the results of the second one. While these findings are quite impressive and seem to answer the second question of this thesis (see section 1.2), it is possible that these findings are not due to the children with autism learning about social interaction from playing with the humanoid robot. Instead, it is possible that these findings are due to the children becoming increasingly familiarized with their human partners over the course of the experiments. If this alternative explanation were true, we would see similar increases in the chidlren's displays of social behaviour regardless of whether they interacted with a humanoid robot. It is doubtful that this is the case, since all of the previous research on social robotics as applied to children with autism would indicate that robots are able to elicit uniquely engaged responses from children with autism that few people can match. Still, in order to rule out such a possibility, our second and third experiment would have to be duplicated using a separate group of children with autism to act as a control and never interacted with robots during the course of the experiment.

8.3.2 Open issues

Although our research has yielded very interesting results and helped to explain many different topics, there remain a number of open-ended issues in social robotics as applied to children with autism that can still be argued either way. One such issue concerns the evolving use of robots to help children with autism and what the role of these robots will become in the future. Specifically, some people are concerned that robots should remain as tools and social mediators for the children instead of the robot becoming a replacement for the child's interactions with people. Such people feel that with our research focusing on the ways that repeatable, predictable robots with easily-understood gestures and facial expressions can help to improve social behaviours of children with autism, there is a danger that some children will only want to interact with artificial humanoids instead of real people due to the ease of doing so. The AuRoRA project and this researcher have always been quite clear on our stances that robots should always remain as social tools / mediators for children with autism and should never become replacements for interacting with other people; it is counterproductive for a child with autism to interact only with nonliving objects since that would result in their social skills and social behaviours can become increasingly abnormal and impaired, thus removing any chance for them to live fulfilling, healthy, and independent lives. However, it is likely that future researchers will still have to explain this ethical viewpoint in order to continue to ameliorate this fear.

Another open issue concerns the robotic appearances that will best benefit children with autism. Specifically, while much has been learned about how children with autism react to different robotic appearances [Michaud and Théberge-Turmel, 2002] [Robins et al., 2004c] [Iacono et al., 2011] and a few have research different robotic behaviours , such research is rarely conducted because of the cost, difficulty, and specialized skill that goes into making robots with drastically different appearances. This is also why many research labs tend to conduct experiments using the robotic platforms that they have on hand, either through purchasing them from third-party vendors or by developing and improving on one particular design over the course of many years. Although the research contained in this thesis found better results when children with autism interacted with the humanoid robot KASPAR than when they interacted with LEGO robots, this has more to do with the different experimental approaches and designs used in the studies than with anything related to the robots. Instead, meta-analyses and extensive reviews need to be conducted on many different research studies to compare and contrast the many different robot designs and determine which apppearances elicit which reactions.

8.4 Future work

In addition to my experimental results supporting my main research hypotheses, they also suggest interesting new directions for future research. Some of these would investigate claims from my work more deeply while some would explore new research areas that were hinted at in my findings, but all of them would draw inspiration from the systems and methods described in this thesis.

8.4.1 Research inspired by playing a collaborative video game with a humanoid robot

Before any research topics inspired by the findings from my second and third experiments can be discussed, it is important to first discuss the methods of data collection for such research. Although manually coded video footage from experiments can yield rich data which tracks the progress of participants at a very find scale, coding videos by hand takes a great deal of time. As such, I suggest that any research which will be inspired by my findings and which will use similar means of data collection should use automatic means of coding behaviours. Specifically, instead of manually coding the children's gaze as they gather around a table to play a game, one could use table-mounted cameras and aim each one upward at a child's face (the camera would actually be aimed where the child's face would typically be located) to infer and code each child's gaze direction as described in the work by Ravindra et al. [2009]. Furthermore, the video feeds from these same cameras could also be used in combination with modern face-detection software to automatically code displays of positive affect such as smiling and laughter. While pinning microphones to the participants' shirts and feeding the microphone audio into speech transcription software would be useful for experiments involving typically developed participants, this would not be a viable strategy when dealing with children with autism due to the likelihood of their social communication impairments affecting the clarity of their speech. As such, although speech would probably still need to be coded by hand, the fact that this would be the only manually coded behaviour would drastically cut down the time required to code up a given video.

Additionally, studies involving robots playing video games with children with autism could still be interesting because the experimental results described in sections 6.3 and 7.3 have shown that interacting with an autonomous robot can still help children with autism to interact better with other people even if the robot's control architecture is specifically geared towards playing a game and interacting with players in simple ways. A video game could still be used as the collaborative medium because they allow a designer to use interprocess communication between the game's processes and the robot's control processes to always give a robot a perfectly noise-free and error-free model of the game's state. This also frees up a designer to devote all of the robot's improved sensing capabilities into interacting with the participants.

Comparing different forms of collaboration

The video games described in sections 4.2 and 4.3 each involved different forms of collaborative play - while “Tilt and roll” required each player to perform an action specific to them at the same time to play the game, “Copycat” required all of the players to perform the same actions at the same time to play the game. A future study could break collaboration down into its distinct components (homogeneous vs heterogeneous actions and simultaneous vs separate timing) in order to determine whether a certain form of collaboration either worked best for improving social behaviour among all children with autism or whether different forms of collaboration worked best for children with different diagnoses of autism. As such, this study would have pairs of children with autism alternate between playing with each other dyadically and playing with an autonomous robot triadically, but the collaborative nature of the games that the children would play would be different for each group: one would have to take turns jointly doing a pose and holding it at the same time to continue playing together, another would have to take turns jointly doing a pose but not necessarily holding it at the same time to continue playing together, another would have to take turns jointly doing different poses and holding them at the same time to continue playing together, another would have to take turns jointly doing different poses but not necessarily holding them at the same time to continue playing together, and another would serve as a control by not having the children or robot play together at all. Instead, this control group could do whichever valid poses they wanted whenever they wanted, and their ability to continue playing would not be tied to the actions of the other players. By comparing the different groups' forms of progress throughout the experiment, one could determine whether a certain from of collaborative play with a robot was best for facilitating social behaviour among children with autism, or whether the children with autism could improve their social behaviours by playing associatively at their own speeds and sharing the same gamespace with a humanoid robot.

Comparing different forms of group play with robots

Chapters 6 and 7 each involved different forms of group play - the experiment described in chapter 6 compared different forms of dyadic play involving a child with autism and either an adult or a robot, while the experiment described in chapter 7 compared pairs of children with autism either playing dyadically or playing triadically with a robot. Although some studies on assistive robots for children with autism have focused on dyadic play while others have focsed on triadic play, no study has compared the different forms of robot-assisted play with each other. As such, a future study could involve three different groups which would all start in a phase where pairs of children with autism dyadically played a collaborative video game together. Two groups would then alternate between phases of previously-described dyadic play involving two children with autism and phases of another form of play; one group would switch to a different form of dyadic collaborative play and have each child with autism play collaboratively with a robot, and another grouup would switch to triadic play involving pairs of children with autism playing collaboratively with a robot. The third group would act as control and not alternate between styles of play at all; instead, this control group would repeat phases of pairs of children with autism playing dyadically. By comparing the different groups' forms of progress, one could determine whether dyadic play with a robot or triadic play with a robot was better for promoting social behaviour among children with autism.

Comparing different forms of robotic interaction

In the experiment described in chapter 7, KASPAR was programmed to speak to the children and occasionally use gestures to express himself in order to make himself as interesting and interactive as possible. Additionally, KASPAR could understand the ways that the children posed with one of their arms, but it had neither microphones nor speech processing software in order to "hear" what the children said. In contrast, the remotely-operated humanoid robots used in the earlier work in the

AuRoRA project were mute and, when they were not being remotely operated by other children, only interacted with children by mimicking their gestures [Robins et al., 2004a] [Robins et al., 2005] [Robins and Dautenhahn, 2006] [Robins et al., 2009]. As such, an interesting future study could examine whether the modalities through which an autonomous robot interacts with children with autism would affect the children's subsequent behaviours with other people. Such a study would have a similar setup as the experiment described in chapter 7, but would involve four groups of children with autism. Each group of children would alternate between a dyadic phase of a pair of children with autism repeatedly playing with each other and a triadic phase of two children repeatedly playing with each other and KASPAR, but each group would interact with KASPAR in slightly different ways. In one of the groups, KASPAR would speak to the children, turn to face them, and would understand certain key words of speech which would be the way the children would be told to choose shapes. However, KASPAR would not gesture toward the shapes with his hands or look at any shape in particular. In a second group, KASPAR would gesture towards the shapes with his hands and look at specific ones, as this would be how children would be taught to interact with it; however, it would never speak to the children and would not be capable of understanding speech. In a third group, KASPAR would both gesture with his hands towards the shapes, look at specific ones, speak to the children and understand certain key words of speech, and the children would be taught to commmunicate with KASPAR through both means. A fourth group would act as a sort of control, as the robot wouldn't communicate with the children at all; instead of playing with them or taking turns of its own, the robot would typically sit with its eyes closed as if it were sleeping. It would only to open its eyes, smile, and nod at the children when they successfully selected a shape. By comparing the children's social behaviours in each group after playing with KASPAR, we could determine whether the children would play differently by interacting with KASPAR in different ways, as well as whether certain groups would have their children display more social behaviours after interacting with their version of KASPAR.

While this entire thesis has focused on how robots can help children with autism by playing collaboratively with them, it would also be very interesting to observe how the degree of the robot's physical embodiment affected its ability to help children with autism. Specifically, one could compare the performances of a fully embodied and co-located robot, a telepresent robot consisting of a video feed of a robot on a life-sized screen, and a virtual robot consisting of a 3D computer simulation of a robot displayed on a life-sized screen, as they played collaborative games with children with autism. Early research on human-robot interactions has shown that real robots are perceived as more engaging than animated ones because of their physical presence and degree of physical embodiment [Kidd and Breazeal, 2004]. Physically emobdied, co-located robots are seen as more watchful and more enjoyable than either telepresent or simulated robots [Wainer et al., 2006], and also more helpful [Wainer et al., 2007]. Furthermore, real co-located robots are also more appealing and seem to promote better play performances as well as more turn-taking than telepresent robots [Kose-Bagci et al., 2009]. In contrast, there is little to no research on how the degree of a robot's physical embodiment affects its interactions with children with autism. Although the work in this thesis has shown that children with autism have responded very positively to robots in many different settings, recent work has also shown that children with autism respond well to virtually-embodied conversational agents, computer programs which teach and interact with children with autism [Milne et al., 2011]. By conducting such a study and observing how socially engaged the children would be with the different robots, how much they would enjoy the different robots, how well they would play with the different robot, and how quickly they would comply with the different robot's requests, we could determine which form of a robot would be best suited for specific kinds of interactions with children with autism. Because it is much easier to design, maintain, field, and upgrade virtual and telepresent robotic agents than actual, physically-embodied robots, knowing that robots with specific forms of embodiment were better suited to specific kinds of interactions with children with autism could save a great deal of time, money, and effort.

8.4.2 Research inspired by participating in a group-based robotics play club

Chapter 5 of the thesis described a study involving an after-school robotics club in which groups of children with autism played and worked together to make their robots accomplish certain goals. This study was heavily inspired by LeGoff's earlier work on group-based LEGO clubs for children with autism [LeGoff, 2004] [LeGoff and Sherman, 2006], and although our research referenced LeGoff's work, it never compared the two studies' findings against each other. This is because there were too many differences in the methods and the forms of data collected in the two experiments for such a comparison to be valid. As such, a future longitudinal study could be conducted which would compare children with autism playing in pairs or triads with autonomous LEGO NXTs in one club, children with autism playing in pairs or triads with non-robotic LEGO bricks in another club, and children with autism receiving typical autism therapy in a control group. Video recordings of the children's interactions in each of the clubs, questionnaires for the parents as well as children, and autism evaluation tests for the children (e.g. ADOS-G, GARS-2) could be used to compare the children's social behaviours in each club before, during, and after the experiment. The results from such a study would help to determine whether playing with other children to program and interact with an autonomous LEGO NXT robot, working with other children to build static, uninteractive structures out of LEGO pieces, or more traditional forms of autism therapy can teach children more social skills.

8.5 Conclusion

8.5.1 Summary of experiments in thesis

The work I conducted in this thesis was inspired by many different fields such as human-robot interaction, autism research, and cooperative play among children. By combining work from all of these fields, I designed studies in which children with autism played collaboratively with an autonomous robot and also occasionally played in similar ways with other people. By comparing the children's behaviours during the two different forms of collaborative play, I was able to infer differences between the children's styles of social interaction while in the presence of a robot and while in the presence of other people. Furthermore, depending on the design of the experiments, I was also able to infer whether playing in the presence of the robot later affected the children's play styles in the presence of only other people.

First study

In my first study, I held an after-school robotics club for children with high-functioning autism by collaborating with SNAAP, an after-school computer club for children with autism who live in the London borough of Barnet. In this club, after I would teach the children about a specific aspect of programming the robots, multiple groups of two or three children would play together in one room with each group trying to program a LEGO NXT robot and make it perform specific tasks or play certain games. Every member of a group had separate roles that were all different and important for successfully programming the NXT robot, and the children rotated through these roles to learn different ways of playing with the robot. As I taught the children more about robotic programming, the tasks and games for the robots became increasingly collaborative and required the robots to autonomously work together in different ways.

Before some of the robotics class sessions, the children also participated in group drawing sessions. These sessions involved the same groups as those in the robotics class, and the children in these groups were instructed to draw a version of an outline of a robot using crayons. However, the instructions were intentionally vague about how collaboratively the children should be while making this drawing.

By videotaping the children's interactions during both the robot group play and drawing sessions, as well as handing out questionnaires after each session and conducting semi-structured interviews after the experiment, we were able to learn a lot about how collaboratively the children played. Specifically, we discovered that the amount of enjoyment a child had at a given class was more strongly related to the amount of social behaviours they exhibited (i.e. robot-related speech, pointing behaviours, and displays of positive affect) than was the amount of time that a child spent with a given group. However, the amount of time a child spent in a given group still affected some of their collaborative behaviours, as a particular group of children experienced significant changes in their social behaviours between their first and last sessions playing together. Furthermore, because the children had marginally significant changes in the amount of time they spent engaged in social play (cooperative, associative, or onlooker play) during the free-form drawing sessions, this suggests that the children generalized their behaviours from the robotics classes into another domain that did not have structured play or robots. In addition, many of the children's parents reported that attending the classes helped or would help their children in social situations such as dealing with other children in school, interacting with people while on family outings, or choosing topics of conversation. As such, the fact that all of these different ways of analyzing the children's behaviour have similar results helps to support our findings.

Second study

For my second study, I designed a two-player collaborative video game in which each player stood on opposite sides of a tabletop screen and controlled the position of one of two perpendicular lines by rolling or tilting a Nintendo Wiimote. These lines moved around on a screen full of 3D shapes, and when both of the lines intersected over a shape while both players selected the shape by simultaneously pressing the triggers on their Wiimotes, the shape would blink while spinning around and a pleasant sound would play from nearby speakers.

In my experiment, I had children with autism alternate between playing this game with a typically developed adult and playing this game with an autonomous humanoid robot known as KASPAR in order to see whether playing and interacting with the robot would affect the children's behaviours when they returned to playing with a human. Both the robot and the human player played the game the same way and said similar things in similar situations so as to make the two settings as similar as possible for the children with autism and make the nature of the other player (human or robot) the only distinguishing feature between the two. Additionally, a human carer was present during every play session to help calm any children who became agitated and to keep the children focused on playing the game.

By videotaping these sessions and coding the videos for different forms of observational data, we were able to determine that the children displayed certain social behaviours (switching gaze focus, taking the initiative in choosing shapes, and successfully selecting shapes) significantly more often during their second time playing with an adult than during their first. Because these two sessions were separated by a play session involving KASPAR the robot, this suggests that playing with KASPAR helped the children to play the game better in certain ways. However, it's also possible that this change in behaviour is due to the novelty effect of the children playing a collaborative video game or to the children becoming more familiar with the adult over time. Furthermore, there were certain behaviours (displaying positive affect, looking at the other player, and switching gaze between the game and the other player) that were performed significantly more often during both sessions which involved playing with KASPAR than during the sessions which involved playing with an adult. This could suggest that the children found the robot to be more interesting and more fun to play with than they did the adult, but it is also possible that these behavioural differences could also be due to the novelty effect of the children playing with a robot.

Third study

My third study involved technical and experimental setups similar to those of the second study, but also different in key ways. Specifically, both studies are similar in that they involved children with autism playing a collaborative video game to select shapes at the same time as another player, and the experimental designs of both studies involved the children alternating between playing with people and playing with KASPAR. Furthermore, the play sessions in both of the studies were videotaped and the children's social behaviours were analyzed for trends.

However, the collaborative game in the third study involved players taking turns imitating each other by posing their arms in specific ways similar to those of stick figures on a tabletop screen. When all the players posed in the same way as one of the set of stick figures on the screen, the shape outline closest to the stick figures in question would subsequently fill in with colour, spin around, and a pleasant sound would play from speakers. Secondly, the third experiment involved pairs of children with autism playing together multiple times on separate days, and each set of contiguous sessions which involved the children playing in one way was called a phase. Thirdly, the study itself involved pairs of children with autism alternating between playing this imitative collaborative game dyadically with each other and pairs of children with autism playing the same game triadically with KASPAR the robot. Fourthly, each child was paired up with a different child during each play session in a given phase to ensure that any interesting results would not just be due to children becoming familiar with playing with one other person. Lastly, to ensure that any changes in the children's play styles during triadic phases involving playing with KASPAR were not due to the novelty effect, each child played dyadically with KASPAR three separate times after their first phase of dyadically playing with another child.

This study found many significant differences between the first and second phases of dyadic play involving two children, all of which suggested that the children paid more attention to the other child playing with them, were more socially engaged with the other child, showed more enjoyment, tried to share their enjoyment more often with the other child, were more communicative, and tried more often to verbally coordinate their cooperative actions with the other child playing during the second phase than during the first. Because these trends appear most apparently between the two dyadic phases, are occasionally reversed or not as significant when compared to the triadic phases, and were neither constant nor continuing in the same upward direction over the course of the many sessions of this study, this suggests that these improvements are due to the children's intervening phase of playing triadically with KASPAR instead of them becoming more familiar with their partners and the game's mechanics over time.

In contrast, there were no significant differences when comparing how the children played between their first and second phases of playing triadically with KASPAR. Because each child participated in a familiarizing phase involving them playing dyadically with KASPAR before playing triadically with KASPAR and another child, this would indicate that the lack of changes in the children's social behaviours between the first and second phases of triadic play are not due to the novelty effect of playing and interacting with an autonomous robot.

Additionally, the children spent more time looking at the other players, selected fewer shapes, and were more likely to be prompted before choosing a shape during the triadic play sessions than the dyadic ones. While the first two changes are likely due to the increase of play partners, the last distinction between the play phases is probably due to KASPAR's specific behaviours and sensing modalities.

8.5.2 Summary of scientific contributions of thesis

Due to the multidisciplinary nature of my research, the findings and techniques described in this thesis have contributed to the advancement of many fields of research.

- **Human-robot interaction:** I have demonstrated in my experiments that autonomous robots can promote social interaction among children with autism by playing collaborative games and interacting with them, whether the robots are humanoid like KASPAR or clearly mechanical like LEGO NXTs. The fact that both kinds of robots, each with such drastically different appearances (humanoid **vs** modular insectoid, respectively), behaviours (moving humanoid arms, head, and eyes **vs** moving around on a flat surface and pushing objects, respectively), and interactive capabilities (speaking, gesturing, making facial expressions in human ways **vs** beeping and turning, respectively), could help children with autism merely by interacting with them has very interesting implications for future research in human-robot interaction.

- **Robot-assisted play:** I developed a collaborative video game in which players faced each other and gathered around a horizontally-oriented screen, which is a novel scenario for studying styles and patterns of play between children with autism and robots. This play configuration could be well-suited in using robots to develop joint attention and mutual gaze in children with autism through co-located play.

  Additionally, having the game exist as a physical, responsive entity which is separate and distinct from the robot (who also participates in the game) could promote new directions for research in robot-assisted play. Instead of a game being an abstract concept, the binding of a game to a physical form with which the robot can interact could make children with autism play with the robot in a more engaged manner.

  Lastly, using a video game as a collaborative medium allows researchers to "cheat" by having the video game process communicate with the robot control process and directly transmit the game's complete state information to the robot's sensory subroutines. This allows researchers to completely bypass the problem of designing a game that a robot can reliably "sense" (e.g. knowing the state of a real-life checkerboard by programming the robot with impressive computer vision algorithms related to shape detection and feature extraction) as well as "act upon" (e.g. designing a robot arm and gripper specifically for moving checkers), and instead devote all of their efforts to allowing the robot to have rich interactions with the children using many different modalities.

- **Assistive robotics:** The findings from my experiments suggest that autonomous robots, whether LEGO NXT robots or KASPAR the humanoid robot, can positively impact the way that children with autism socially interact with other people in the context of a collaborative game. Moreover, instead of simply observing how the children with autism interacted with people *while in the presence* of the robot, my experiments also examined how these children behaved with people *after* they interacted with the autonomous robot and found that their behaviours were more socially interactive.

  Further research in assistive robotics could benefit from observing and measuring the children's social behaviours both before and after interacting with the robot. Instead of only focusing on how the robot can be beneficial to the children's interactions as long as it is present, this technique could show differences in the children's behaviours in more typical settings, perhaps even those outside of the collaborative game. Showing such a difference would strongly suggest that the robot's interactions would have enduringly therapeutic effects on the children's behaviour.

- **Autism research:** My research focused on the interactions of the children with autism and autonomous robots in the context of playing a collaborative game; it did not study autism itself. However, the experimental setups and hardware as well as software systems used in my research could be used by other reserachers to study many other aspects of autism in novel ways. Although specialists would be needed to modify the robot's behaviours and alter aspects of the collaborative game, as the systems I developed were not constructed as modifiable elements of a framework, these technical individuals could work together with psychologists to design new experimental play scenarios for studying autism.

Appendix A

Publications

In all of the publications described below, I was listed as the primary author because I wrote the documents and undertook all of the experimental work while receiving feedback and advice from my supervisors on my writing and scientific approaches, respectively.

The information from the conference paper and journal article listed below were used in section 3.1 which discusses the LEGO NXT robots constructed for my first study, section 4.1 which talks about the arena games from my first study, and chapter 5 which discusses the methodology and findings of my first experiment.

- Josh Wainer, Kerstin Dautenhahn, Ben Robins (2008). *Using robots to foster collaboration among groups of children with autism in an after-school class setting: An exploratory study.* Proc. of 1st Workshop on Design for Social Interaction through Physical Play at the 2nd International conference on Fun and Games, 22-24 October 2008, Eindhoven, The Netherlands.

- Joshua Wainer, Ester Ferrari, Kerstin Dautenhahn, Ben Robins (2010). *The effectiveness of using a robotics class to foster collaboration among groups of children with autism in an exploratory study.* Journal of Personal and Ubiquitous Computing, 14:445-455.

The information from the conference paper and journal article listed below were used in section 3.2 which discusses KASPAR, the humanoid robot that was used in my second and third study, section 4.2 which talks about the dyadic, collaborative video game “Tilt and roll” used in my second study, and chapter 6 which discusses the methodology and findings of my second experiment.

- Joshua Wainer, Kerstin Dautenhahn, Ben Robins, and Farshid Amirabdollahian (2010). *Collaborating with Kaspar: Using an Autonomous Humanoid Robot to Foster Cooperative Dyadic Play among Children with Autism.* 10th IEEE-RAS International Conference on Humanoid Robots (Humanoids ‘10) December 2010, Nashville, TN.
- Joshua Wainer, Kerstin Dautenhahn, Ben Robins, Farshid Amirabdollahian (2012). *Fostering cooperative dyadic play among children with autism using the autonomous humanoid robot KASPAR.* International Journal of Social Robotics (submitted)

Appendix B

Questionnaires for children and parents from first experiment

Figure B.1: Children's questionnaire

SNAAP Robotics classes

Date of session: ________________________ Your name: ________________________

We would like to ask you a few questions that will help us in future to organise robotics classes. Please answer the following questions by making an X somewhere on the line between the two ends of the answer scale. There are no wrong answers; we are simply interested in your opinion on the robotics classes you attend!

Here is an example of how to answer the questions below:

Example: Do you like computers?

☐ ☐ ☐ ☐ ☐ ■ ☐

Not at all | So-so | Very much

The above answer shows that the person who coloured in the square likes computers.

Now, here are the questions for you:

1. What did you think of this week's robotics class?

   ☐ ☐ ☐ ☐ ☐ ☐ ☐

   It was not fun | It was okay | It was a lot of fun

2. How often did you work with other children during today's robotics class?

   ☐ ☐ ☐ ☐ ☐ ☐ ☐

   Never | Sometimes | All the time

3. How easy was it to work with other children during today's robotics class?

   ☐ ☐ ☐ ☐ ☐ ☐ ☐

   Very hard | So-so | Very easy

Please continue on the next page.

4. Did something unusual happen during today's class? If so, what was it?
   If you can think of anything, please write your answer on the lines below!

   ____

   ____

   ____

Thank you for completing the questionnaire!

Figure B.2: Parent's questionnaire, page 1

Contact:
Josh Wainer
University of Hertfordshire
School of Computer Science
College Lane, Hatfield, Herts AL10 9AB
Email: J. Wainer@herts.ac.uk
Phone: 079 4273 7874

Session date: ____________________ Child's name: ______________________________

As part of my PhD project where I try to encourage collaboration among children with autism, I would very much appreciate if you could complete this questionnaire after each SNAAP Robotics session. This information will only be used to evaluate the effectiveness of the robotics classes; we will not use it to judge your child in any way.

Please answer the following questions by making a mark anywhere between the two ends of the answer spectrum.

Here is an example of how to answer the questions below:

Example: Does your child seem to enjoy using computers?

☐ ☐ ☐ ☐ ■ ☐ ☐

Not at all — About average — Very much

The person who answered the above question believes their child enjoys using computers more than the average person.

1. How much do you think your child enjoyed this week's robotics class?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Did not like it — Thought it was average — Really enjoyed it

Figure B.3: Parent's questionnaire, page 2

2. How frequently did your child collaborate with other children during this week's class?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Never — Occasionally — All the time

3. How well do you think they collaborated with other children during this week's class?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Not very well — About average — Very well

4. In terms of social behaviour, how would you describe your child's behaviour outside of SNAAP during this past week?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Very unsociable — Neutral — Very sociable

Please answer the following questions in the space provided (a few notes suffice).

5. Do you think your child learned something from this week's class? If so, what?

____

____

____

6. Was any of your child's behaviour unusual or unexpected during this week's class? If so, how?

____

____

____

We very much appreciate your valuable time to complete the questionnaire.

Appendix C

Interview questions for parents from first experiment

1. How old is your child?
2. When was your child diagnosed as being autistic? What evaluation criteria were used (ADOS-G, ADI-R, DSM-IV, etc)and how severe is their condition? When were these criteria last used? If your child was not diagnosed with any of the above criteria or if you do not know their diagnosis, at what age-level are they currently learning in school?
3. How many robotics club sessions did your child attend?
4. Did their attitude to the club change over time?
5. Have you noticed any changes in how your child...
    - works with or collaborates with other children...
    - interacts in social situations...
    - solves problems...
    - behaves with friends and family...

...since starting the robotics club?

6. Overall, what do you think of the robotics club?

7. What changes would you or your child like to see made to the club?

8. Would you attend another similar robotics class if it were offered next year?

Appendix D

Sample teaching presentation from robotics class in first experiment

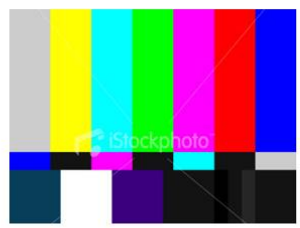
Figure D.1: Presentation slide 1

The Light Sensor

This sensor tells the robot how much light it sees. This will work the same whether it looks at a light source (the sun, a lamp, etc) or whether it looks at an object that reflects light. This works with objects that are white, black, and shades of gray, but it also works with colours, too! Because of how it's positioned, our robots will use this sensor to figure out when something on the floor has changed colour.

Figure D.2: Presentation slide 2

See what the light sensor sees!



- Turn the robot on by pressing the orange button
- Press Left or Right until you get to “**View**”, then press the orange button.
- Press Left or Right until you get to “**Light Sensor**” with a white light bulb, then press the orange button.
- Press Left or Right until you get to “**Port 3**”, then press the orange button.
- With the robot on the ground, place different coloured pieces of paper under its light sensor. Can you find two different colours that have similar values according to the light sensor?

Figure D.3: Presentation slide 3

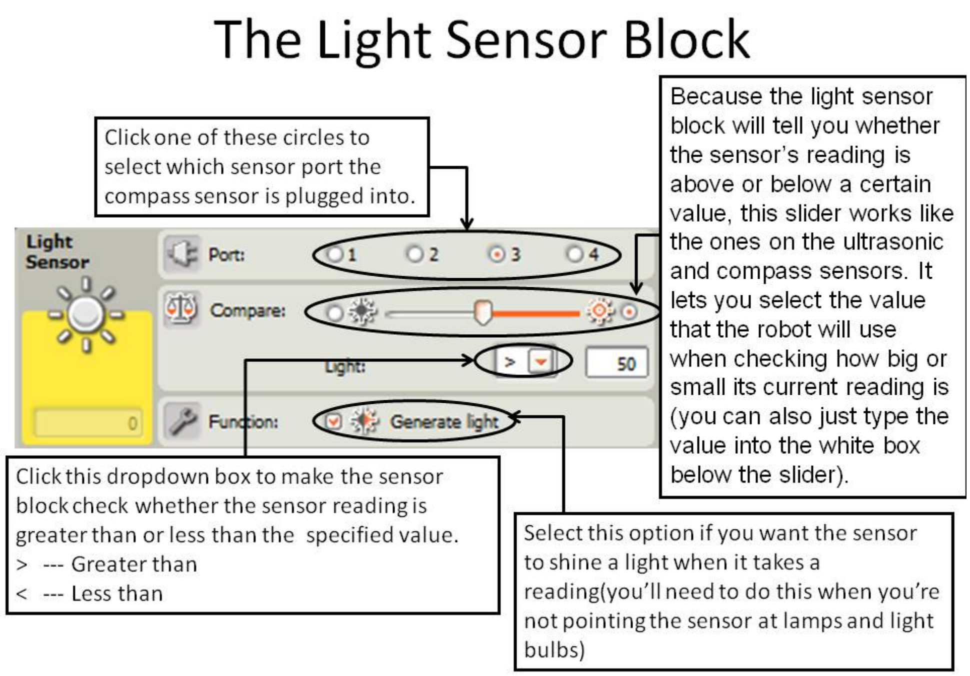


Figure D.4: Presentation slide 4

Program 1: Wait and Move (with light)

- Make your robot move until it hits a bright patch of the ground! This is actually very similar to the “move and wait” set of commands:

- For the “Wait” block, just make it to use the light sensor instead of the ultrasonic one. Try making the “Wait” block be triggered by the brightness of different coloured pieces of paper!

Figure D.5: Presentation slide 5

Program 2: “Walls of Light”

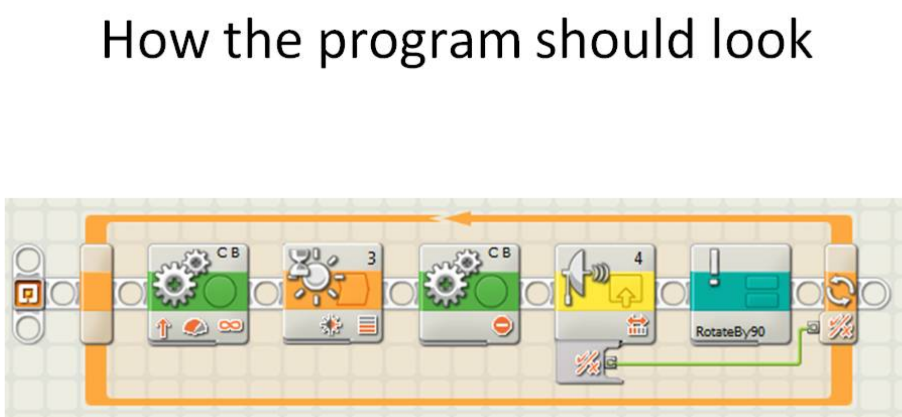
We’re going to program our robots to always:

- Go straight ahead forever
- Rotate 90’ if they drive over a white piece of paper on the ground

•They’ll finally stop doing these things if they see an object in front of them within 20 cm!

Once the robots are doing this consistently, we’ll play a game with all of the robots in the arena trying to activate all the sensors!

Figure D.6: Presentation slide 6



Appendix E

Consent forms for our experiments

Figure E.1: The letter of consent for our first experiment.

University of Hertfordshire

Joshua Wainer
School of Computer Science
University of Hertfordshire
College Lane, Hatfield
Hertfordshire
AL10 AB

Dear Parent,

Prof. Kerstin Dautenhahn, Dr. Ben Robins and I of the University of Hertfordshire are involved in the SNAAP Robotics Club, which supplements the SNAAP multimedia club with a weekly course designed both to teach children about robotics and to study whether the robots can function as social mediators for the children. Specifically, the children will learn how to program Lego Mindstorms NXT robots and how to make them interact and work together in the real world. While the children are programming their robots and making them collaborate with the other children's robots, we will observe whether cooperation and socialization among the children is linked with collaboration among their robots.

With the support of Mrs. Christine Haugh, Mr. Matt Connolly, and the other SNAAP administrators, we will be conducting the Robotics Club from 4 to 6 pm on Mondays starting on the 25th of February. The club will be held in the same rooms at North Finchley Catholic High School in which SNAAP is usually held. The club will last for two hours and be divided into sessions that will last between twenty and thirty minutes. Every session in a given day will focus on the same material, and each child will learn about robotics during one of these sessions. In this way, every child will be able to program their own robot in spite of there being three robots altogether.

The sessions will be videotaped and will provide a valuable contribution to our research, and are vital to the development of the robots as better aids for the children's education and development. Each session will be fully supervised and safety factors will be carefully considered.

We would be grateful if you could complete the section at the bottom of this letter to give your consent to your child participating in these activities with the robots, and we thank you for your support.
(Please note: the real name of your child will never be used in any data analysis or publication of the results)

If you have any further queries, please do not hesitate to contact me at the numbers below.

Thank you for your support

Joshua Wainer
Email address – j.wainer@herts.ac.uk
Mobile number - 079 4273 7874

- -

I give permission for my child ____________________ to take part in the SNAAP Robotics Club at North Finchley Catholic High School, including the video recording of the sessions.

I also agree that any stills and/or video sequences from these trials may be used for scientific publication or presentation about the project within the scientific community.

Signed: ________________________________ Date: ____________

Please return this to Josh Wainer at the address on the top of this sheet

Figure E.2: The letter of consent for our second experiment.

University of Hertfordshire

Department of Computer Science
University of Hertfordshire
College Lane
Hatfield
Hertfordshire
AL10 AB

Dear Parent,

Prof. Kerstin Dautenhahn, Dr. Ben Robins and I of the University of Hertfordshire are involved in the AuRoRA project which studies how toy-like robots can be used as tools to develop the social interaction skills of children with autism. Specifically, our research examines how robots can be used by people to help in the development of collaboration skills among children on the autistic spectrum.

We have run trials in the past at various schools including a number of the National Autistic Society's schools, and with the agreement of Mr. Mike Philp, we will be running more trials at Southfield School. These will involve sessions of approximately 30 minutes long, where the children could play a simple video game with a robot, individually, as well as play the same games with another person.

The sessions will be videotaped and will provide a valuable contribution to our research, and are vital to the development of the robots as better aids for the children's education and development. Each session will be fully supervised and safety factors are carefully considered.

We would be grateful if you could complete the section at the bottom of this letter to give your consent to your child participating in these trials with the robots, and we thank you for your support. Please note: the real name of your child will never be used in any data analysis or publication of the results.

Further information on the project may be found on the internet at http://www.aurora-project.com. If you have any further queries please do not hesitate to contact me on the numbers below.

Thank you for your support!

Joshua Wainer
Email address – j.wainer@herts.ac.uk
Mobile number - 079 4273 7874

- -

I give permission for my child ____________________ to take part in trials of the AuRoRA project at Southfield School, including the video recording of the sessions.

I also agree that any stills and/or video sequences from these trials may be used for scientific publication or presentation about the project within the scientific community.

Signed: ______________________________ Date: ____________

Please return this to the school office for the attention of Joshua Wainer

Figure E.3: The letter of consent for our third experiment.

University of Hertfordshire

Department of Computer Science
University of Hertfordshire
College Lane
Hatfield
Hertfordshire
AL10 AB

Dear Parent,

Prof. Kerstin Dautenhahn, Dr. Ben Robins and I of the University of Hertfordshire are involved in the AuRoRA project which studies how toy-like robots can be used as tools to develop the social interaction skills of children with autism. Specifically, our research examines how robots can be used by people to help in the development of collaboration skills among children on the autistic spectrum.

We have run trials in the past at various schools including a number of the National Autistic Society's schools, and with the agreement of Mr. Mike Philp, we will be running more trials at Southfield School. These will involve sessions of approximately 30 minutes long, where two children could play a simple video game together as a pair or a group of two children and an interactive robot could play the same game together.

The sessions will be videotaped and will provide a valuable contribution to our research, and are vital to the development of the robots as better aids for the children's education and development. Each session will be fully supervised and safety factors are carefully considered.

We would be grateful if you could complete the section at the bottom of this letter to give your consent to your child participating in these trials with the robots, and we thank you for your support. Please note: the real name of your child will never be used in any data analysis or publication of the results.

Further information on the project may be found on the internet at http://www.aurora-project.com. If you have any further queries please do not hesitate to contact me on the numbers below.

Thank you for your support!

Joshua Wainer
Email address – j.wainer@herts.ac.uk
Mobile number - 079 4273 7874

- -

I give permission for my child ____________________ to take part in trials of the AuRoRA project at Southfield School, including the video recording of the sessions.

I also agree that any stills and/or video sequences from these trials may be used for scientific publication or presentation about the project within the scientific community.

Signed: ______________________________ Date: ____________

Please return this to the school office for the attention of Joshua Wainer

Appendix F

Schedule of sessions in third experiment

May, 2010

- Phase A_1
  - May 7th
    * Ryan & Toni
    * Harry & Clive
    * Ryan & Mute
    * Toni & Connor
  - May 10th
    * Clive & Toni
    * Harry & Ryan
    * Clive & Mute
    * Connor & Harry
  - May 11th
    * Ryan & Connor

        - Connor & Clive
        - Mute & Harry
    - May 14th
        - Connor & Mute
        - Ryan & Clive
        - Harry & Toni
        - Mute & Toni
- Phase F
    - May 18th
        - Harry
        - Ryan
        - Toni
        - Clive
        - Mute
    - May 21st
        - Connor
        - (2nd) Mute
        - (2nd) Harry
        - (2nd) Toni
        - (2nd) Ryan
    - May 24th
        - (2nd) Clive
        - (3rd) Mute
        - (3rd) Harry
        - (3rd) Ryan

- May 25th
  * (3rd) Clive
  * (2nd) Connor
  * (3rd) Toni
- May 28th
  * (3rd) Connor

June, 2010

- Phase B_1
  - June 11th
    * Harry & Toni
    * Ryan & Clive
    * Ryan & Mute
    * Toni & Mute
  - June 14th
    * Connor & Mute
    * Toni & Connor
    * Harry & Clive
    * Ryan & Toni
  - June 15th
    * Clive & Mute
    * Ryan & Connor
    * Connor & Clive
  - June 18th
    * Connor & Harry

    * Harry & Ryan
    * Toni & Clive
    * Harry & Mute

- Phase A_2
  - June 21st
    * Connor & Mute
    * Ryan & Clive
    * Clive & Mute
    * Harry & Ryan
    * Connor & Harry
  - June 22nd
    * Clive & Harry
    * Ryan & Mute
    * Toni & Ryan
    * Connor & Toni
  - June 25th
    * Clive & Toni
    * Harry & Mute
    * Toni & Harry
  - June 28th
    * Connor & Clive
    * Connor & Ryan
    * Mute & Toni
- Phase B_2
  - June 29th

    - Connor & Ryan
    - Mute & Connor
    - Clive & Mute

July, 2010

- July 2nd
    - Toni & Connor
    - Ryan & Toni
    - Mute & Ryan
    - Clive & Harry
- July 9th
    - Ryan & Clive
    - Toni & Mute
- July 15th
    - Harry & Connor
    - Toni & Clive
    - Mute & Harry
- July 16th
    - Clive & Connor
    - Harry & Toni
    - Ryan & Harry

Appendix G

Observational coding schemes used in our experiments

Figure G.1: The coding scheme used during the group-based robotics class in my first experiment. Every observation focused on a single child's behaviour, although "Shared gaze" and "Shared positive affect" involved observing the other child in the main child's group. Since the focus was on one player per observation, we did not bother using subjects in our coding scheme. See section 5.2.2 for more information.

Behavior Name	Description			Properties	Mo...	Cha...	
Proxemic	distance between children less than 4 feet	w	q	State Event	...	...	
Speech	beginning of a complete sentence when a child is talking about the robot	z		Point Event	...	...	
Shared Gaze	children from the same group look at the same object (even if they are not close to each other)	s	a	State Event	...	...	
Pointing	pointing to one object with finger or foot (eyes can be out of view)	x		Point Event	...	...	
Shared positive affect		c		Point Event	...	...	

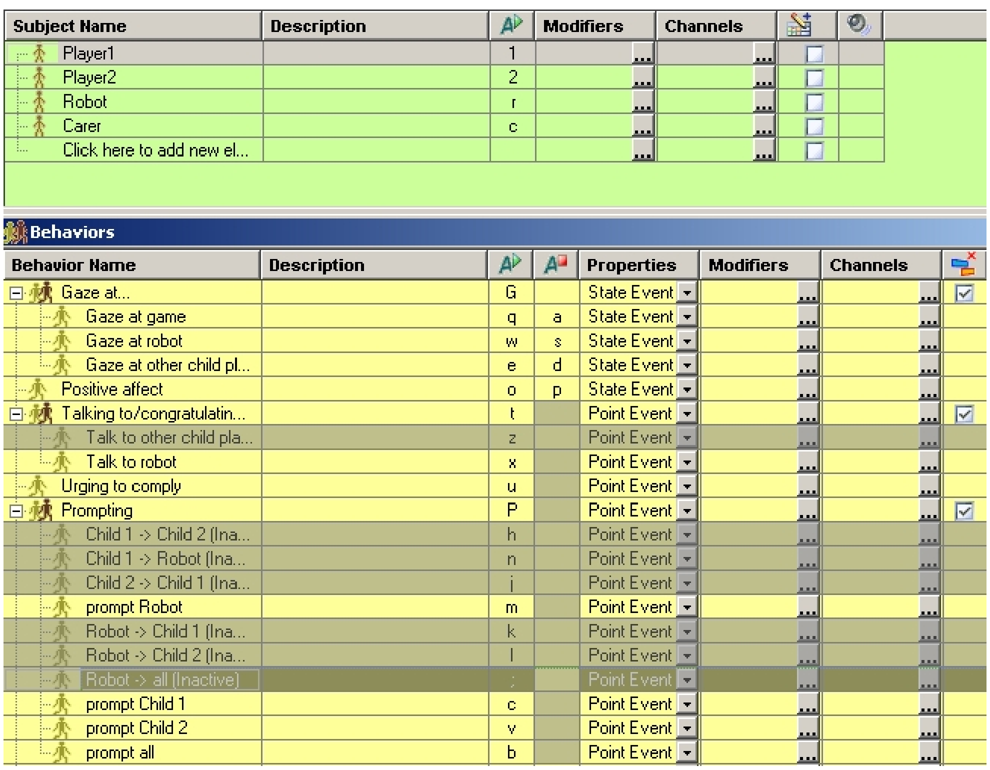
Figure G.2: The coding scheme used during the group drawing sessions in my first experiment. Each observation focused on a single child's behaviour, with every video possibly having multiple observations depending on the children in it. Because we focused on one child per observation, we did not bother using subjects in our coding scheme. See section 5.3.2 for more information.

Behavior Name	Description			Properties	Modifiers	Channels	
Talking		t	g	State Event			☑
Social talking		e		State Event			
Nonsocial talking		w		State Event			
Not talking		q		State Event			
Conflict		m		Point Event			
Drawing		f		State Event			☑
No drawing		a		State Event			
Separate drawing		s		State Event			
Shared drawing		d		State Event			
Harmony		z		Point Event			

Figure G.3: The coding scheme used during the second experiment. Each observation mainly focused on a single child's behaviour, but also coded up the carer's promptings and the typically developed adult's choosing of shapes, as well. Each video only had one observation associated with it. Because we focused on one child per observation, we did not bother using subjects in our coding scheme. See section 6.2.2 for more information.

Behavior Name	Description			Properties	Modifiers	Channels	
Gaze at the...		g		State Event			☑
game		q		State Event			
other player		w		State Event			
unknown		e		State Event			
something else		r		State Event			
carer		t		State Event			
experimenter		a		State Event			
Positive affect		s	d	State Event			
Prompting		p		Point Event			☐
Other player prompts		b		Point Event			
Experimenter/carer pr...		x		Point Event			
Choosing		c		Point Event			☐
Child verbally choose...		h		Point Event			
Other player chooses...		o		Point Event			
Behavior1	This Behavior group has be...			Point Event			☑
Noteworthy event		n		Point Event			

Figure G.4: The coding scheme used during the third experiment. Because two children played together in every phase except for the familiarization phase F and we wanted to look for trends in the children's interactions, every observation coded up both children's reactions as well as the promptings and urgings of the carer, but the robot's behaviours were not manually coded. Instead, the subject listing of "Robot" was used when we integrated the robot's automatically-generated behaviour logs from its play session with our own observations. See section 7.2.2 for more information.



Subject Name	Description	Key	Modifiers	Channels		
Player1		1	...	...	☐	
Player2		2	...	...	☐	
Robot		r	...	...	☐	
Carer		c	...	...	☐	
Click here to add new el...			...	...	☐	

Behaviors

Behavior Name	Description	Key	Stop key	Properties	Modifiers	Channels	
Gaze at...		G		State Event	...	...	☑
Gaze at game		q	a	State Event	...	...	
Gaze at robot		w	s	State Event	...	...	
Gaze at other child pl...		e	d	State Event	...	...	
Positive affect		o	p	State Event	...	...	
Talking to/congratulatin...		t		Point Event	...	...	☑
Talk to other child pla...		z		Point Event	...	...	
Talk to robot		x		Point Event	...	...	
Urging to comply		u		Point Event	...	...	
Prompting		P		Point Event	...	...	☑
Child 1 -> Child 2 (Ina...		h		Point Event	...	...	
Child 1 -> Robot (Ina...		n		Point Event	...	...	
Child 2 -> Child 1 (Ina...		j		Point Event	...	...	
prompt Robot		m		Point Event	...	...	
Robot -> Child 1 (Ina...		k		Point Event	...	...	
Robot -> Child 2 (Ina...		l		Point Event	...	...	
Robot -> all (Inactive)		;		Point Event	...	...	
prompt Child 1		c		Point Event	...	...	
prompt Child 2		v		Point Event	...	...	
prompt all		b		Point Event	...	...	

Bibliography

Nintendo. URL `http://wii.nintendo.com`.

The aurora project, *http://www.aurora-project.com*, September 2010. URL `http://www.aurora-project.com`.

Us autism and asperger association, May 2012. URL `http://www.usautism.org/who_are_you_autism.html`.

The American Psychiatric Association, editor. *Diagnostic and Statistical Manual of Mental Disorders*. American Psychiatric Association, Washington DC, 4th edition edition, 1994.

Farshid Amirabdollahian, Ben Robins, and Kerstin Dautenhahn. Robotic skin requirements based on case studies on interacting with children with autism. In *Presented at Tactile Sensing workshop at IEEE Humanoids*, 2009.

Angelika Anderson, Dennis W. Moore, Rebecca Godfrey, and Claire M. Fletcher-Flinn. Social skills assessment of children with autism in free-play situations. *Autism*, 8(4):369–385, 2004. doi: 10.1177/1362361304045216. URL `http://aut.sagepub.com/cgi/content/abstract/8/4/369`.

A J Attwood. *Aspergers syndrome: A guide for parents and professionals*. Jessica Kingsley Publishers, 1998.

R. Avanzato. Collaborative mobile robot design in an introductory programming course for engineers. *Computers in Education Journal*, 4:67–70, 1999.

R Avanzato. Mobile robotics for freshman design, research, and high school outreach. In *IEEE International Conference on Systems, Man, and Cybernetics*, 2000.

R. Bakeman. *Observing interaction: an introduction to sequential analysis.* Cambridge University Press, 1986.

Roger Bakeman and John Mordechai Gottman. *Observing interaction : an introduction to sequential analysis.* New York : Cambridge University Press, 2nd ed edition, 1997. ISBN 052145008X.

Bally/Midway. Rampage. [Arcade], 1986.

Simon Baron-Cohen, Alan M. Leslie, and Uta Frith. Does the autistic child have a "theory of mind"? *Cognition*, 21:37–46, 1985.

Simon Baron-Cohen, Jennifer Richler, Dheraj Bisarya, Nhishanth Gurunathan, and Sally Wheelwright. The systemizing quotient: an investigation of adults with asperger syndrome or high -functioning autism, and normal sex differences. *Philosophical Transactions of the Royal Society of London B*, 358:361–374, 2003.

Jennifer Bass and James Mulick. Social play skill enhancement of children with autism using peers and siblings as therapists. *Psychology in the schools*, 44(7): 727–735, 2007.

Alberto Battocchi, Ayelet Ben-Sasson, Gianluca Esposito, Eynat Gal, Fabio Pianesi, Daniel Tomasini, Paola Venuti, Patrice L Weiss, and Massimo Zancanaro. Collaborative puzzle game: a tabletop interface for fostering collaborative skills in children with autism spectrum disorders. *Journal of Assistive Technologies*, 4 (1):4–13, 2010.

N. Bauminger, D. Goren-Bar, E. Gal, P.L. Weiss, J. Kupersmitt, F. Pianesi, O. Stock, and M. Zancanaro. Enhancing social communication in high functioning children with autism through a colocated interface. In *IEEE 9th Workshop on Multimedia Signal Processing*, pages 18–21, 2007.

Nirit Bauminger. The facilitation of social-emotional understanding and social interaction in high-functioning children with autism: Intervention outcomes. *Journal of Autism and Developmental Disorders*, Vol. 32:pp. 283–298, 2002.

Randall Beer, Hillel Chiel, and Richard Drushel. Using autonomous robotics to teach science and engineering. *Communications of the ACM*, 42(6):85–92, 1999.

S Besio, F Caprino, and E Laudanna. Profiling robot-mediated play for children with disabilities through icf-cy: The example of the european project iromec. In K Miesenberger, J Klaus, W.L. Zagler, and A. I. Karshmer, editors, *ICCHP*, volume 5105, pages 545–552. Springer Heidelberg, 2008.

Aude Billard, Ben Robins, Jacqueline Nadel, and Kerstin Dautenhahn. Building robota, a mini-humanoid robot for the rehabilitation of children with autism. *RESNA Assistive Technology Journal*, 19(1):37–49, 2006.

M. P. Blow, Kerstin Dautenhahn, A. Appleby, C.L. Nehaniv, and D. Lee. Perception of robot smiles and dimensions for human-robot interaction design. In *Proc. 15th IEEE Int. Symp. on Robot and Human Interactive Communication (RO-MAN06)*, pages pp. 469–474, Hatfield, UK, September 2006.

O. Bogdashina. *Communication issues in autism and Asperger syndrome.* Jessica Kingsley Publishers, London, Philadelphia, 2005.

A. S. Bondy and L. A. Frost. *The picture exchange communication system: Training manual.* Pyramid, Cherry Hill, NJ, 1994.

G Bourhis and P Pino. Mobile robotics and mobility assistance for people with motor impairments: rational justification for the vahm project. *IEEE Transactions of Rehabilitation Engineering*, 4(1):7–12, 1996.

C. Breazeal, C.D. Kidd, A.L. Thomaz, G. Hoffman, and M.; Berlin. Effects of nonverbal communication on efficiency and robustness in human-robot teamwork. In *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2005.

Cynthia Breazeal, Guy Hoffman, and Andrea Lockerd. Teaching and working with robots as a collaboration. In *Proceedings of the Third International Joint Conference on Autonomous Agents and Multiagent Systems*, 2004.

Jerome Bruner. Nature and uses of immaturity. In Kevin Connolly and Jerome Bruner, editors, *The Growth of Competence*. Academic Press, 1974.

Charles G . Burgar, Peter S. Lum, Peggy C. Shor, and H.F. Machiel Van der Loos. Development of robots for rehabilitation therapy : The palo alto va/stanford experience. *Journal of Rehabilitiation Research*, 37(6):663–673, 2000.

Laurie Carr, Marco Iacoboni, Marie-Charlotte Dubeau, John C. Mazziotta, and Gian Luigi Lenzi. Neural mechanisms of empathy in humans: A relay from neural systems for imitation to limbic areas. *Proceedngs of the National Academy of Sciences*, 100:5497–5502, 2003.

Fulvia Castelli, Chris Frith, Francesca Happ, and Uta Frith. Autism, asperger syndrome and brain mechanisms for the attribution of mental states to animated shapes. *Brain*, 125:1839–1849, 2002.

R. Ĉeponiené, T. Lepistö, A. Shestakova, R. Vanhala, P. Alku, R. Näätänen, and K. Yaguchi. Speech-sound-selective auditory impairment in children with autism: they can perceive but do not attend. *Proceedings of the National Academy of Sciences*, 100:5567–5572, 2003.

T. Charman and Simon Baron-Cohen. Brief report: Prompted pretend play in autism. *Journal of Autism and Developmental Disorders*, 27:325332, 1997.

K Colby and D Smith. Computers in the treatment of non speaking autistic children. *Current Psychiatric Therapy*, Vol. 11:pp. 1–17, 1971.

Eric Courchesne, Alan J Lincoln, Beverly A Kilman, and Robert Galambos. Event-related brain potential correlates of the processing of novel visual and auditory information in autism. *Journal of Autism and Developmental Disorders*, 15:55–76, 1985.

N. Dahlbäck, A. Jönsson, and L. Ahrenberg. Wizard of Oz studies - why and how. *Knowledge-Based Systems*, Vol. 6:pp. 258–256, 1993.

Kerstin Dautenhahn. Robots as social actors: Aurora and the case of autism. In *Proc. CT99, The Third International Cognitive Technology Conference*, pages 359–374, San Francisco, August 1999.

Kerstin Dautenhahn. Design spaces and niche spaces of believable social robots. In *Proceedings of IEEE International Workshop on Robot and Human Interactive Communication (RO-MAN)*, 2002.

Kerstin Dautenhahn. Socially intelligent robots: dimensions of humanrobot interaction. *Philosophical Transactions of the Royal Society of London B*, 362:679–704, 2007.

Kerstin Dautenhahn and Aude Billard. Games children with autism can play with robota, a humanoid robotic doll. In *Proceedings of the 1st Cambridge Workshop on Universal Access and Assistive Technology*, 2002.

Kerstin Dautenhahn and Iain Werry. Towards interactive robots in autism therapy: Background, motivation and challenges. *Pragmatic and Cognition*, 12:pp 1–35, 2004.

Kerstin Dautenhahn, Chrystopher L. Nehaniv, Michael Walters, Ben Robins, Hatice Kose-Bagci, N. Assif Mirza, and Michael Blow. Kaspar - a minimally expressive humanoid robot for human-robot interaction research. *Applied Bionics and Biomechanics, Special issue on "Humanoid Robots"*, 6:pp. 369–397, September 2009.

Geraldine Dawson, Deborah Hill, Art Spencer, Larry Galpert, and Linda Watson. Affective exchanges between young autistic children and their mothers. *Journal of Abnormal Child Psychology*, 18:335–345, 1990.

Geraldine Dawson, Leslie Carver, Andrew N Meltzoff, Heracles Panagiotides, James McPartland, and Sara J. Webb. Neural correlates of face and object recognition in young children with autism spectrum disorder, developmental delay, and typical development. *Child Development*, 73:700–717, 2002.

Brigitte Denis and Sylviane Hubert. Collaborative learning in an educational robotics environment. *Computers in Human Behavior*, 17:465–480, 2001.

Deborah Dewey, Catherine Lord, and Joyce Magill. Qualitative assessment of the effect of play materials in dyadic peer interactions of children with autism. *Canadian Journal of Psychology*, 42:242–260, 1988.

P. Dillenbourg. What do you mean by 'collaborative learning' ? In P. Dillenbourg, editor, *Collaborative-learning: Cognitive and Computational Approaches*. Elsevier, 1999.

P. Dillenbourg, M. Baker, A. Blaye, and C. O'Malley. The evolution of research on collaborative learning. In E. Spada and P. Reiman, editors, *Learning in Humans and Machine: Towards an interdisciplinary learning science*. Elsevier, 1996.

John Drury, John Scholtz, and Hank Yanco. Awareness in human-robot interactions. In *IEEE International Conference on Systems, Man and Cybernetics*, pages 111–119, 2003.

Steven Dubowsky, Frank Genot, Sara Godding, Hisamitsu Kozono, Adam Skwersky, Haoyong Yu, and Long Shen Yu. Pamm - a robotic aid to the elderly for mobility assistance and monitoring: A "helping-hand" for the elderly. In *Proceedings of IEEE International Conference on Robotics and Automation (ICRA)*, 2000.

A. Duquette, F. Michaud, and H. Mercier. Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism. *Autonomous Robots, Special Issue on Socially Assistive Robots*, Vol. 24:pp. 147–157, 2008. Special Issue on Socially Assistive Robots.

K. Evans and J. Dubowski. *Art therapy with children on the autistic spectrum: beyond words.* Jessica Kingsley Publishers, 2001.

I. Fasel, G.O. Deak, J. Triesch, and J. Movellan. Combining embodied models and empirical research for understanding the development of shared attention. In *Proc. of the 2nd International Conference on Development and Learning*, pages pp. 21–27, 2002.

David Feil-Seifer and Maja Matarić. Defining socially assistive robotics. In *Proceedings from the IEEE 9th International Conference on Rehabilitation Robotics*, 2005.

David Feil-Seifer and Maja Matarić. Toward socially assistive robotics for augmenting interventions for children with autism spectrum disorders. *International Symposium on Experimental Robotics*, 54:201–210, 2008a.

David Feil-Seifer and Maja J. Matarić. Automated detection and classification of positive vs negative robotic interactions with children with autism using distance-based features. In *Proceedings of 6th ACM/IEEE International Conference on Human Robot Interaction*, 2011.

David Feil-Seifer, Kristine Skinner, and Maja Matarić. Benchmarks for evaluating socially assistive robotics. *Interaction Studies: Psychological Benchmarks of Human-Robot Inteaction*, 8(3):423–439, 2007.

David J. Feil-Seifer and Maja J. Matarić. B3ia: An architecture for autonomous robot-assisted behavior intervention for children with autism spectrum disorders. In *IEEE Proceedings of the International Workshop on Robot and Human Interactive Communication*, August 2008b.

Ester Ferrari, Ben Robins, and Kerstin Dautenhahn. Therapeutic and educational objectives in robot assisted play for children with autism. In *Proceedings of the 18th IEEE International Symposium on Robot and Human Interactive Communication*, 2009.

Tiffany Field, Tory Field, Chris Sanders, and Jacqueline Nadel. Children with autism display more social behaviours after repeated imitation sessions. *Autism*, 5(3):317–323, 2001.

E Fombonne. The prevalence of autism. *The Journal of the American Medical Association*, Vol. 289:pp. 87–89, 2003.

Terrence Fong, Illah Nourbakhsh, and Kerstin Dautenhahn. A survey of socially interactive robots. *Robotics and Autonomous Systems*, 42:143–166, 2003a.

Terrence Fong, Charles Thorpe, and Charles Baur. Multi-robot remote driving with collaborative control. *IEEE Transactions on Industrial Electronics*, 50:699–704, 2003b.

Terrence W. Fong, Chuck Thorpe, and C. Baur. Collaboration, dialogue and human-robot interaction. In *Proceedings of 10th International Symposium of Robotics Research, Lorne, Victoria, Australia*, pages pp. 255–268, London, November 2001. Springer-Verlag.

Dorothée François, Daniel Polani, and Kerstin Dautenhahn. Towards socially adaptive robots: A novel method of real-time recognition of human-robot interaction styles. In *Proceedings of the 8th IEEE-RAS International Conference on Humanoid Robots*, 2008.

Dorothée François, Stuart Powell, and Kerstin Dautenhahn. A long-term study of children with autism playing with a robotic pet: Taking inspirations from non-directive play therapy to encourage children's proactivity and initiative-taking. *Interaction Studies*, 10:324–373, 2009.

Karl J Friston. Functional and effective connectivity in neuroimaging: a synthesis. *Human Brain Mapping*, 2:56–78, 1994.

U Frith. *Autism: Explaining the Enigma*. Blackwell, 1989.

Uta Frith and Francesca Happ. Autism: beyond "theory of mind". *Cognition*, 50: 115–132, 1994.

Eynat Gal, Nirit Bauminger, Dina Goren-Bar, Fabio Pianesi, Oliviero Stock, Massimo Zancanaro, and Patrice L. (Tamar) Weiss. Enhancing social communication of children with high-functioning autism through a co-located interface. *Artificial Intelligence & Society*, 24:75–84, 2009.

Catherine Garvey. *Play*. Cambridge University Press, 1977.

R J Gaylord-Ross, T G Haring, C Breen, and V Pitts-Conway. The training and generalization of social interaction skills with autistic youth. *Journal of Applied Behavioral Analysis*, 17(2):229–247, 1984.

Leonardo Giusti, Massimo Zancanaro, Eynat Gal, and Patrice L. (Tamar) Weiss. Dimensions of collaboration on a tabletop interface for children with autism spectrum disorder. In *Proceedings of the annual conference on Human factors in computing systems*, 2011.

M. A. Goodrich and A. C. Schultz. Human-robot interaction: A survey. *Foundations and Trends in Human-Computer Interaction*, 1(3):203–275, 2007.

Kristof Goris, Jelle Saldien, Innes Vanderniepen, and Dirk Lefeber. The huggable robot probo, a multi-disciplinary research platform. In *Proceedings of the EU-ROBOT Conference*, 2008.

Kristof Goris, Jelle Saldien, Bram Vanderborght, and Dirk Lefeber. How to achieve the huggable behavior of the social robot probo? a reflection on the actuators. *Mechatronics*, 21:490–500, 2011.

Temple Grandin. *Thinking in pictures*. Doubleday Publisher, 1995.

S I Greenspan and S Wieder. *The child with special needs: Encouraging intellectual and emotional growth*. Perseus Books, Reading, MA, 1998.

F. M. Gresham and S. N. Elliott. *Social Skills Rating System*. American Guidance Service, Circle Pines, MN, 1990.

Edward T Hall. *The Hidden Dimension*. Anchor Books, 1966.

Antonia Hamilton. Emulation and mimicry for social interaction: a theoretical approach to imitation in autism. *Quarterly Journal of Experimental Psychology*, 61:101–115, 2008.

Elisabeth L. Hill. Executive dysfunction in autism. *Trends in Cognitive Sciences*, 8:26–32, 2004.

Pamela J. Hinds, Teresa L. Roberts, and Hank Jones. Whose job is it anyway? a study of human-robot interaction in a collaborative task. *Human-Computer Interaction*, 19(1):151–181, 2004.

R Peter Hobson and Anthony Lee. Imitation and idenfitification in autism. *Journal of Child Psychology and Psychiatry*, 40(4):649–659, 1999.

P Howlin. *Social Behaviour in Autism*, chapter An Overview of Social Behaviour in Autism, pages 103–132. Plenum, New York, 1986.

Claire Hughes and James Russell. Autistic children's difficulty with mental disengagement from an object: Its implications for theories of autism. *Developmental Psychology*, 29:498–510, 1993.

Philippe E. Hurbain. Color sensors showdown, December 2011. URL `http://www.philohome.com/colcomp/cc.htm`.

Marco Iacoboni and Mirella Dapretto. The mirror neuron system and the consequences of its dysfunction. *Nature*, 7:942–951, 2006.

Iolanda Iacono, Hagen Lehmann, Patrizia Marti, Ben Robins, and Kerstin Dautenhahn. Robots as social mediators for children with autism - a preliminary analysis comparing two different robotic platforms. In *IEEE International Conference on Development and Learning (ICDL)*, 2011.

E.M. Järvinen. Lego/logolearning environment in technology education: An experiment in a finnish context. *The Journal of Technology Education*, 9:47–59, 1998.

Esa Matti Järvinen and Jukka Hiltunen. Automation technology in elementary technology education. *Journal of Industrial Teacher Education*, 37:51–76, 2000.

Shafali S. Jeste and Charles A. Nelson III. Event related potentials in the understanding of autism spectrum disorders: an analytical review. *Journal of Autism and Developmental Disorders*, 39:495–510, 2009.

R Jordan. *Autistic Spectrum Disorders - An Introductory Handbook for Practitioners.* David Fulton Publishers, London, 1999.

Rita Jordan. Social play and autistic spectrum disorders. *Autism*, Vol. 7(No. 4):pp 347–360, 2003.

Marcel Adam Just, Vladimir L. Cherkassky, Timothy A. Keller, and Nancy J. Minshew. Cortical activation and synchronization during sentence comprehension in high-functioning autism: evidence of underconnectivity. *Brain*, 127:1811–1821, 2004.

Marcel Adam Just, Vladimir L. Cherkassky, Timothy A. Keller, Rajesh K. Kana, and Nancy J. Minshew. Functional and anatomical cortical underconnectivity in autism: evidence from an fmri study of an executive function task and corpus callosum morphometry. *Cerebral Cortex*, 17:951–961, 2007.

Leonard E Kahn, Michele L Zygman, W Zev Rymer, and David J Reinkensmeyer. Robot-assisted reaching exercise promotes arm movement recovery in chronic hemiparetic stroke: a randomized controlled pilot study. *Journal of NeuroEngineering and Rehabilitation*, 3(12), 2006.

C Kasari, M Sigman, P Mundy, and N Yirmiya. Affective sharing in the context of joint attention interactions of normal, autistic, and mentally retarded children. *J Autism Dev Disord*, 20(1):87–100, 1990. ISSN 0162-3257. URL `http://www.biomedsearch.com/nih/Affective-sharing-in-context-joint/2139025.html`.

Connie Kasari, Stephanny Freeman, and Tanya Paparella. Joint attention and symbolic play in young children with autism: a randomized controlled intervention study. *Journal of Child*, 47(6):611–620, 2006.

Christian Keysers. *The empathic brain.* Createspace, 2011.

Cory D Kidd and Cynthia Breazeal. Effect of a robot on user perceptions. In *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2004.

S Kiesler and J. N. Cummings. What do we know about proximity and distance in work groups? a legacy of research. In P Hinds and S Kiesler, editors, *Distributed Work*, pages 57–80. The MIT Press, Cambridge, MA, 2002.

Chris L. Kleinke. Gaze and eye-contact: a research review. *Psychological Bulletin*, 100(1):78–100, 1986.

Hatice Kose-Bagci, Ester Ferrari, Kerstin Dautenhahn, Dag Sverre Syrdal, and Chrystopher L. Nehaniv. Effects of embodiment and gestures on social interaction in drumming games with a humanoid robot. *Advanced Robotics*, 23:1951–1996, 2009.

H. Kozima and H. Yano. Designing a robot for contingency detection game. In *Proc. of Workshop on Robotic and Virtual Interactive Systems in Autism Therapy*, 2001.

H. Kozima, C. Nakagawa, and Y. Yasuda. Interactive robots for communication-care: A case-study in autism therapy. In *Proc. of the IEEE International Workshop on Robot and Human Interactive Communication*, pages pp. 341–346, 2005.

Hideki Kozima, Yuriko Yasuda, and Cocoro Nakagawa. Social interaction facilitated by a minimally-designed robot: Findings from longitudinal therapeutic practices for autistic children. In *Proceedings of 16th IEEE International Conference on Robot & Human Interactive Communication*, 2007.

Hideki Kozima, Marek Michalowski, and Cocoro Nakagawa. Keepon: A playful robot for research, therapy, and entertainment. *International Journal of Social Robotics*, 1:3–18, 2009.

Gernot Kronreif and Barbara Prazak-Aram. Robot and play - from assistance to mediation. In *Proceedings of Robotic Helpers: User Interaction, Interfaces and Companions in Assistive and Therapy Robotics, a workshop at ACM/IEEE HRI*, 2008.

Thomas Laengle, Thomas Hoeniger, and Lanjuan Zhu. Cooperation in human-robot-teams. In *Proceedings of the IEEE International Symposium on Industrial Electronics*, 1997.

E. Landau. *Autism.* Franklin Watts, 2001.

Jean Lave and Etienne Wenger. *Situated learning: Legitimate peripheral participation.* Cambridge University Press, 1991.

Susan Leekam, Simon Baron-Cohen, Dave Perrett, Maarten Milders, and Sarah Brown. Eye-direction detection: A dissociation between geometric and joint attention skills in autism. *British Journal of Developmental Psychology*, 15:77–95, 1997.

D. B. LeGoff. Use of lego as a therapeutic medium for improving social competence. *Journal of Autism and Developmental Disorders*, 34(5):557571, 2004.

D. B. LeGoff and M. Sherman. Long-term outcome of social skills intervention based on interactive lego©play. *Autism*, 10(4):317–329, 2006.

Hector Levesque, Philip Cohen, and José Nunes. On acting together. In *Proceedings of the 8th National Conference on Artificial Intelligence (AAAI)*, 1990.

Simon P. Levine, David A. Bell, Lincoln A. Jaros, Richard C. Simpson, Yoram Koren, and Johann Borenstein. The navchair assistive wheelchair navigation system. *IEEE Transactions on Rehabilitation Engineering*, 7(4):443–451, 1999.

Susan E Levy, David S Mandell, and Robert T Schultz. Autism. *Lancet*, 374: 1627–1638, 2009.

Kristin Liebal, Costanza Colombi, Sally J. Rogers, Felix Warneken, and Michael Tomasello. Helping and cooperation in children with autism. *Journal of Autism and Developmental Disorders*, Vol. 38(Number 2):pages 224–238, 2008. doi: 10.1.1.150.1344.

Dale H. Litwhiler and Terrance D. Lovell. Usb data acquisition units in engineering technology applications. *International Journal of Modern Engineering*, 5(1), 2004.

Changchun Liu, Karla Conn, Nilanjan Sarkar, and Wendy Stone. Online affect detection and robot behavior adaptation for intervention of children with autism. *IEEE Transactions on Robotics*, 24:883–896, 2008.

P. Ljunglöf, A. Berman, B. Claesson, S. Ericsson, F. Kronlid, I. M. Müller, and C. Ottesjö. Lekbot: A talking and playing robot for children with disabilities. In *Proceedings from the 2nd Workshop on Speech and Language Processing for Assistive Technologies (SPLAT)*, 2011.

Peter Ljunglöf. Trik: A talking and drawing robot for children with communication disabilities. In *Proceedings of DiaHolmia: Workshop on the Pragmatics and Semantics of Dialogue*, 2009.

Andrea Lockerd and Cynthia Breazeal. Tutelage and socially-guided robot learning. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2004.

Michael J. Lyons, Ruth Campbell, Andre Plante, Mike Coleman, Miyuki Kamachi, and Shigeru Akamatsu. The noh mask effect: vertical viewpoint dependence of facial expression perception. *Proceedings of the Royal Society of London B*, 267: 2239–2245, 2000.

Richard M. Mahoney, H. F. Machiel Van der Loos, Peter S. Lum, and Chuck Burgar. Robotic stroke therapy assistant. *Robotica*, 21:33–44, 2003.

Thomas W. Malone, Thomas W. Malone, Kevin Crowston, and Kevin Crowston. What is coordination theory and how can it help design cooperative work systems. In *Proceedings of the Third Conference on Computer-Supported Cooperative Work, Los Angeles, Calif., Oct. 8-10*, pages 357–370, New York, October 1990. ACM Press.

Patrizia Marti. Bringing playfulness to disab. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, 2010.

Patrizia Marti, Claudio Moderini, Leonardo Giusti, and Alessandro Pollini. A robotic toy for children with special needs: from requirements to design. In

Proceedings of 11th IEEE International Conference of Rehabilitation Robotics, 2009.

J Mehrholz, T Platz, J Kugler, and M Pohl. Electromechanical and robot-assisted arm training for improving arm function and activities of daily living after stroke (review). *Cochrane Database of Systematic Reviews*, (4), 2008. Article number CD006876.

G. Metta, P. Fitzpatrick, and L. Natale. Yarp: Yet another robot platform. *International Journal on Advanced Robotics Systems*, Vol. 3 (1)(No. 1):pp 43–48, 2006.

Luanna Meyer, Ann Fox, Anita Schermer, Deanna Ketelsen, Nancy Montan, Kathy Maley, and David Cole. The effects of teacher intrusion on social play interactions between children with autism and their non-handicapped peers. *Journal of Autism and Developmental Disorders*, 17(3):315–332, 1987.

F. Michaud and F. Théberge-Turmel. Mobile robotic toys and autism. In K. Dautenhahn, A. Bond, L. Canamero, and B. Edmonds, editors, *Socially Intelligent Agents - Creating Relationships with Computers and Robots*, pages pp. 125–132. Kluwer Academic Publishers, 2002.

David P Miller and Marc G Slack. Design and testing of low-cost robotic wheelchair prototype. *Autonomous Robots*, 2:77–88, 1995.

Marissa Milne, Martin Luerssen, Trent Lewis, Richard Leibbrandt, and David Powers. *A comprehensive book on autism spectrum disorders*, chapter Embodied conversational agents for education in autism, pages 387–412. Intech, 2011.

D Moore. Computers and people with autism. *Communication*, Summer:pp 20–21, 1998.

Peter Mundy, Marian Sigman, Judy Ungerer, and Tracy Sherman. Defining the social deficits of autism: the contribution of non-verbal communication measures. *Journal of Child Psychology and Psychiatry*, 27(5):657–669, 1986.

Michael Murias, Sara J. Webb, Jessica Greenson, and Geraldine Dawson. Resting state cortical connectivity reflected in eeg coherence in individuals with autism. *Biological Psychiatry*, 62:270–273, 2007.

Scott M. Myers and Chris Plauch Johnson. Management of children with autism spectrum disorders. *Pediatrics*, 120:1162–1182, 2007.

Jacqueline Nadel. Imitation and imitation recognition: functional use in preverbal infants and nonverbal children with autism. In AN Meltzoff, W Prinz, KW Fischer, and G Hatano, editors, *The Imitative Mind: Development, Evolution, and Brain Bases*, chapter 2. Cambridge University Press, 2002.

Jacqueline Nadel, Sabine Croué, Marie-Jeanne Mattlinger, Pierre Canet, C. Hudelot, C. Lécuyer, and Mary Martini. Do children with autism have expectancies about the social behaviour of unfamiliar people? *Autism*, 4(2):133–145, 2000. doi: 10.1177/1362361300004002003. URL `http://aut.sagepub.com/content/4/2/133.abstract`.

Chris Nikolopoulos, Deitra Kuester, Mark Sheehan, and Sneha Dhanya. Investigation on requirements of robotic platforms to teach social skills to individuals with autism. In Maarten H. Lamers, Fons J. Verbeek, Ozgur Akan, Paolo Bellavista, Jiannong Cao, Falko Dressler, Domenico Ferrari, Mario Gerla, Hisashi Kobayashi, Sergio Palazzo, Sartaj Sahni, Xuemin (Sherman) Shen, Mircea Stan, Jia Xiaohua, Albert Zomaya, and Geoffrey Coulson, editors, *Human-Robot Personal Relationships*, volume 59 of *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*, pages 65–73. Springer Berlin Heidelberg, 2011a. ISBN 978-3-642-19385-9. URL http://dx.doi.org/10.1007/978-3-642-19385-9$_9$. 10.1007/978 − 3 − 642 − 19385 − 9$_9$.

Christos Nikolopoulos, Deitra Kuester, Mark Sheehan, Shashwati Ramteke, Aniket Karmarkar, Supriya Thota, Joseph Kearney, Curtis Boirum, Sunnihith Bojedla, and Angela Lee. Robotic agents used to help teach social skills to children with autism: the third generation. In *Proceedings of the 20th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, 2011b.

Illah Nourbakhsh, Kevin Crowley, Ajinkya Bhave, Emily Hamner, Thomas Hsiu, Andres Perez-Bergquist, Steve Richards, and Katie Wilkinson. The robotic autonomy mobile robotics course: Robot design, curriculum design and educational assessment. *Autonomous Robots*, 18:103–127, 2005.

I.R. Nourbakhsh, E. Hamner, K. Crowley, and K. Wilkinson. Formal measures of learning in a secondary school mobile robotics course. In *Proceedings on the IEEE International Conference on Robotics and Automation (ICRA)*, 2004.

Kate O'Connor, Jeff P Hamm, and Ian J Kirk. Neurophysiological responses to face, facial regions and objects in adults with asperger's syndrome: an erp investigation. *International Journal of Psychophsyiology*, 63:283–293, 2007.

Samuel L. Odom and Phillip S. Strain. A comparison of peer-initiation and teacher-antecedent interventions for promoting reciprocal social interaction for autistic preschoolers. *Journal of Applied Behavioral Analysis*, 19(1):59–71, 1986.

Samuel L. Odom, Scott R. McConnell, Mary A. McEvoy, Carla Peterson, Michaelene Ostrosky, Lynette K. Chandler, Richard J. Spicuzza, Annette Skellenger, Michelle Creighton, and Paddy C. Favazza. Relative effects of interventions supporting the social competence of young children with disabilities. *Topics in Early Childhood Special Education*, 19(2):75–91, 1999.

Claire O'Malley. Designing computer systems to support peer learning. *European Journal of Psychology of Education*, 7:339–352, 1992.

Gina Owens, Yael Granader, Ayla Humphrey, and Simon Baron-Cohen. Lego® therapy and the social use of language programme: an evaluation of two social skills interventions for children with high functioning autism and asperger syndrome. *Journal of Autism and Developmental Disorders*, 38:1944–1957, 2008. ISSN 0162-3257. URL `http://dx.doi.org/10.1007/s10803-008-0590-6`. 10.1007/s10803-008-0590-6.

S. Ozonoff and Robin McEvoy. A longitudinal study of executive function and theory of mind development in autism. *Development and Psychopathology*, 6: 415–431, 1994.

Sally Ozonoff and Jenise Jensen. Brief report: Specific executive function profiles in three neurodevelopmental disorders. *Journal of Autism and Developmental Disorders*, 29:171–177, 1999.

Sally Ozonoff, Bruce F Pennington, and Sally J Rogers. Executive function deficits in high-functioning autistic individuals: Relationship to theory of mind. *Journal of Child Psychology and Psychiatry*, 32:1081–1105, 1991.

Seymour Papert. *Mindstorms: children, computers, and powerful ideas.* Basic Books, Inc., New York, NY, USA, 1980. ISBN 0-465-04627-4.

Martha Parten. Social play among preschool children. *Journal of Abnormal and Social Psychology*, 27:243–269, 1932.

Bruce F Pennington and Sally Ozonoff. Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry*, 37:51–87, 1996.

David J. Perdue. *The unofficial Lego Mindstorms NXT inventor's guide.* No Starch Press, Inc, 2008.

Jean Piaget. *Play, Dreams, and Imitation in Childhood.* W. W. Norton and Co, 1962.

G. Pioggia, M.L. Sica, M. Ferro, R. Igliozzi, F. Muratori, A. Ahluwalial, and D. De Rossi. Human-robot interaction in autism: Face, an android-based social therapy. In *Proceedings of the 16th IEEE International Conference on Robot & Human Interactive Communication*, 2007.

Anne Marie Piper, Eileen OBrien, Meredith Ringel Morris, and Terry Winograd. Sides: a cooperative tabletop computer game for social skills development. In *Proceedings from the ACM Conference onComputer-supported Cooperative Work (CSCW)*, 2006.

S Powell. *The use of computers in teaching people with autism.* Autism on the agenda: papers from a National Autistic Society Conference, London, London, 1996.

GB Prange, MJ Jannink, CG Groothuis-Oudshoorn, HJ Hermens, and MJ Ijzerman. Systematic review of the effect of robot-aided therapy on recovery of the hemiparetic arm after stroke. *Journal of Rehabilitiation Research and Development*, 43(2):171–184, 2006.

David Premack and Guy Woodruff. Does the chimpanzee have a theory of mind? *Behavioral and brain sciences*, 4:515–526, 1978.

Sadhana Puntambekar, Kris Nagel, Roland Hübscher, Mark Guzdial, and Janet L. Kolodner. Intra-group and intergroup: an exploration of learning with complementary collaboration tools. In Rogers Hall, Naomi Miyake, and Noel Enyedy, editors, *Proceedings of Computer Support for Collaborative Learning.* University of Toronto, 1997.

Qualifications and Curriculum Authority. The p scales: level descriptors p1 to p8, 2009.

P Ravindra, S De Silva, Katsunori Tadano, Azusa Saito, Stephen M. Lambacher, and Mastake Higashi. Therapeuritc-assisted robot for children with autism. In *Proceedings of IEEE/RSJ International Conference on Intelligent Robts and Systems*, 2009.

G Restall and J Magill-Evans. Play and preschool children with autism. *American Journal of Occupational Therapy*, 48:113120, 1994.

Giacomo Rizzolatti and Laila Craighero. The mirror-neuron system. *Annual Review of Neuroscience*, 27:169–192, 2004.

B. Robins and K. Dautenhahn. Encouraging social interaction skills in children with autism playing with robots: A case study evaluation of triadic interactions involving children with autism, other people (peers and adults) and a robotic toy. *ENFANCE*, 59(1):72–81, 2007.

B. Robins, K. Dautenhahn, R. te Boekhorst, and A. Billard. Effects of repeated exposure of a humanoid robot on children with autism. In S. Keates, J. Clarkson, P. Langdon, and P. Robinson, editors, *Designing a more inclusive world*, chapter 23, pages 225–236. Springer-Verlag, 2004a. URL `http://robota.epfl.ch`. Sponsor: Swiss National Science Foundation.

B. Robins, K. Dautenhahn, R. te Boekhorst, and A. Billard. Robotic assistants in therapy and education of children with autism: Can a small humanoid robot help encourage social interaction skills? *Universal Access in the Information Society (UAIS)*, Vol. 4(No. 2):pp 105–120, 2005.

B. Robins, K. Dautenhahn, and J. Dubowski. Does appearance matter in the interaction of children with autism with a humanoid robot? *Interaction Studies*, 7: 509–542, 2006.

B. Robins, N. Otero, E. Ferrari, , and K. Dautenhahn. Eliciting requirements for a robotic toy for children with autism - results from user panels. In *RO-MAN07 - International Symposium on Human and Robot Communication*, 2007.

B. Robins, K. Dautenhahn, and P. Dickerson. From isolation to communication: A case study evaluation of robot assisted play for children with autism with a minimally expressive humanoid robot. In *Proc. the Second International Conferences on Advances in Computer-Human Interactions, ACHI 09*, 2009.

Ben Robins and Kerstin Dautenhahn. The role of the experimenter in hri research - a case study evaluation of children with autism interacting with a robotic toy. In *Proc. 15th IEEE International Symposium on Robot and Human Interactive Communication*, pages pp. 646–651, Piscataway, NJ, 2006. IEEE.

Ben Robins and Kerstin Dautenhahn. Developing play scenarios for tactile interaction with a humanoid robot: A case study exploration with children with autism. *Lecture Notes in Computer Science*, 6414:243–252, 2010.

Ben Robins, Kerstin Dautenhahn, and Janek Dubowski. Investigating autistic childrens attitudes towards strangers with the theatrical robot - a new experimental paradigm in human-robot interaction studies. In *13th IEEE International Workshop on Robot and Human Interactive Communication*, 2004b.

Ben Robins, Kerstin Dautenhahn, Rene te Boekhorst, and Aude Billard. Robots as assistive technology - does appearance matter? In *13th IEEE International Workshop on Robot and Human Interactive Communication*, 2004c.

Ben Robins, Paul Dickerson, Penny Stribling, and Kerstin Dautenhahn. Robot-mediated joint attention in children with autism: A case study in robot-human interaction. *Interaction Studies*, 5(2):161–198, 2004d.

Ben Robins, Ester Ferrari, and Kerstin Dautenhahn. Developing scenarios for robot assisted play. In *Proceedings of the 17th IEEE International Symposium on Robot and Human Interactive Communication*, 2008.

Ben Robins, Farshid Amirabdollahian, Ze Ji, and Kerstin Dautenhahn. Tactile interaction with a humanoid robot for children with autism: A case study analysis involving user requirements and results of an initial implementation. In *19th IEEE International Workshop on Robot and Human Interactive Communication (RO-MAN 10)*, 2010.

Y. Rogers and S.E. Lindley. Collaborating around vertical and horizontal large interactive displays: Which way is best? *Interacting with Computers*, Vol. 16:pp 1133–1152, 2004.

J. Roschelle and S. Teasley. The construction of shared knowledge in collaborative problem solving. In C. OMalley, editor, *Computer-supported collaborative learning*, pages pp. 69–97. Springer-Verlag., New York, 1995.

R. Rosenthal and R.L. Rosnow. *Essentials of behavioral research: Methods and Data Analysis (third edition)*. McGraw-Hill, 2008.

James Russell, Suzanne Hala, and Elisabeth Hill. The automated windows task: the performance of preschool children, children with autism, and children with moderate learning difficulties. *Cognitive Development*, 18:111–137, 2003.

Jelle Saldien, Kristof Goris, Bram Vanderborght, and Dirk Lefeber. On the design of an emotional interface for the huggable robot probo. In *The Reign of Catz and Dogz, AISB*, 2008a.

Jelle Saldien, Kristof Goris, Selma Yilmazyildiz, Werner Verhelst, and Dirk Lefeber. On the design of the huggable robot probo. *Journal of Physical Agents*, 2(2):3–11, 2008b.

Tamie Salter, Rene te Boekhorst, and Kerstin Dautenhahn. Detecting and analysing children's play styles with autonomous mobile robots: a case study comparing observational data with sensor readings. In *Proceedings of the 8th Conference on Intelligent Autonomous Systems (IAS-8)*, 2004.

Brian Scassellati. How social robots will help us to diagnose, treat, and understand autism. In *Proceedings of the 12th International Symposium of Robotics Research (ISSR '05)*, October 2005a.

Brian Scassellati. Quantitative metrics of social response for autism diagnosis. In *Proceedings of the 14th IEEE international workshop on robot and human interactive communication (ROMAN 05)*, 2005b.

Stacey Scott, Karen Grant, and Regan Mandryk. System guidelines for co-located, collaborative work on a tabletop display. In *Proceedings of the Eighth European Conference on Computer Supported Cooperative Work*, 2003.

Jennifer Krebs Seida, Maria B Ospina, Mohammad Karakhaneh, Lisa Hartling, Veronica Smith, and Brenda Clark. Systematic reviews of psychosocial interventions for autism: an umbrella review. *Developmental Medicine and Child Neurology*, 51:95–104, 2009.

Amitta Shah and Uta Frith. Why do autistic individuals show superior performance on the block design task? *Journal of Child Psychology and Psychiatry*, 34:1351–1364, 1993.

Takanori Shibata, Kazuyoshi Inoue, and Robert Irie. Emotional robot for intelligent system - artificial emotional creature project. In *IEEE International Workshop on Robot and Human Communication*, 1996.

Takanori Shibata, Teruaki Mitsui, Kazuyoshi Wada, Akihiro Touda, Takayuki Kumasaka, Kazumi Tagami, and Kazuo Tanie. Mental commit robot and its application to therapy of children. In *Proceedings of IEEE / ASME International Conference on Advanced Intelligent Mechatronics*, 2001.

Steven Shooter and Mark McNeill. Interdisciplinary collaborative learning in mechatronics at bucknell university. *Journal of Engineering Education*, 91:339–344, 2002.

Ace L. Sidner, Candace L. Sidner, Christopher Lee, Christopher Lee, Neal Lesh, and Neal Lesh. Engagement rules for human-robot collaborative interactions. In *Proc. IEEE International Conference on Systems, Man & Cybernetics (CSMC)*, volume 4, pages 3957–3962, 2003.

M Sigman and E Ruskin. Continuity and change in the social competence of children with autism, down syndrome, and developmental delays. *Monographs of the Society for Research in Child Development*, 64(1):1–130, 1999.

Marian Sigman and Judy Ungerer. Cognitive and language skills in autistic, mentally retarded, and normal children. *Developmental Psychology*, 20(2):293–302, 1984.

Philip Strain, Mary Kerr, and Elizabeth Ragland. Effects of peer-mediated social initiations and prompting/reinforcement procedures on the social behavior of autistic children. *Journal of Autism and Developmental Disorders*, 9(1):41–54, 1979.

Taito. Bubble bobble. [Arcade], 1986.

Tsuyoshi Tasaki, Shohei Matsumoto, Hayato Ohba, Shunichi Yamamoto, Mitsuhiko Toda, Kazunori Komatani, Tetsuya Ogata, and Hiroshi G. Okuno. Dynamic communication of humanoid robot with multiple people based on interaction distance. *Transactions of the Japanese Society for Artificial Intelligence*, 20:209–219, 2005.

Danielle M. Thorp, Aubyn C. Stahmer, and Laura Schreibman. Effects of sociodramatic play training on children with autism. *Journal of Autism and Developmental Disorders*, 25(3):265–282, 1995.

Karen Toth, Jeffrey Munson, Andrew N. Meltzoff, and Geraldine Dawson. Early predictors of communication development in young children with autism spectrum disorder: Joint attention, imitation, and toy play. *Journal of Autism and Developmental Disorders*, 36:993–1005, 2006.

The United States of America, editor. *Aeronautical information manual: official guide to basic flight information and ATC procedures (online)*. Federal Aviation Administration, Washington D.C., 2012.

Marjo Virnes. Robotics in special needs education. In *Proceedings of the 7th International Conference on Interaction Design and Children (IDC)*, 2008.

Fred R. Volkmar and Linda C. Mayes. Gaze behavior in autism. *Development and Psychopathology*, 2:61–69, 1990.

Lev Vygotsky. *Mind in Society*. Harvard University Press, 1978.

Kazuyoshi Wada, Takanori Shibata, Tomoko Saito, and Kazuo Tanie. Analysis of factors that bring mental effects to elderly people in robot assisted activity. In *Proceedings of the IEEE / RSJ Intl. Conference on Intelligent Robots and Systems*, 2002.

Kazuyoshi Wada, Takanori Shibata, Tomoko Saito, and Kazuo Tanie. Effects of robot-assisted activity for elderly people and nurses at a day service center. *Proceedings of the IEEE*, 92(11):1780–1788, 2004.

Kazuyoshi Wada, Takanori Shibata, Tomoko Saito, Kayoko Sakamoto, and Kazuo Tanie. Psychological and social effects of one year robot assisted activity on elderly people at a health service facility for the aged. In *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*, 2005.

Josh Wainer, David Feil-Seifer, Dylan Shell, and Maja J. Matarić. The role of physical embodiment in human-robot interaction. In *IEEE Proceedings of the International Workshop on Robot and Human Interactive Communication*, pages 117–122, 2006.

Josh Wainer, David Feil-Seifer, Dylan Shell, and Maja J. Matarić. Embodiment and human-robot interaction: a task-based perspective. In *16th IEEE International Conference on Robot & Human Interactive Communication*, 2007.

Josh Wainer, Kerstin Dautenhahn, Ben Robins, and Farshid Amirabdollahian. Collaborating with kaspar: Using an autonomous humanoid robot to foster cooperative dyadic play among children with autism. In *Proc. IEEE-RAS International Conference on Humanoid Robots*, pages 631 – 638, December 2010.

S. Weir and R. Emanuel. Using logo to catalyse communication in an autistic child. Technical Report DAI Research Report No. 15, University of Edinburgh, 1976.

Patrice L. (Tamar) Weiss, Eynat Gal, Sigal Eden, Massimo Zancanaro, and Francesco Telch. Usability of a multi-touch tabletop surface to enhance social competence training for children with autism spectrum disorder. In *Proceedings of the Chais conference on instructional technologies research*, 2011.

Iain Werry, Kerstin Dautenhahn, and William Harwin. Evaluating the response of children with autism to a robot. In *RESNA 2001, Rehabilitation Engineering and Assistive Technology Society of North America*, Reno, Nevada, USA, June 22 - 26 2001a.

Iain Werry, Kerstin Dautenhahn, Bernard Ogden, and William Harwin. Can social interaction skills be taught by a social agent? the role of a robotic mediator in autism therapy. In M. Beynon, C. L. Nehaniv, and K. Dautenhahn, editors, *Proceedings of CT2001, The Fourth International Conference on Cognitive Technology: Instruments of Mind, LNAI 2117*, pages pp. 57–74, 2001b.

Andrew J O Whitehouse and Dorothy V M Bishop. Do children with autism switch off to speech sounds? an investigation using event-related potentials. *Developmental Science*, 11:516–524, 2008.

Justin H G Williams. Self-other relations in social development and autism: multiple roles for mirror neurons and other brain bases. *Autism Research*, 1:73–90, 2008.

Justin H G Williams, Andrew Whiten, Thomas Suddendorf, and David I Perrett.

Imitation, mirror neurons, and autism. *Neuroscience and Biobehavioral Reviews*, 25(4):287–295, 2001.

WilliamsElectronics. Joust. [Arcade], 1982.

L. Wing. *The autistic spectrum.* Constable Press, London, 1996.

Lorna Wing, Judith Gould, Sybil R. Yeates, and Lorna M. Brierly. Symbolic play in severely mentally retarded and in autistic children. *Journal of Child Psychology and Psychiatry*, 18:167–178, 1977.

P. J. Wolfberg and A. L. Schuler. Fostering peer interaction, imaginative play, spontaneous language in children with autism. *Child Language Teaching and Therapy*, 15(1):4152, 1999.

Britta Wrede, Stefan Kopp, Katharina Rohlfing, Manja Lohse, and Claudia Muhl. Appropriate feedback in asymmetric interactions. *Journal of Pragmatics*, 42: 2369–2384, 2010.

Sharon Wulff. The symbolic and object play of children with autism: A review. *Journal of Autism and Developmental Disorders*, 15:139–148, 1985.

Holly A. Yanco and Jill L. Drury. Classifying human-robot interaction: an updated taxonomy. In *Proc. IEEE Conf. on Systems, Man and Cybernetics, The Hague, The Netherlands*, volume 3, pages 2841–2846, New York, NY, 2004. IEEE Press.

Holly A. Yanco and James Gips. Driver performance using single switch scanning with a powered wheelchair: robotic assisted control versus traditional control. In *RESNA 98*, 1998.

Massimo Zancanaro, Leonardo Giusti, Eynat Gal, and Patrice Weiss. Three around a table: the facilitator role in a co-located interface for social competence training of children with autism spectrum disorder. In Pedro Campos, Nicholas Graham, Joaquim Jorge, Nuno Nunes, Philippe Palanque, and Marco Winckler, editors, *Human-Computer Interaction: INTERACT 2011*, volume 6947 of *Lecture Notes in Computer Science*, pages 123–140. Springer Berlin / Heidelberg, 2011. ISBN 978-3-642-23770-6. URL http://dx.doi.org/10.1007/978-3-642-23771-3$_1$1. $10.1007/978 - 3 - 642 - 23771 - 3_1 1$.