A Humanoid Robot as Assistive Technology for Encouraging Social Interaction Skills in Children with Autism

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Abstract

Interactive robots, virtual environments and other computer based technologies are increasingly applied in rehabilitation therapy and education. The research presented in this thesis investigates the potential use of a humanoid robot as assistive technology for encouraging social interaction skills specifically in children with autism. The research focuses on ways in which the humanoid robot can engage autistic children in simple interactive activities such as turn-taking and imitation games, and how the robot can assume the role of social mediator, encouraging the children to interact with the robot, with each other and with co-present adults. The research also investigates which robot design (in terms of appearance) best facilitates these interactions. The approach that was developed in the research adopted a longitudinal repeated measure design, carried out over a long period of time. Based on the video material documenting the interactions, several quantitative and qualitative analyses were conducted. The quantitative analyses showed an increase in the duration of pre-defined interactional behaviours toward the later trials. The quantitative analysis in regard to the robot's appearance clearly indicated, by their response, the children's preference for interaction with a plain featureless robot over interaction with a human-like robot. Qualitative analyses in the form of case-study evaluations of segments of trials are presented, observing the children's activities in their interactional context. Some of the analyses focus on joint attention skills which play a fundamental role in human development and social understanding. In the setting used, joint attention emerges from natural and spontaneous interactions between the children and an adult and between the children and other children. The analyses revealed further aspects of social interaction skills (such as imitation,

turn-taking, role-switch, body-orientation) and communicative competence that the children showed. The results show how children exhibited interaction skills where the robot, assuming the role of a social mediator, served as a salient object mediating joint attention with other people (adults and children).

Contents

Chapter 1

Introduction

In recent years, software and robotic based interactive learning environments have increasingly been studied from the standpoint of their use in the therapy or education of people with autism (see section 2.3). The work presented in this thesis is part of the Aurora project, rooted in assistive technology and robot-human interaction research (AURORA 2005). The project investigates the potential use of robots as therapeutic or educational 'toys' specifically for use by children with autism. Children with autism have impaired social interaction, social communication and imagination, and have difficulties in forming social relationships. They are often described as being outside the culture in which they live, showing what is sometimes described as "aloofness", a typical avoidance behaviour that autistic children show toward other people. The research presented in this thesis focuses on the ways that a small humanoid robot can engage autistic children in simple interactive activities, such as turn-taking or imitative interactions, with the overall aim of encouraging basic communication and social interaction skills.

Being an inter-disciplinary project, the approach to this research is inspired by

therapeutic issues (see also section 3.1). In art therapies, such as dance, art, drama or play therapy, people use the various art forms as a medium through which to explore issues and experiences in their lives. They feel safe knowing that they are acting/'playing' outside themselves. This distancing, as provided by these media, is at the core of the therapeutic process in all art therapies (Cattanach 1999a). In situations where direct interaction between people is too difficult, or not possible at all, art therapy may use props which can become particularly significant as *bridges* for relating to others, be it in the client therapist relationship, or in relationships amongst peers (Bannerman-Haig 1999, Meekums 2002). Sara Bannerman-Haig provides an account of a case study where she is working with an adolescent boy, who was resisting any direct intervention from her. Some props were placed at the edge of the space and provided the *first access point* for interaction in several months. The props gave the boy *a channel he could communicate through*, and from that point onwards their relationship started to develop and he began to include the therapist in his play, interacting with her through the props (Bannerman-Haig 1999). Similarly, when peers in a group session are facing difficulties in communicating directly with each other, or in tolerating other people entering their own personal space, a focus on an outside object may provide a projective distance necessary for the people to feel safe to interact. The object becomes the mediator for these interactions.

In a similar way, by the use of robots as possible therapeutic or educational toys, we may create this distance whereby autistic children can feel safe; with the robot acting as a mediator the children can be encouraged to explore their interaction with other people in a way that is non-threatening to them.

This thesis investigates specific research questions about a) the effects of repeated exposure to a humanoid robot, b) the appearance of the robot, and c) the role of

the robot as a mediator in the interaction between autistic children and their peers and adults.

1.1 Overview of the Research

1.1.1 Methodological Considerations

A) Preparations :

- **Finding subjects for the trials -** this involved contacting two local authorities (Essex and Hertfordshire), contacting head teachers, setting up meetings, visiting schools and proposing collaboration. Good working relationships with schools are essential for the research.

- **Programming the robot -** some of the robot's pre-defined behaviour needed modification according its users' (children with autism) level of development (e.g. the speed of movements of the robot's limbs and head, or a sequence of movements to parts of various pre-recorded pieces of music, etc). In addition, the robot interface needed re-programming for an easy remote control operation via a laptop. This re-programming was repeated several times during the preparations for the different stages of the research (different children in different schools, different scenarios were investigated etc).

- **Obtaining parental consent -** this included sending letters to parents (via the school) introducing the research and requesting their consent for the participation of their children in the trials, for video recording of their children and for publishing results which might include photo stills

of the children. This process repeated itself several times when consent to appear in different TV documentary programs were sought after. Trials could only begin after obtaining consent from the parents (see sample letter in appendix C)

B) Selection process :

- **Special observation sessions during school activities -** these observation sessions were aimed at observing the children's social behaviour during their daily activities at school i.e. during break time in the playground, around the table at lunch time, in reading/story telling classes, in art and craft classes, in movement/physical education classes. These sessions focused on individual children and followed and observed each child's behaviour in the different settings. Approximately 30 hours of these observations took place over 13 special visits to the two collaborating schools prior to the commencement of trials with the robot.

- **Conducting preliminary trials -** conducting various trials where the children were presented with the opportunity to play and interact with the robot. In these preliminary trials I monitored the children's reaction and response to the robot, to each other and to me- the only experimenter present. This was done in conjunction with ongoing consultations with their teachers. Forty-one such preliminary trials took place, some with individual autistic children and the robot, some with different pairs of children with autism and the robot, and some with the robot and with pairs of children where only one is autistic. These trials helped in selecting the children that later participated in the main study.

The nature of autism is such that children's behaviour, skills and abilities differ enormously. The selection process was aimed at discovering which children were potentially most likely to benefit from trials with the robot (on their own and with the other children). It took into account each child's skills and development assessments that were periodically carried out by the teachers, as well as the children's availability, their curriculum activities and other commitments they might have.

C) Conducting and recording the trials :

All the trials in this research were solely arranged and carried out by myself and I was the sole investigator present. This included the setting up of the rooms (i.e. clearing out unwanted furniture, setting up the robot, the laptop and two video cameras), conducting the experiments, remotely operating the robot, activating the cameras and closely monitoring the children in the most un-intrusive way (see 'the role of the experimenter' section below). I have conducted 74 trials during the main study and recorded 249 minutes of video data in total. Including the preliminary trials, I conducted 115 individual trials (476 minutes of video footage in total).

D) Analysing the data :

I analysed second by second 12,720 seconds (212 minutes) of video footage, watching videos several times during the studies described in chapter 4 and 5, scoring and evaluating pre-defined micro behaviours of the children. These scores were the basis for the quantitative analysis that helped to create interaction profiles for each of the children that took part in theses studies. I also monitored very closely and in great detail all the video footage from all the

trials, many times over and produced an observational and qualitative analysis of the results. In one part of the investigation (see chapter 6) I carefully selected short sequences to be analyzed in greater detail, partly using Conversation Analysis (CA) with the help of an expert. CA can help to focus in depth on the autistic child's activities in their interactional context, to understand subtle details of the events that take place during such interactions and to highlight interactional competencies on the part of the child that otherwise might be overlooked.

1.1.2 Ethical Considerations

This research has been approved by the Ethics Committee of the University of Hertfordshire. In addition, I applied for an Enhanced Disclosure, and an Enhanced Criminal Record Certificate was issued by the Criminal Record Bureau (CRB). In the light of the nature of the population that participated in this research, I was also constantly aware of the following issues and took extra precautions to ensure they were met at all times:

consent :

- Parents consent - as stated above, the parents were informed about the nature and practices taken in the research, they gave their consent for the participation of the children in the research and for its publication within the scientific community. Additional consent was sought after for any exposure outside the immediate scientific community (e.g. for television programs).

- The head teacher at Bentfield school and the head of Autism Provision at Middleton school were regularly consulted, and were ongoingly made aware of trial procedures and outcomes.

Well-being of participants :

- At Bentfield school, all trials were conducted with the child's carer present. During trials, myself and the carer consulted each other as needed, constantly aware of the well-being of the child (and the robot). At Middleton school, similar consultation took place after the trials as a teacher wasn't available to be present during trials. In both schools, trials would stop if the children exhibited any sign of distress.

- The robot's behaviour, although simple and by and large repetitive, was constantly changed by small degrees in how the robot was responding to a child, so as to avoid perpetuating stereotypical and repetitive behaviour that is characteristic of autism.

Privacy and trust :

- Confidentiality and anonymity of the participants was kept at all time.

1.1.3   The role of the experimenter

Unlike traditional Human-Robot Interaction (HRI) research where trials include the subjects and the robot, and the experimenter not only does not take part in the experiment but is often also located out of sight, here, in this research, the contrary case applies. The research investigates how to encourage social interaction skills

in children with autism. One of the main impairments of this user group lies in communication and social interaction, therefore the approach taken in the research is that if the children do initiate any interaction with the experimenter they *should* get a response and encouragement. Thus the experimenter should include himself as part of the trial, adopting the stance of 'passive participation', to be another possible instrument for encouraging social interactions, to be available and ready to respond to the children should they initiate interaction with him.

Furthermore, similar to a therapist in a therapy session, the experimenter should be 'in contact' with the children all the time with the 'finger on the pulse' to be able to respond accurately to the children (via the robot when they interact with the robot) and to 'seize the opportunity' for further possible interactions should they arise even if it means the need to change the pre-planned procedure of the trial. Although working to a plan, the experimenter needs be able to deviate from it and grasp any opportunity to expand and develop the interactions. In such situations an experienced experimenter can respond from 'gut feelings' or 'intuition' but also needs to concentrate hard and think quickly in selecting the most valuable variation on the basic theme of the original plan. At the same time this process requires a great deal of awareness in order to maintain the overall containment and structure of the trial.

Although this research is based in Computer Science and robotics and not in therapy, the approach described above is in some ways very similar to approaches used by therapists in therapy sessions. To conduct successful and safe research using this approach requires an experimenter with a lot of experience in therapy and with access to expert advice (in the field of autism).

Being the sole experimenter, my years of experience working in various capacities

with disabled people became vital to the success of the research. I am a qualified dance movement therapist with 14 years of experience in providing therapeutic and creative movement sessions to people with various physical and mental disabilities. Without this experience, I don't think that the chosen approach, where the experimenter has a specific role and is an important part of the trial, would have been possible.

1.2 Overview of the Thesis

Chapter 2 provides background knowledge in the areas of autism, socialisation and learning, and assistive technology, and at the end summarises the motivation behind the research and sets out the research questions.

Section 2.1 starts with an overview about autism and highlights the communication and social interaction difficulties that people with autism have. It continues with a brief overview of some of the main theories put forward to explain autism which are relevant to this research (i.e. Executive Function, Theory of Mind, Central Coherence Theory) and it shows how interaction with robots could ease some of the social interaction difficulties that people with autism are facing.

Section 2.2 discusses briefly various principles of social learning and social development (e.g Vygotsky's social development theory, Bruner's cognitive growth, Activity Theory) and their application in Human Robot Interaction (HRI).

Section 2.3 examines the use of robots in therapy and education in general, and continues with an overview of the specific use of computer technology

and robotic systems in autism therapy and education. It then gives a more detailed account of the robotic research done previously in the Aurora Project with children with autism as a precursor to the work presented in this thesis. **Section 2.4** gives the motivation behind the research and sets out three research questions.

Chapter 3 discusses the approach taken in designing the trials, which was also influenced by principles used in therapy. It then introduces the robotic platform used (a humanoid robotic doll called Robota) and discusses the robot's adaptation for use specifically by children with autism.

Chapter 4 presents a longitudinal study with four children with autism who were repeatedly exposed to the humanoid robot over a period of several months using basic imitative and turn-taking games. Different behavioural criteria (including Eye Gaze, Touch, Near and Imitation) were evaluated based on video data of the interactions, and the results of the quantitative and qualitative analysis that was performed are discussed.

Chapter 5 presents an investigation into the effect of the robot's design (appearance) on facilitating and encouraging the interaction of children with autism with a humanoid robot. Two different types of robots were used: a life-sized 'Theatrical Robot' (a mime artist behaving like a robot) as described in **section 5.3** and the small humanoid robotic doll called *Robota* (**section 5.4**). The study compares the children's levels of interaction with and response to both robots in two different scenarios; one where the robots were dressed like a human (an 'ordinary person' in the case of the Theatrical Robot, and a 'pretty-girl' appearance in the case of the humanoid robotic doll), including

an uncovered face; and the other when the 'robots' appeared with plain clothing and with a featureless, masked face. Quantitative and qualitative results of the evaluation of the video data of the interactions are discussed.

Chapter 6 focuses on the investigation into which ways and to what extent a robot can assume the role of a social mediator, an object of shared attention - encouraging autistic children to interact with the robot, with each other and with co-present adults.

Section 6.1 gives a short review of current studies in autism research of *joint attention* skills in children with autism.

Section 6.2 provides an in-depth evaluation, in part using Conversation Analysis, of segments of trials where joint attention emerged in natural and spontaneous ways when three children with autism interacted with the robot and with an *adult* (the investigator). The data, which is presented in the form of transcripts and photo stills, demonstrates how children with autism can respond to the changing behaviour of their co-participant (the investigator). It also shows that the robot provides a salient object, or mediator for joint attention.

Section 6.3 provides a case study evaluation of segments of trials where four children with autism interacted with a robot as well as with *each other*. The data, which is presented in the form of photo stills, shows how the children skilfully orientate and re-orientate their bodies in a way that was sensitive to the activities of the adult, the robot and another child. The analysis showed how the children exhibited interaction skills where the robot served as a salient object mediating joint attention with *other children*.

Chapter 7 provides a summary of the experimental results of all three areas of the investigation and lays out lessons learnt during the research (**Section 7.1**).

Section 7.2 raises some cautions concerning the social isolation and stereotyped behaviour frequently exhibited in children with autism. It presents some examples taken from the trials where the children exhibit such behaviour, and discusses ways of ensuring that the robots become social mediators and do not reinforce the stereotyped behaviour in the children and their tendency to social isolation. It also brings examples of interaction where social behaviour elements in the children have been directed at the robot and raises the awareness of the goal of the research, to help the children to increase their social interaction skills with other people and not simply to create a relationship with a 'social' robot.

Chapter 8 This last chapter draws conclusions and provides some outlook for the possible future use of robots in therapy or education of children with autism.

1.3   Contribution of the Thesis

Encouraging social interaction skills in children with autism is a challenging aim and addresses deep issues about the nature of social interaction, social relationships and the 'meaning' of human-human contact. Studying robotic assistants in this domain adds an additional level of complexity. However, when approaching this challenge from the bottom up, taking it one step at a time, this thesis provides evidence as to the possible role of robots in therapy and education of children with autism, and can contribute to knowledge in two main areas:

1) Assistive Robotics - The thesis contributes to the knowledge of assistive robotics

research in general and in the context of autism more specifically:

- The longitudinal approach taken in the design of the study and the methods used in conducting the trials clearly demonstrate the need for and the benefits of such long term studies in order to reveal the full *potential of robots* as assistive technology for children with autism.

- Some of the methods developed, such as repeated exposure to the robot with a *great degree of freedom* for interaction, the *familiarization phase* and the *learning phase* which were introduced to the longitudinal study, are novel in the area of research into assistive robotics for people with autism.

2) Human Robot Interaction (HRI)- The thesis contributes to the knowledge of HRI research with information about robot design for specific applications and about new experimental methods:

- By addressing the question in HRI research, to what degree robots used in interaction with humans should or should not closely resemble human beings (e.g. possessing a lot of facial features such as eyes, mouth, eyebrows etc.), the results from this research contribute to the search for a better and more tailored robotic design according to needs of specific user groups e.g. a better design that will elicit specific basic interaction skills in children with autism.

- The method developed for this investigation, i.e. the Theatrical Robot technique, is a novel technique in HRI research, that potentially can provide early information crucial to robot design.

Note: Although this thesis did not aim directly at contributing to autism research or to autism therapy, results however indicate the potential use of robots in autism research therapy and education:

- The indication is that the robot can encourage imitative and turn-taking skills in children with autism, as well as mediating interaction with peers and adults. This potentially can lead to benefits in the education and therapy of children with autism.

- In addition, it is shown here how a) a humanoid robot can provide an enjoyable focus of (joint) attention that can reveal details of the communicative and social competencies of children with autism, and b) how the robot as an embodied entity can become an excellent tool for exploring how children with autism might interact with other embodied entities such as humans (e.g. other children). Both these points might potentially make a contribution to autism research since it highlights certain aspects of the specific nature of autism.

Chapter 2

Background and Motivations

"Finding shared social meaning may be difficult for those with autism, but this does not mean that we should abandon social learning....."

Stuart Powell

Helping Children With Autism to Learn, 2000

This chapter reviews some of the theories which form the background to this research. It provides some understanding about autism and the difficulties people with autism face in their day to day life, and about socialization and learning processes, and, as the motivation for this research, it shows how robots could possibly play a role in helping these children to bridge the gap between themselves and the society in which they live.

2.1   Autism

Autism here refers to the term Autistic Spectrum Disorders, a range of manifestations of a disorder that can occur to different degrees and in a variety of forms (Jordan 1999). The exact cause or causes of autism is/are still unknown. Autism is a lifelong developmental disability that affects the way a person communicates and relates to people around them. People with autism often have accompanying learning disabilities. Generally, autism affects more males than females (NAS 2005). For detailed diagnostic criteria the reader is referred to DSM-IV, the Diagnostic and Statistical Manual of Mental Disorders, issued by the American Psychiatric Association (American Psychiatric Association 1995). The main impairments that are characteristic of people with autism, according to the National Autistic Society (NAS 2005), are impaired social interaction, social communication and imagination (referred to by many authors as the triad of impairment, e.g. (Wing 1996)):

a) Impairment in social interaction - this refers to an inability to relate to others in meaningful ways. It comprises a difficulty in forming social relationships and an impairment in understanding others' intentions, feelings and mental states. For a person with autism it is perfectly reasonable to answer a friend's question "How do you like the color of my new car" with, for example, "I think the color is awful".

b) Impairment in social communication - including verbal and non-verbal communication. This manifests itself, for example, in difficulties in understanding gesture and facial expressions, and a difficulty in understanding metaphors or other 'non-literal' interpretations of verbal and non-verbal language. For example, for a person with autism the most reasonable answer to the question,

"Do you know where I can find the train station" is likely to be either "Yes, I do" or "No, I don't", illustrating an inability to understand that what people say or do needs to be *interpreted* with respect to the person's intentional, motivational and emotional states.

c) Impairment in imagination and fantasy - the development of play and imagination activities is limited. For example, children with autism do not get engaged in role-play or pretend play (e.g. pretending to be a princess, a knight or football star) as intensely as typically developing children.

Moreover, people with autism show little reciprocal use of eye-contact and rarely get engaged in interactive games. They also have a tendency toward repetitive behaviour patterns and have a resistance to any change in routine. In addition some people with autism have hyper-sensitive sensory conditions. Touch can be excruciating, smell could be overpowering, sound, even at an average volume could hurt, and sight could be distorted (Gillingham 1995). For some the need to maintain sameness and resist any change is very strong in order to moderate potentially overpowering sensory stimulus. The above mentioned impairments can lead to a substantially decreased probability of being able to lead an independent life. The learning of meaning (e.g of objects, events) which is central to our way of living in society, enabling us to learn and manage our world, does not occur naturally in autism (Powell 2000). Even high-functioning people with autism might encounter great difficulties in learning the everyday 'social rules' that guide our lives.

There are many theories put forward to explain autism and there is currently an ongoing debate concerning which one of them is the primary theory in explaining autism impairments. The focus of the Aurora project and of the research described

in this thesis is on the possible effect and usefulness of the robots on children with autism and is *not* to investigate the nature of autism itself. This research therefore, does not subscribe to *any particular* theory of autism. The following is a brief review of some of the main theories that are being debated in autism research and which are relevant to our work, and that help to shed light on the social impairment of people with autism.

- **Executive Function**- this is a term that covers a range of high level processes that help to organize, order and control our actions, especially actions in novel contexts (Happe 1999). These involve capabilities in monitoring actions and planning future actions, holding information in working memory, being able to inhibit or delay automatic actions and response, initiating behavior and shifting between activities flexibly (shifting set). Executive dysfunction underlies many social and non-social impairments and is widespread in a number of developmental disorders, although impairment in set shifting and planning capabilities is characteristic of autism.

- **Theory of Mind** - This refer to a person's ability to infer what other people think, believe and want in order to predict how they will behave. Typically children develop the ability to appreciate the mental states of others around the third or fourth year of life. By then, most children not only have knowledge of their own mental and emotional states, but understand that others also have mental and emotional states of their own (theory of mind hypothesis). This ability to read others' mental states does not seem to be fully developed in children with autism and researchers suggest that children with autism have an impaired theory of mind (Baron-Cohen, Tager-Flusberg and Cohen

2000, Frith 1989), and thus are unable to understand other people's intentions, feelings or needs. An inevitable consequence of this deficit is communication difficulties (Frith 1989). Deficits in theory of mind can account for both the avoidance of social contact and for an inappropriate approach, both of which are consequences of not understanding other people in terms of what they think or feel or want.

- **Central Coherence Theory**- the integration of diverse information, pulling it together to construct higher level meaning in context, is called by Frith *central coherence* (Frith 1989, Frith and Happe 1994). People use this global configuration mechanism, for example, to summarise a story, retaining the gist of it while not remembering all the details, or to contextually understand many ambiguous words used in everyday speech. Frith suggested that this tendency to process information in context for global meaning is disturbed in autism. This theory can explain why people with autism are often preoccupied with details and parts, and may be good in performing tasks that require attention to local information, but fail to extract the gist or configuration and will perform poorly in tasks which require the recognition of global meaning or where the integration of stimuli in context is needed.

2.1.1 Needs and Facilitation

Human-human interaction is multi-modal, involving not only verbal language, but also a rich body language, gestures etc., and many of these are expressed in a subtle and unconscious manner. To be able to easily interpret other people's behaviour, it is necessary to interpret their intentions, to consider their emotional state, to have the

knowledge of social and cultural norms and conventions, to be able to perceive social cues and so on. In short, the social behaviour of people can be very complex and subtle. For a person with a deficit in 'mind-reading' skills, as has been demonstrated in people with autism, this social interaction can appear unpredictable, and very difficult to interpret.

Psychological studies have shown that children with autism prefer simple designs in toys and predictable environments, e.g (Ferrara and Hill 1980). These can provide the starting points for future therapeutic intervention when the complexity of the therapeutic toys can be slowly increased. Different from human beings, interactions with robots can provide this *simplified, safe, predictable* and *reliable* environment where the complexity of interaction can be controlled and *gradually* increased.

2.2 Theories & Approaches of Socialization and Learning

From the moment of birth, each individual embarks on a developmental process of social learning and acquires the knowledge and skills to be an effective member of his family and, later on, of society. This process, which varies from culture to culture and consists of learning opportunities and experience, is referred to as a socialization process and plays a critical role in the formation of social and personal behaviour (Brim-Jr. 1966, Cohen 1976). Being a member of a social group within a specific culture also plays a crucial role in establishing personal identity. Most of Vygotsky's Social development theory (Vygotsky 1978) places the emphasis on social interactions and states that interaction plays a fundamental role in the development of cognition (e.g Vygotsky's *Zone of Proximal Development* see 2.2.2 below). Lave,

too, showed the importance of social interaction in learning (Lave and Wenger 1991). For Lave, learning is *situated*, it is a function of the activity, the context and the culture in which it happens. She argues that social interaction and collaboration is a critical component of learning. Direct personal relationships help to establish personal growth. These relationships occur primarily within the immediate social units where the child shares experiences and interacts, e.g family, school and peer groups, (Cohen 1976). The literature shows that, for people with autism, the skills for social learning are impaired and personal relationships are often non existent (see section 2.1). This may cause a delay in their mental, emotional and personal growth.

Bruner (1967) showed how growing is not only a process from inside out, but firstly relates to the society or culture in which the person lives, where growth starts by the process of internalizing the basic modes of representation of the world (i.e. action, image and symbol) that exist in a person's culture, *accumulating* it for future use, amplifying his or her abilities to learn and grow. At first the child gets to know the world by the habitual actions he uses for coping with it. Then he develops imagery that, combined with the actions, is gradually translated into language. In Bruner's view, growth of the mind is assisted from outside the person by the culture he or she lives in. In his discussion about the nature of knowing, Bruner (1971) returned to the three basic systems of representation. He showed that through *action* we learn about something by experience, acquiring skills by doing (e.g riding a bicycle); that through *imagery* we summarize it in a representative icon (it has been said that one picture is better than thousand words); and that *symbolic representation*, like language, allows us to describe things whether we have experienced them or no, and whether they exist in the world or no. Unfortunately

for children with impaired imagination and communication (as is the case in autism) development is delayed, some don't have any language skills at all while others have very limited language, and so the only learning that can occur is by experience (individual as opposed to social learning).

2.2.1   Social Learning and Imitation

Social learning and imitation play a significant role in the development of social cognition. Imitation, being an important tool used for transferring knowledge in animal (including human) societies (and more recently, within computational and robotic agents), is an efficient mechanism of social learning (Dautenhahn and Nehaniv 2002). Various aspects of imitation in infancy (e.g body movement, facial expressions, vocalisation) are used as means of communication between infant and care givers that help to create the sense of mutuality that exists between social partners and forges links between the infant and other people (Rogers, Hepburn, Stackhouse and Weher 2003, Hobson and Lee 1999). Furthermore, this kind of social interaction, where the parent imitates the infant, mirroring back to them their actions and expressions, helps to prompt a developmental change in the infant (Meltzoff and Moore 1999). Imitation can serve not only as a learning tool to acquire new physical skills (like the usage of various objects e.g knife and fork) but also provides the foundation for learning about the social world that surrounds us (Dautenhahn and Werry 2004, Nadel, Guérini, Pezé and Rivet 1999). Most of our human behaviour is learnt through observation of others which forms the basis that later informs and guides us in our actions.

2.2.2   Vygotsky's Zone of Proximal Development

According to Vygotsky, the potential for cognitive development depends upon the level of development achieved when children engage in social interaction. Vygotsky called it the *Zone of Proximal Development* (ZPD) which is created by the type of learning that can only occur when a child is interacting with people in his environment and in cooperation with his peers. The range of skills that a child can develop with guidance from an adult or when interacting with other children (e.g. during play) is more than the child can achieve alone. Vygotsky continues to explain that, once these learning processes are internalized, they become the child's own mastered skills (Vygotsky 1978).

2.2.3   Play and Development

As early on as infancy, the creation and use of auxiliary stimuli plays a crucial part in the child's development (Vygotsky 1978). The source of these stimuli comes from cultural tools that exist in the society which the child belongs to, including the language of those around him/her and by means produced by the child himself. Play activity is one of the striking examples of the creation and use of these stimuli and, according to Vygotsky, is the primary means of children's cultural development. He sees the biological foundation of behaviour intertwined with the changing social condition, both inseparable components at each stage of the child's development.

Winnicott too, spoke about the importance of cultural experience in what he called potential space between the individual and the environment, e.g. baby and mother, child and family, individual and society, (Winnicott 1971). He continues by saying that this experience builds up confidence and leads to trust. For him, this

cultural experience is a derivative of play and he saw it as sacred to the individual, as it allows him/her to experience creative living. Bruner (1990) has shown that the motivation for play, and that play itself, is socially constructed. Meanings of things are learnt in a social way within a particular context (Bruner 1990, Powell 2000). Contemporary work in activity theory also shows how children's play is socially and culturally constructed (Hakkarainen 2003).

2.2.4   A Dyadic Model of Interaction

Interaction with the environment provides stimuli in what can be viewed as a dyadic model, that influences and controls the behaviour of the child and is crucial to child development (Cohen 1976).

Here, the interaction between the child and the environment is based on reciprocal stimulation that creates transitions of change and modification. This leads to refinement in the nature of the child's behaviour, which also becomes more orderly. An example of this can be observed when an infant makes initial attempts at motor co-ordination. As he receives approval and encouragement from his carer (e.g parent) he puts more effort into it, and that leads to a small refinement that leads to more encouragement and so on. This sequence of actions and reinforcements becomes orderly and predictable, and could enhance the quality of the child's behaviour and can affect the speed with which he develops.

This dyadic model of interaction with the environment could be implemented in robotic systems that can be used with autistic children to provide stimuli and reinforcement in a controlled manner (a gradual increase in complexity) helping the child learn basic social behaviour skills.

Being a programmable system, a robot can provide various stimuli that could

promote the child to interact with it in different ways. The ability to modify the response of the robot according to the way the child interacts, and to repeat this modified response, can make the cycle of actions and reinforcement orderly and predictable. Robotic systems could have a built-in capability to *gradually* increase the complexity of the interaction thus providing more complex stimuli that may promote further learning (e.g. simple imitation games might become more complex turn-taking activities.)

2.2.5   Social learning and HCI

Traditionally, Human Computer Interaction (HCI) research, design and evaluation has been informed by models of human internal cognition based on sensory, cognitive and motor activities (Dix and Finlay 2004). As the application of computer systems became more diverse and widespread, design models started to take into account the relationship between internal cognition and the outside world. Design rationale in many areas of HCI is being motivated by principles of *activity theory*. It regards any human activity not as the isolated activity of a single person, but inside the context of being part of and influenced by the culture of the society in which it takes place. Activity theory has its roots in the psychological framework which was developed by Vygotsky and his colleagues early last century (Carroll 2003). They analyzed human activity not in isolation but as being *mediated* by technical tools, psychological signs like language and concepts and by the community (socially developed practices) (Bertelsen and Bødker 2003). Vygotsky's Zone of Proximal Development (see section 2.2.2) emphasizes the fact that learning and development are socially mediated. Leont'ev, Vygotsky's student and colleague, viewed human individual activity as a system within the system of social relations and claimed

25

that it could not exist without social relationships and social life (Wertsch 1985).

2.2.6   From Embodied Robots to Embodied Cognition

Our basic social interaction skills are acquired from a very early age through our on-going experience with the world and in endless interactions with the people around us. During our interaction with the environment where other people exist, we have also developed 'mind-reading skills' (Baron-Cohen 1995), which in time become 'second nature' to us, helping us to interpret cues given by other people, predict and participate in social behaviour and communication, either in direct interaction with them or during our interaction with the environment where other people also exist. For example, when walking in a crowded street we rely on these 'mind reading' skills to negotiate our path through other people and obstacles. Another example is driving a car on a public road. We can learn the principle and mechanics of driving a car, and even have the experience of driving it on an empty or private road, but to successfully drive it on a public road among other drivers requires more than simply the motor skills. It depends also on the continuous use of background know-how and common sense which is acquired through *accumulated* past experience (Varela, Thompson and Rosch 1993). How could a person with impaired 'mind-reading skills' (such as in the case of autism) be able to build this accumulated past experience that will help him/her to interact directly with other people, or indirectly in an environment where other people co-exist? For people with autism, where iconic and symbolic representation skills are severely impaired (e.g impaired imagination, very little or no language skills at all at the low end of the spectrum, etc.) the main avenue left for the possible development of communication and social interaction skills might be through action. There are currently software packages and virtual

environment tools to teach social life skills helping people with autism rehearse problematic real-life situations (see section 2.3.1). In the field of HCI, the limitation of computers used in social interaction environments are already acknowledged and taken into account in the design of new systems (Dix and Finlay 2004). Important elements in face to face communication, such as eye-gaze, eye contact and body alignment, which help to establish the sense of engagement and maintain the focus of the interaction, are substantially (if not completely) reduced when the attention is focused on a keyboard and a screen. The use of body movement is also very restricted in this situation. However in using a three dimensional embodied robot as a therapeutic or educational toy, not only can an autistic child learn basic interaction skills in a naturally encouraging context (e.g playing) but it also promotes a full body experience on the part of the child (which a two-dimensional computer screen can't provide). This may encourage a variety of interactions, and can help to increase body awareness and sense of self, as well as providing greater opportunities to interact with others (see interactions in trials described in chapter 6), adding to the background of understanding and know-how which is so crucial in developing social interaction skills.

Knowledge, in the words of Varela et al.,"depends on being in a world that is inseparable from our bodies, our language, and our social history - in short, from our *embodiment*" (Varela et al. 1993, page 149).

2.3   Assistive Technology

2.3.1   Robotic and Computer Technologies in Autism Education and Therapy

Research suggests that people with autism generally feel comfortable in predictable environments, and more specifically, enjoy interacting with computers, e.g. (Colby and Smith 1971, Powell 1996, Moor 1998). One possible explanation has been put forward by (Murray 1997) who noted that the attention of people with autism tends to be fixed on isolated objects apart from the surrounding area. She argued that computers are the ideal resource to break into this world because they are allowed to join the individual's attention tunnel which focuses on the screen and thus external events can be ignored more easily. She added that the use of computers in the education and therapy of people with autism can help develop self-awareness, increase self-esteem and be an aid to effective communication as it can motivate the individual to speak, read or to share their achievements. Hershkowitz also made a strong case for the usage of computers in therapy and education (Hershkowitz 1997, Hershkowitz 2000). She found that the implementation of computer based learning provides a very effective method for teaching language and academic skills to children with autism, and in helping adults to become independent.

In recent years there have been many examples of using interactive systems in the therapy or education of people with autism. Such systems include virtual reality or virtual environments e.g. (Strickland 1996, Strickland 1998, Parsons, Beardon, Neale, Reynard, Eastgate, Wilson, Cobb, Benford, Mitchell and Hopkins 2000). Therapists and teachers are increasingly using virtual reality tools to teach social and life skills (e.g. recognising emotions, crossing the road, learning where and how

to sit down in a populated cafeteria). The regulated computer environment that virtual reality can offer is used to help people with autism rehearse problematic real-life situations and learn how to better cope with the real world (Strickland, 1998). Similarly, computer based interactive simulations in areas such as food, play and hygiene been found effective in enhancing appropriate functional communication in natural classroom settings (Hetzroni and Tannous 2004).

Another example of interactive computer technology that has been used to help children with autism learn how to recognise social displays of affect is the Affective Social Quest (Blotcher and Picard 2002). Here a multi-media system synthesizes interactive social situations using an animated show containing emotionally charged video clips. The child, communicating with the system via toy-like objects (dolls with different emotional expressions) can be prompted by the system to identify the displayed emotion, or can explore different emotional situations himself.

For decades, the use of *robots* in education has been an active area of research (Papert 1993, Dautenhahn 1999, Druin and Hendler 2000). In utilising interactive devices, educators have seen a profound and beneficial effect on how children develop and grow, how pupils could engage in activities that are meaningful to them, sharing their discoveries with their classmates or turning to them for help and advice. In some early work in the 70's, (Weir and Emanuel 1976) investigated the use of a remotely-controlled mobile robot as a therapeutic or educational device for one child with autism and reported positive effects of a LOGO turtle on a seven year old boy. In this work the robot did not have any autonomous behaviour, nor did the child have any direct physical interaction with the robot. The robot was operated remotely by the child by pressing buttons in a box.

More recently, Michaud and Théberge-Turmel studied the use of mobile robotic

toys in helping children with autism develop social skills. They explored various robotic designs, each with particular characteristics, that could best engage the children. They presented playful interactions of children with autism with robots in a variety of designs, such as an elephant, a spherical robotic 'ball', a robot with arms and a tail, and other designs (Michaud and Théberge-Turmel 2002, Michaud, Duquette and Nadeau 2003). The work, which was carried out as an engineering project, focused on exploring the design space of robots that can facilitate interactions with children. As such, the results of playful interactions of children with autism and robots were presented in a narrative account, without any systematic evaluations (qualitative or quantitative), and little is known about any specific benefits to the children, nor about the history of the children. Other work that studies the use of robots in playful interactions with children with autism was carried out by (Wada, Shibata, Saito and Tanie 2002) who developed a seal pet robot called Paro as an assistive tool in rehabilitation and robot assisted activity. Paro has been proposed as a tool that could benefit elderly people, hospitalized children, as well as children with autism. However, in this work too, very little has been documented about the particular history of the children and the specific nature of therapeutic effects that can be linked to the robot e.g. what types of robotic behaviour were beneficial to the child, and what types of therapeutically relevant behaviours were targeted.

Increasingly, researchers are developing humanoid robots that can interact with people in the same way that people interact with people. Scassellati for example, used an upper-torso humanoid robot, called Cog to research how a robot can naturally communicate with humans using joint attention behavior (Scassellati 1999, Scassellati 2001). Breazeal and Scassellati studied social learning in robotics

using imitation (Breazeal and Scassellati 2002). Breazeal used the interpretation of human social cues as one of the architectural elements built into the sociable 'infant' robot Kismet (Breazeal 2002). At the same time, researchers are using robotic systems to study the development of social skills in people. Fasel et al. used simulated and robotic systems to explore the development and dysfunction of shared (joint) attention in toddlers with and without developmental disabilities such as autism (Fasel, Gedeon, Triesch and Movellan 2002). Kozima and Yano worked with a humanoid robot (a robotic human's upper body, called *Infanoid*) that could create and maintain basic joint attention with a human (Kozima and Yano 2001). They planned to develop a contingency-detection game that autistic children could play, and possibly use to learn social interaction skills. More recently (Kozima, Nakagawa and Yasuda 2005), developed a small creature-like robot, very simple in appearance, and reported that the robot promoted spontaneous play in children with developmental disorders, and they observed the emergence of social communication with the robot and another person.

As part of a recent new initiative Yale researchers Klin Jones and Volkmar from the Yale Child Study Centre, are using advanced eye tracking devices and motion capturing systems in their autism research monitoring autistic children's eye-gaze in various emotionally charged scenarios. They are now embarking on a new collaboration with Scassellati, who builds robots with human-like facial expressions, to study children's social development and to investigate ways that the robot can help autistic patients to develop social skills (Farely 2004).

2.3.2   Robots in the Aurora project

As stated earlier, the Aurora project investigates the potential use of robots as thera-
peutic or educational 'toys' specifically for use by children with autism. The research
focuses on ways that robotic systems can engage autistic children in various interac-
tive activities such as turn-taking and imitation games, with the aim of encouraging
basic communication and social interaction skills. A core area of the investigation is
how the robots can be used as social mediators, objects of shared attention, and en-
courage interaction with peers (other children with and without autism)and adults.
The Aurora team uses humanoid and non-humanoid robots in its investigations.
Quantitative and qualitative techniques for evaluating interactions of a single child
with autism with a non-humanoid mobile robot were presented e.g. in (Dauten-
hahn, Werry, Rae, Dickerson and Stribling 2002, Werry, Dautenhahn and Harwin
2001b, Werry 2003). It was shown that individual children paid acute attention
to the robot, enjoyed interacting with it, explored the robot's various behaviours,
and in one case even tried to 'help' the robot in its obstacle avoidance behaviour.
Also, a comparative study was carried out in order to compare the impact of the
robot with a non-robotic toy. The statistical analysis of behavioral observations re-
vealed that children with autism directed significantly more eye gaze and attention
toward the robot, supporting our hypothesis that the robot represents a salient ob-
ject suitable for encouraging interaction. In a later study with pairs of children with
autism Werry et al. (2001) illustrated the non-humanoid robot's ability to provide
a focus of attention and shared attention. The robot's role as a *mediator* became
clearly apparent in how the children interacted with other people present in the same
room, including child-teacher, child-investigator and child-child interactions. In one
instance one child learnt a new interaction with the robot from the experimenter,

and later taught this skill to a second child. In another instance more able children shared with their teacher the experience of their interaction with the robot, asking the teacher questions about the robot's abilities etc. Although the robot successfully provided a focus of attention, there were also cases where it promoted non-social play, where a pair of children attempted interaction with the robot at the same time in competition with each other, or simply without acknowledging the presence of each other. Different from Werry (2003), where the children were exposed to the robot only once or twice, I have adopted a longitudinal approach, where the same children were repeatedly provided with the opportunity to interact with the robot over a long period of time (see section 3.1). I further investigated the robot's role as a social mediator, this time with a humanoid robot, and an in-depth analysis of the mediating role of the robot is presented in chapter 6.

A precursor of the work presented in this thesis is the study conducted by (Dautenhahn and Billard 2002) who reported a first set of trials with 14 children with autism interacting with a humanoid robotic doll called Robota. The central theme of these trials was imitation games between the robot and the children. A computational vision system analyzed gross arm movements of the children that in turn could trigger the robot to imitate the child. Also, Robota performed movements on its own in order to encourage the children to mirror the robot's movements. The lessons learnt from these initial trials (discussed below) contributed to the design of the current research.

2.4   Summary

Social interactions are thought to be fundamental to the development of cognition, language and social intelligence. Whether it happens at home or in school, the notion of "Piagetian learning" as phrased by Papert - i.e "the *natural, spontaneous* learning of people, in their interaction with their environment" ((Papert 1993) pp 156), is reflected through the various socialization and developmental theories that have been briefly reviewed in this chapter. These theories emphasise the importance of acquiring social interaction skills and the potential for human development that these skills provide. And herein lies the core motivation behind this research project. Play and imagination, communication and social interaction skills are the main areas of impairment in autism (see 2.1). As these skills do not develop naturally in children with autism, it is of paramount importance to provide more situations in which the child has the opportunity to interact with other people in social settings. From a very early age, social devices such as turn-taking, imitation and joint attention create the social settings necessary for the infant's natural development of social, cognition and communication skills (Nadel et al. 1999).

Basic assumption of the research was that for children with autism, who generally feel comfortable in a predictable environment, and more specifically, who enjoy interacting with computerized systems (see 2.3.1), having the opportunity to play simple turn-taking and imitation games with a robot, where the robot can also act as a social mediator when other children are present, might provide the social setting that encourages the much needed social interaction skills.

The previous work within the Aurora project with the humanoid robotic doll Robota (as mentioned above) hoped to initiate imitative interaction games between

the robot and the children. However the results were inconclusive. Although it indicated a possible usefulness of the robot in this situation, a number of drawbacks in the original setup were identified which limited the outcome of that study. In this previous work (Dautenhahn and Billard 2002), the children were required to sit still at a table, facing the robot, and to move their arms in a very distinct manner. This was because of the limitations of the vision systems that could not identify subtle movements, or movements that weren't performed very close to the robot. The children's participation in the interaction games also substantially depended on explicit encouragement by a teacher who sat next to them. The authors concluded that overall, this setup did not seem to facilitate the emergence of *spontaneous, proactive, and playful* interactions. What is more, each child was exposed to the robot only once. In this situation not only could accidental parameters outside the context of the trials potentially have a significant effect on the interactions observed, but also the change in the child's routine, having to cope with an unfamiliar 'toy' and being in a room with a stranger (the investigator) could all be potentially stressful circumstances for an autistic child and might affect his/her behaviour during the trial.

The wish to remedy these drawbacks and to further expand the possible use of the robot as a therapeutic or educational tool, contributed to the motivation of the current research, and helped to form the basic approach taken in the research.

Compared with using computer software or virtual environments, interactions with an interactive physical robot contribute important real-time, multi-modal, and *embodied* aspects which are characteristic of face-to-face social interaction among humans (Dautenhahn and Werry 2004), see also section 2.2.6. However it is unrealistic to assume that robots will be suitable for all possible applications of computer

technology for children with autism. Ultimately, various types of virtual or robotic interactive systems are likely to fulfill different roles and niches in the spectrum of possible applications for children with autism that can potentially enhance their quality of life, help them live independently and contribute to their social integration in society.

2.4.1 The Research Questions

As stated above, this research investigates the potential use of a robot as a therapeutic or educational 'toy' by children with autism, with an aim to encourage basic communication and social interaction skills. It focuses mainly on two areas: the use of simple imitation and turn taking games in encouraging these skills and the possible role of the robot as a social mediator, an object of shared attention, that can encourage interaction with peers and adults.

- **Imitation and turn-taking games**- Imitation plays a critical role in the development of social cognition and communication skills from a very early age, and it was also found to be a good predictor of social capacities in children with autism (see more on imitation and autism in section 4.1). As seen above (section 2.1) a common feature in the behaviour of people with autism is the avoidance of social contact with other people. They usually show very little reciprocal use of eye-contact and rarely engage in interactive games. Studies into the behaviour of children with autism also suggest that they might demonstrate a preference for interacting with objects rather then with other people. Thus, if a robot succeeds in engaging children with autism in a variety of interactions, including turn-taking and imitation games, then it

may potentially contribute to the children's development of interaction skills.

- **Robot as social mediator**- Initial trials with a mobile robot illustrated the possibility that the robot could provide a focus of attention and shared attention in trials with pairs of children with autism (see section 2.3.2). Children's use of non-verbal interactive resources like gaze and protodeclarative pointing, to share their attention on an object or a third person with others, are referred to as joint attentional skills. An integral part of social interaction skills is the ability to respond to and to initiate joint attention activities. Impairment in these skills, described as *joint attention deficit* are often associated with children with autism. Research in the last few decades has indicated that young children with autism are impaired in their ability to initiate these indicating activities, or at least their onset is markedly delayed (see more on joint attention and autism in section 6.1). And thus again, if a robot succeeds in engaging children with autism in a variety of interactions, then it may potentially become a *social mediator*, where autistic children initiate and orientate to joint attention bids in interactions involving the robot and other people (peers or adults).

Based on the positive findings in these two areas of research during the previous trials in the Aurora project (see section 2.3.2), the current research reported here continued the investigation with a new approach. This approach adopted a longitudinal repeated measure design, built over a long period of time, that can facilitate the design of unconstrained scenarios of interactions with a high degree of freedom for the children to interact with a robot. This approach facilitated the investigation of the following three research questions:

1. To what extent can repeated exposure to a robot over long period of time, using basic imitation and turn-taking games, encourage social interaction skills in children with autism?

2. In what way and to what extent can a robot assume the role of a social mediator encouraging the interaction of children with autism with other people (peers or adults)?

3. Which robot designs, in terms of appearance, will best facilitate interactions with children with autism?

Chapter 3

The Trials

"Experimental observation is better executed in play and school than in psychologist laboratory....."

L. S. Vygotsky

Mind in Society, 1978

Note: All trials described in this thesis were solely arranged and carried out by the author, who was also the only investigator present.

3.1 The Approach

In line with many other research activities in assistive robotics the work in the Aurora project is strongly guided by the needs and preferences of individual sub-

jects. This often involves working with a small group subjects in order to explore and evaluate the potential of a particular assistive robot and to assist its development, c.f. (Hillman 2003). Note, in assistive robotics the use of control groups is usually not relevant since robotic systems are being developed for the purpose of assistance, not as a tool in an investigation of how a specific target group differs from other subjects without the particular impairments of physical, mental or social functions concerned. The work described in this thesis specifically targets children with autism as a potential 'user group', working on a long-term basis with a small group of children. This approach is different from large-scale experimental studies e.g. in psychology, aiming at statistically determining differences between experimental conditions, involving control groups (Rogers et al. 2003). Given the nature of autism (a spectrum disorder) which implies huge differences among the subjects, and the therapeutic/educational background, the work is guided by the individual needs and preferences of the children. Given this specific context, the trials were designed within a rather broad context (compared to studies in experimental psychology or HRI research e.g. (Sidner, Kidd, Lee and Lesh 2004), exploring the interaction space involving children with autism and a robot interacting in a familiar and relatively unconstrained environment.

The approach in designing the trials and the methods used in them have been influenced by those taken in therapy. In play therapy for example, the playroom is like a blank canvas ready for the child to create and communicate, and the toys are the tools to aid this communication (Daniel 1999). In a very similar way, initially the trials were designed to provide the children with a great degree of freedom to explore their interaction with the robot and later on the interaction and communication with each other or with the adult present, where the robot is the toy, the tool to aid this

communication.

Another influencing aspect adopted from therapy is the notion that sessions should have a simple, clear structure, where the interaction could become *another cultural routine* which gives the child a sense of belonging (Cattanach 1999b). In a very similar way, the time spent with the robot can become a familiar routine and can serve as an anchor where the child feels safe to explore should he wish to. Therefore, whenever it was possible, the investigator tried to incorporate the activity with the robot into the children's timetable at school. For those children who communicate with their teacher through pictorial cards with symbols which represent various activities in their daily routine at school, the investigator provided the teacher with a card with a picture of the robot on it, to be included in their cards system so that it can be used in the same way as for the other activities the child participate in at school.

As described earlier, previous studies with the humanoid robot in the Aurora project could only involve the children in a very restricted range of behaviour. They had to sit down in front of the robot, and perform accurate movements in order for the robot's visual system to be able to recognize the movement. Also in these trials the children were exposed to the robot only once. This very limited exposure to the robots is also characteristic of many other HRI studies and with autistic children in particular.

The new approach that was developed in this research adopted a longitudinal repeated measure design, built over a long period of time, that can facilitate the design of unconstrained scenarios of interactions with a high degree of freedom for the children to interact with a robot in a reassuring environment, where the predictability and repetitive behaviour of the robot is a comforting factor. The

interactive scenarios can be very simple to begin with, and as the child becomes more comfortable and gains more confidence and skills, there is the possibility of a gradual increase in the complexity of interaction. Another advantage of using a robot over a period of time is the possibility of introducing a variety of playful scenarios. Real time physical interaction (in contrast to virtual environment and other computer systems) in playful scenarios may encourage full-body experience, which can increase body awareness and sense of self. This is very important, specifically in the case of autism, since there is evidence from autism research that people with autism have movement disturbance and body image distortions which are likely to affect the individual's abilities and motivation to relate to other people (Leary and Hill 1996). An interactive environment with a high degree of freedom for a child to move around in any way he chooses, with freedom to explore the robot in a physical way (providing it is safe for the child and the robot), can encourage a stronger sense of (physical) self and might promote physical interaction with other children. It can also increase the level of enjoyment during play and thus make social interaction a more positive experience.

3.2   The Robotic Platform - *Robota*

The robotic platform used in this research is a robot called **Robota** - a 45 cm high, humanoid robotic doll (see figure 3.1). The main body of the doll contains the electronic boards (PIC16F870, 4MHz and 16F84, 16MHz) and the motors that drive the arms, legs and head giving 1 DOF (degree-of-freedom) to each. The robot also has the capability to be connected to various sensors such as infrared emitters/ receivers, light detectors and more, which were not used in these trials. The arms,

legs and head of the robot are plastic components of a commercially available doll. The robot can react to touch by detecting passive motion of its limbs and head through its potentiometers. For a complete description of Robota see (Billard 2003, Billard, Robins, Nadel and Dautenhahn 2005). Robota can have a PocketPC (such as Compaq iPAQ-3850) together with a FlyCAM-CF camera on board, mounted on the front of the robot, or it can be connected through a serial link to a PC with a quick-cam camera. The robot can use speech synthesis, speech processing and video processing of data from the camera. Using its motion tracking system, Robota can copy upward movements of the user's arms, and sideways movements of the user's head when the user sits very still and close to the robot, looking straight at it, engaging in turn-taking and imitation games with the robot. Machine learning algorithms allow Robota to be taught e.g. a sequence of actions as well as a vocabulary.

Figure 3.1:   The robot in its various types of appearance. The figure on the left shows the 'undressed' version revealing the robotic parts that control its movement.

Robota had originally been developed by Aude Billard as a robotic toy that supports a rich spectrum of multi-modal interactions with typically developing children, involving speech, music and movements. However, many behavioral qualities

that are required in situations of social interaction are less natural to children with autism. Such qualities would include: being still, having a long enough focus of attention, and maintaining gaze on another's face. These are advanced tasks for children with autism to perform as it lies directly in one of the main areas of their impairment - communication and social interaction. Therefore, in this research, Robota's features of speech processing, motion tracking, and learning were not used. As explained above the trials are designed to be unconstrained, with minimal structure, to allow the children to have the greatest degree of freedom. Possibly other features of Robota could be used in future research where more structure and complexity can slowly be introduced into the trials, allowing the children time to build their confidence and increase their social interaction skills according to their abilities. In the current research the robot has been programmed to operate in two basic modes: a) as a 'dancing toy' where it moved its arms, legs and head to the beat of pre-recorded music. Three types of music have been used - children's rhymes, pop music and classical music, following the teacher's advice as to the children's liking; b) as a puppet, whereby the investigator is the puppeteer and moves the robot's arms, legs or head by a simple press of buttons on his laptop (this approach is related to the Wizard-of-Oz technique used in human-computer interaction (HCI) and more recently in human-robot interaction (HRI) research, e.g. (Maulsby, Greenberg and Mander 1983, Hüttenrauch, Green, Norman, Oestreicher and Eklundh 2004). It was very important for this specific user group, that the robot responds very accurately and consistently. This could be achieved to a very high degree when the investigator operated the robot remotely. The robot could then accurately respond to the child's arm, leg and head movements even when the child was not facing the robot directly or was not in close proximity to the robot. The investigator's control of the robot

was hidden from the children.

Chapter 4

Imitation and Turn Taking Games with Robota

Imitation plays an important part in social learning both in children and adults. Research suggests that mutual imitation in infancy help to develop understanding of others, including mental states and sharing of emotion and it provides an essential base for the building of self awareness and awareness of others (Jordan 1999). This chapter investigate the effects of repeated exposure to a small humanoid robot on children with autism. It explores how and if, by using imitation and turn-taking games, the robot can help encourage social interaction skills in these children.

4.1   Imitation and the Case of Autism

From birth, imitation plays a critical role in the development of social cognition and communication skills, helping an infant in forging links with other people (Nadel et al. 1999). Imitation and turn taking games are used in therapy to promote better

body awareness and sense of self, creativity, leadership and the taking of initiative both in children and adults (as used in Dance Therapy by (Kalish 1968, Levy 1988, Payne 1990)). There are currently contradictory findings in respect of imitative deficits in autism. Some researchers suggest autism-specific impairments in imitation (Rogers and Pennington 1991, Meltzoff and Gopnik 1993) whilst others show that autistic children are able to engage in immediate imitation of familiar actions (Hames and Langdell 1981).

Nadel explored the use of imitation as a communicative means in infants with autism (Nadel et al. 1999) and found significant correlation between imitation and positive social behavior. Her findings indicate that imitation is a good predictor of social capacities in children with autism. In addition, it was also found that autistic children improve their social responsiveness when they are being imitated (Dawson and Adams 1984, Tiegerman and Primavera 1981, Nadel et al. 1999). In therapy too, imitation, reflection and synchronous movement work has been used with autistic children to develop social interactions (Costonis 1978, Adler 1968).

4.2   A Longitudinal Study at Bentfield School

This section presents a longitudinal study with four children with autism who were repeatedly exposed to a humanoid robot over a period of several months, using basic imitative and turn taking games. Our aim was to encourage imitation and social interaction skills, and the hypothesis was that repeated exposure to an interactive small humanoid robot will increase these skills and will promote a variety of interactions that could be observed and documented. Different behavioural criteria

(including Eye Gaze, Touch, Near and Imitation) were evaluated based on the video data of the interactions. The results clearly demonstrate the crucial need for long-term studies in order to reveal the full potential of robots in therapy and education of children with autism.

4.2.1 The Longitudinal Approach

As mentioned in section 2.4, in previous trials with *Robota* each child was only exposed once to the robot, a situation where accidental parameters can potentially have a significant effect on the interactions observed. The longitudinal repeated measure design taken here, reduces the influence of variables that could lead to 'accidental outcomes', because the same subjects are used. For example, it was noticed that unplanned changes in the schedule of activities prior to a trial, such as canceling the school's assembly, can significantly affect the children's behavior because of the change to their routine. Also in longitudinal studies there are fewer cases of random variation to obscure the effects of the experimental conditions.

It is very common in therapy to design programs of intervention/treatment to take place over a period of a year or longer, where, for example, 50 or more sessions of Art Therapy are not unusual (Evans and Dubowski 2001), or in Dance Movement therapy e.g. (Siegel 1984, Adler 1968) where case studies show that it might take six months or more for the first breakthrough in the interaction between the therapist and an autistic child to occur.

Similarly, in education there is increasing use of the Qualification and Curriculum Authority's (QCA's) P-scales assessment method (QCA 2005) to assess pupils'

performance and to support monitoring of progression and target setting for pupils with learning difficulties. This is usually done once a year and although in many cases the pupils move up a level at the end of a year, often pupils show very slow progress in some developmental areas and stay at the same level for more than a year, simply covering more ground at that level.

A common approach in therapy involves the therapist gradually attuning to the client. This slow process reduces anxiety and distress levels and allows the gradual development of the therapeutic relationship. For these reasons, and because of the long term projection that is used in education, we designed our trials to take place over a longer period of time. On the one hand this aimed at minimizing the anxiety and distress the autistic children might find themselves in, caused by a change of routine, being in a novel situation with a new and unusual toy (the robot), and a new person (the investigator). On the other hand it was deemed important to allow enough time for the children to use any interaction skills they might already possess (e.g. eye-contact, turn-taking, imitation), in a reassuring environment, where the predictability and repetitiveness of the robot's behavior is a comforting factor. Furthermore, this would also allow enough time and opportunity for the children to possibly improve their social interaction skills by attempting imitation and turn-taking games with the robot while slowly increasing the unpredictability of the robot's actions.

Additionally, monitoring of the children's reaction to different appearances of the robot was necessary in order to find which appearance of the robot best facilitated the interaction. In a previous study where children with autism played with

different non-robotic toys it was shown that the children approached social objects more readily if they were simple in appearance (Ferrara and Hill 1980). In the current longitudinal study this involved two different appearances of the robot, one a 'pretty girl doll' and the other with plain clothing with a featureless head (see the second and third pictures from the left in figure 3.1 above). The comparison of these two experimental conditions is discussed in chapter 5 (for completeness purposes, details of all robot appearances used in the current longitudinal study can be found in Appendix A).

Overall, this approach has been designed to allow the children to have unconstrained interaction with the robot with a high degree of freedom, on their terms to begin with (providing it is safe for the child and safe for the robot). This approach has also been designed to build a foundation for further possible interactions with peers and adults using the robot as a mediator as described in chapter 6.

4.2.2   Trial Setup and Procedures

The trials took place in Bentfield Primary school in Essex, UK, a mainstream school with approximately 220 typically developing pupils. The school also has an Enhanced Provision unit to cater for nine pupils with various learning difficulties and physical disabilities. These pupils, each accompanied by a carer, pursue their own unique curriculum and are integrated in the mainstream classes, according to their age group. They participate in any class activity that they are able to.

The trials were conducted in the light and sound room at the school. This is a familiar room for the children, as they often use it for various activities. The light

and sound area, which is an extended part of the room, was closed off by a curtain leaving a large empty area of approximately 5.5x4.5 m, with a carpeted floor. The room had one door and several windows overlooking the school playgrounds.

The robot was connected to a laptop and placed on a table against the wall at one side of the room. Two stationary video cameras were placed in the room, one at the side to capture the area in front of the robot and the children when approaching the robot, and the other camera placed behind the robot in order to capture the facial expressions of the children as they interacted with the robot in close proximity. It was felt that having manned cameras (with yet more adult strangers in the room) would be too intrusive and would cause additional stress to the children. However, despite having two cameras in most of the trials, there were periods of time when the children moved outside the range of the cameras, as the nature of the trials gave them the freedom to move around in the large room.

4.2.2.1   The Children

Four autistic children age 5-10 from the Enhanced Provision unit at Bentfield primary school were selected by their teacher to participate in the trials. Each child participated in as many trials as was possible during that period (nine trials each on average). The children[1] are:

- Andy - Age 5, in the Reception class. Andy uses only two or three words but is beginning to communicate using the Picture Exchange Communication System (PECS).

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[1] All names of the children mentioned in this thesis are pseudonyms

- Don - Age 6, in year one. Don has some limited verbal expression which he uses to express some needs, likes and dislikes. He understands simple directions associated with routines.

- Billy - Age 10, in year 5. Billy has autism combined with severe learning difficulties. He has no verbal language and uses symbols and signs to make choices and to express basic needs. He will generally have a go at whatever task he is presented with unless he is feeling unwell when his behaviour deteriorates.

- Tim - Age 10 , in year 5. He has verbal language which he may use to express needs but often elects not to do so. He can be very difficult to motivate and it is sometimes very difficult to channel his attention toward a particular task.

Once a year the school assesses the pupils' performance using the QCA's P-scale method. It is important to view the children's behavior during the trials in the context of their personal development level which was assessed by their teacher six months prior to the trials. According to the assessment of their personal and social development level, in the subject of attention, Andy and Don have been assessed at a level where they pay rigid attention to their own choice of activity, and are highly distractable in activities or tasks led by others. Billy and Tim have been assessed at a level where they can attend to an adult directed activity but require one-to-one support to maintain their attention. In the area of interacting and working with others, Andy was assessed at a level where he engages in solitary play or work and shows little interest in the activities of those around him. Don, Billy and Tim were assessed at a level where they might take part in work/play with one other person and take turns in simple activities with adult support.

4.2.2.2   Trial Procedures

Before each trial, the robot was placed on a table ready to start with a click of a button from the laptop. The investigator was sitting next to this table operating the laptop when necessary. The cameras, operated by a remote control, were set to standby mode ready to record.

The children were brought to the room by their carer, one at a time. Each trial lasted as long as the child was comfortable with staying in the room. The trials stopped when the child indicated that he wanted to leave the room or if he became bored after spending 3 min already in the room. The average duration of trials was approximately 3 min. A few of the trials lasted up to 5 min, a few others were just under 3 min, and two ended very shortly after they started when the children left the room after 40 sec and 60 sec.

The trials were designed to progressively move from very simple exposure to the robot to more complex opportunities for interaction. There were three phases to this:

Setup A - Familiarization. During the first three trials, the robot was placed inside a large open box painted black inside, similar to a puppet-show setting (see Fig. 4.1 left). At this stage in the trials the robot was operating in its dancing mode, moving its limbs and head to the rhythm of pre-recorded music. This was simply intended to attract the children's attention to the robot. The children mostly watched while sitting on the floor or on a chair, but occasionally left the chair to interact with the robot more closely (watching closely, touching etc).

This section of the trials was designed mainly for the children to familiarize themselves with the robot (a new toy) and so the carer gave no instructions or tasks for the children to do, simply minimal verbal encouragement if and when this was needed (e.g. "look", "there", "what is it?" etc). The children were left to do what they chose to do. The carer and the investigator were generally only observing, intervening only if the child was about to harm the robot (i.e. pushing or pulling the robot's limbs using excessive force). The investigator did not initiate communication or interaction with the child, but did respond when addressed by the child.

Setup B - Learning. In later trials, the box was removed, the robot was placed openly on the table and the children were actively encouraged to interact with the robot. In this stage, the carer introduced physical encouragement, standing with the child near the robot and moving the child's limbs to show him how the robot could imitate his movement (see Fig. 4.1 center). The children could then continue the interaction with the robot on their own. In this situation, the robot was operating in its puppet mode, where the investigator as puppeteer caused the robot to accurately respond to the child's arm, leg and head movements (even when the child was not facing the robot directly or was not in close proximity to the robot). Note that the investigator's control of the robot was hidden from the children (although the laptop was placed on the table where the robot stood, it was covered with a black cloth similar to the one which covered the table).

Setup C - Free interactions. In the last couple of trials, whenever possible, the children were not given any instructions or encouragement to interact with the

robot, and were left to interact and play imitation games on their own initiative if they chose to do so. On these occasions, the robot was again operated as a puppet by the investigator. The investigator was able to recognize even subtle expressions of the child and to quickly respond to the child's movements, and also to introduce further complexity of turn-taking and role-switch into the simple imitation game (see Fig. 4.1 right).

familiarization   learning   free interactions
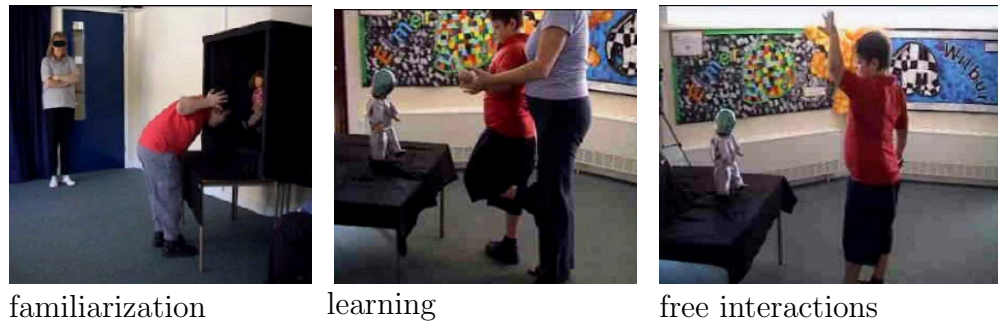
Figure 4.1: The three phases of the trials.

4.2.3 Interaction Profile Analysis

Four elementary behaviour criteria were defined, and were evaluated throughout the period of trials, based on the video footage. These behaviours were:

1. *Eye gaze* (when directed at the robot).

2. *Touch* (when the child touched any part of the robot).

3. *Imitation* (this included direct imitation of the robots movements, delayed imitation and response to the robots movement, and attempted imitation of the robots movement).

4. *Near* (this included the child approaching the robot and staying in close proximity to the robot regardless of the child's other behaviours).

Quantitative and qualitative analysis of the data creates an interaction profile for each of the children who participated in the trials.

4.2.4   Results of the Quantitative Analysis

The video data from each and every trial for a given child was segmented into 1 sec intervals. The trials were coded by scoring the above defined elementary behaviours every second of the trial, cf. (Tardiff, Plumet, Beaudichon, Waller, Bouvard and Leboyer 1995, Dautenhahn et al. 2002). The scores for each trial were then summed up and yielded the total number of occurrences of each behaviour during a specific trial and the total duration of the child's engagement in each behaviour during that trial. The trials varied in duration, therefore the duration of a behaviours was standardized by expressing it as a proportion of the trial duration.

To verify the reliability of the coding of the children's various behaviours and to ensure interrater reliability, a subset (10%) of the trials video data for each of the children, randomly selected, was coded independently by a second researcher. The average percentage of agreement between the two observers for the pre-defined elementary behaviours of the children was 96. This level of percentage of agreement between observers is commonly thought to be good. In order to check the reliability of scoring Cohen's kappa coefficient was used. A value of 0.60 or higher is generally considered sufficient to indicate that chance alone is not accounting for the agreement. Some researchers, as described in (Bakeman 1986), are going fur-

ther and characterize kappas of 0.40-0.60 as fair, 0.60-0.75 as good, and over 0.75 as excellent. The kappa scores obtained in the test of the subset of trials for the four children were on average 0.79 (0.74 for Don, 0.78 for Billy, 0.83 for Tim, and 0.84 for Andy).

4.2.4.1   Results and discussion

The data analysis produced various graphs showing changes in the children's behaviour (during child-robot interaction) over a period of time. For each child, the trend of each of their behavioural criteria was followed from day 1, when the first trial took place, to day 101 when the last trial was conducted.

The graphs in Figs. 4.2 – 4.5 show the changes in behaviour for each of the children during the period of the longitudinal study. Figure 4.2 shows that the values for the behaviours of Touch, Imitation and Near all increase considerably toward the later trials, i.e. from day 92 onward. For eye gaze, the highest scores occur during the first two trials on day 1 and day 8. This could be attributed to the novelty of the situation and to the fact that the carer decided to offer the child a chair to sit in front of the robot to watch this new toy. Naturally, a high score for eye gaze can be expected in this situation. However, if these first two trials are disregarded, it can be noticed that the trend for eye gaze, too, increases from the third trial onwards, resulting in a relatively high score on the last trial on day 101.

Figure 4.3 which shows the behaviour of Tim during the trials, demonstrates a considerable increase of the scores for near, eye gaze and imitation toward days 92 and 94. Touch, although with a very low score, also occurred only on day 92.

When interpreting the graphs, it is important to remember that autism, being a spectrum disorder, can occur to a different degree and in a variety of forms.
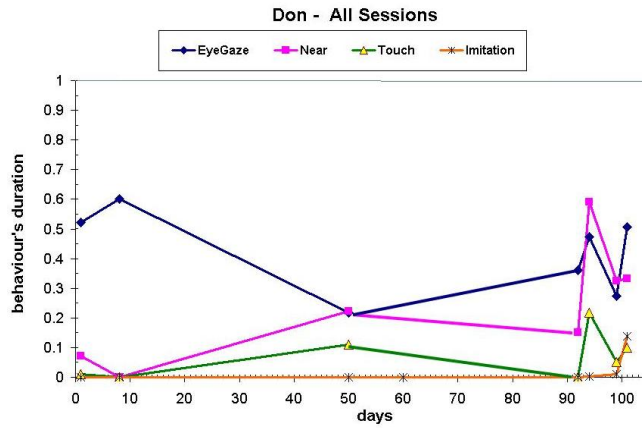
Figure 4.2:   Scores for the four behavioural elements of Don
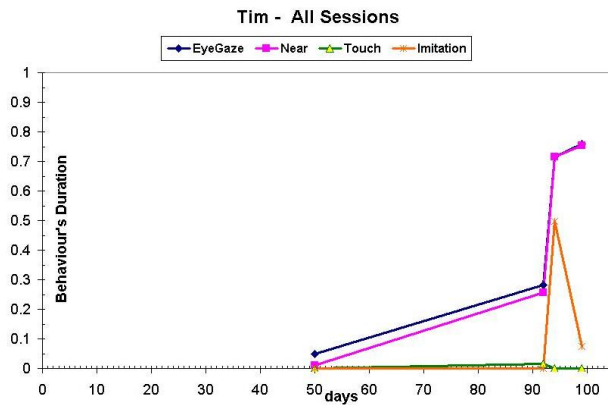
Figure 4.3:   Scores for the four behavioural elements of the subjects Tim .

Furthermore, the children that took part in the trials are of different ages and different levels of development. Therefore, these graphs can provide only a very general view of what might be possible to achieve with some children with autism. As stated earlier, it is important to view the children's behaviour during the trials in the context of the assessment of their personal and social development level which

brought other influences to the trials, such as having a chair to sit on in early trials, or a constant encouragement the child needed to receive from his carer in order to remain focused. Figure 4.4 shows the behaviour of Andy during the trials.
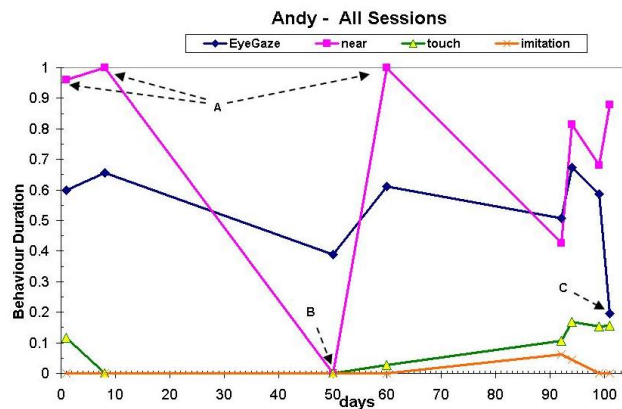
Figure 4.4: Scores for the four behavioural elements of Andy.

Andy, being only 5 years old, is highly distractable in activities or tasks led by others (see assessment above) and during the familiarization phase of the trials he needed constant encouragement from his carer to remain focused. Point A in the graph above refers to trials 1, 2, and 4, where the carer placed a chair next to the robot for Andy to sit on and watch the robot, hence the very high score in the Near criterium. During the third trial (point B- day 50), Andy was sitting on the carer's lap throughout the trial and as the carer herself was sitting some distance away from the robot, the score for Andy for Near equals zero. Point C marks a considerable drop in eye gaze toward the robot. However, it highlights again the need to view the results in the context of what actually happened in the trial itself. In this trial, once the long period of familiarization was passed, Andy surprised the carer and experimenters involved: he initiated a long interaction with

59

the investigator, using the robot as an object of shared attention. Andy showed at this point unexpected communicative skills (described in chapter 6) and the entire episode with this particular child provided very positive indications as to the possible role of the robot as a mediator in interactions between autistic children and other people.
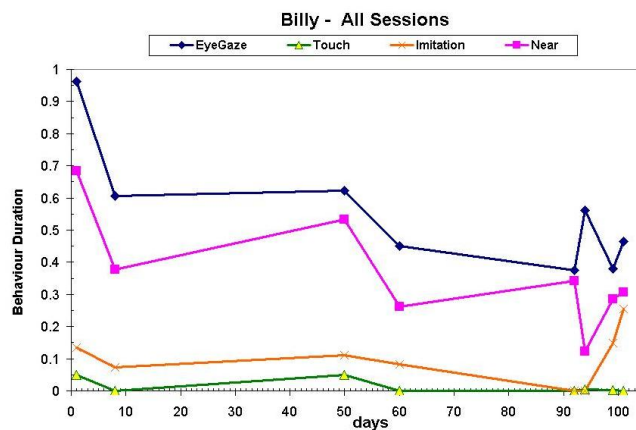
Figure 4.5: Scores for the four behavioural elements of Billy.

As the children differed in their personal development levels, for some the main interactions with the robot were by means of eye gaze or touch only. Developmentally, according to their teacher, it was too early for the younger children Andy and Don to comprehend imitation. For others, imitation was an achievable goal after the period of familiarization and learning (this applies to Billy and Tim – the older boys) while touch did not play a major part in their interaction with the robot. An example of this can be seen in Figure 4.5. Billy touched the robot only rarely. He rather explored the new toy in his own way, walking freely in the room, approaching and walking away from the robot frequently in each trial. In one trial, he even performed what seemed to be a dance, directed at the robot (see Figure 6.9 in section

60

7.2.3). However, his main achievement was that the longitudinal approach allowed him enough time to get familiar with the robot, to learn imitation games, and to engage with the robot on his own initiative (as can be seen in the graph for the behavioural criteria of Imitation).

The data also allowed monitoring of each behavioural element separately, over the entire period of the trials, across all the children. The graphs in figures 4.6 & 4.7 show examples of the results. As it becomes clear from the discussion above, even when a larger sample size of children were available, averaging behaviour scores across children is not appropriate in this study since our study focuses on the individual interaction histories of each child.
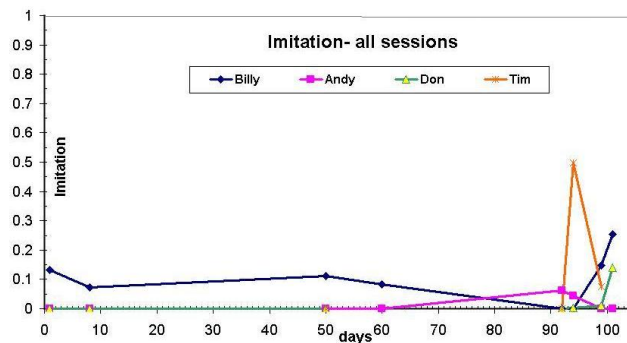
Figure 4.6: Trend of Imitation scores as it appeared in all children throughout all the trials with a visible increase at the end of the trial period from day 92 onwards.

4.2.5 Results of Qualitative Analysis

As stated earlier, one of the overall questions that was investigated is whether exposure to and interaction with the robot can help to increase the autistic child's social interaction skills using imitation and turn-taking games for this purpose. During the
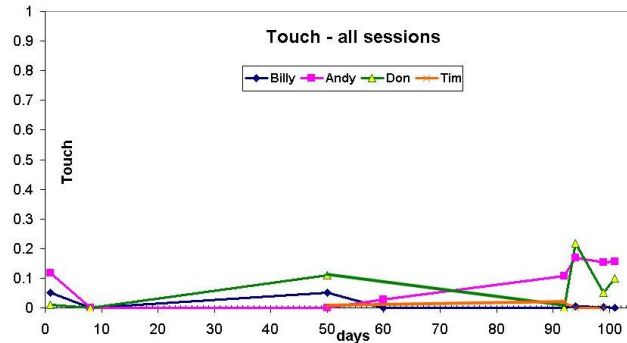
Figure 4.7: Scores for Touch that increase for some of the children in the last trials, days 92-101.

analysis of the video recordings of this set of trials, several occasions were noticed in which the children also interacted with the adults in the room (i.e. their carer, or the investigator). Sometimes this occurred in relation to the robot, when the robot acted as a mediator or an object of shared attention, but at other times these interactions were not robot related. To understand the events that take place in such interactions requires attention to the autistic child's activities in their interaction context. The quantitative analysis alone, based on the frequency and duration of the basic behaviours, cannot reveal some important aspects of social interaction skills (imitation, turn-taking and role-switch) and the communicative competence that the autistic children showed during the trials.

4.2.5.1 Results and Discussion

A comprehensive qualitative analysis of some of those segments of the trials where the children showed social interaction skills and communicative competence is discussed in chapter 6. However, the following provides a description of a very short segment (duration of 32 secs) taken from one child's trial on the second to last day of

this longitudinal study, where the child (Tim) interacted with the robot and showed advanced interaction skills not seen before (see also figure 4.8):

	Action		Response
1.	Robot raises left arm	-	Child mirrors and raises right arm
2.	Robot raises left arm	-	Child mirrors and raises right arm
3.	Robot raises left arm	-	Child mirrors and raises right arm
4.	Robot raises right arm	-	Child mirrors and raises left arm
5.	Robot raises right arm	-	Child mirrors and raises left arm
6.	pause (under 1 sec)		
7.	Child raises right arm	-	Robot mirrors and raises left arm
8.	Robot raises left arm	-	Child starts to raise left arm, quickly drops it and raises right arm
9.	Child raises left arm	-	Robot mirrors and raises right arm
10.	Robot turns head to the right	-	Child mirrors and turns head to left
11.	Robot turns head to the right	-	Child mirrors and turns head to left
12.	Child shakes head up and down	-	Robot turns head to left
13.	Child pauses		
14.	Robot raises right arm	-	Child starts to raise right arm, quickly drops it and raises left arm

It can be observed that during this segment Tim showed the following social interaction skills:

63

a) straightforward imitation of various body parts movements (lines 1-5, 9-11,14),

b) the child realized when he made a mistake in imitation and corrected himself (lines 8, 14)

c) the child initiated interaction as part of the imitation and turn-taking game without any pre–determined cue, thus causing a role-switch (lines 7, 9)

d) the child tried to initiate interaction using a new movement, shaking the head up and down. The child indicated a comprehension that this movement is beyond the robot's capability and so moved on without insisting on that movement (line 13).

Figure 4.8: Tim shows advanced interaction skills.

As stated above, these are advanced interaction skills in children with autism. It is not generally common for children with autism to *take initiative* in interactions. What is more, as described by his teacher, Tim is usually very difficult to motivate, yet here he not only initiated interaction in the imitation game but also tried out new movements - skills which he had not shown before.

4.2.6 Discussion of Results

This chapter presented a novel study of longitudinal research on the exposure of children with autism to a humanoid robot. Relatively little work has been done on using robots as assistive technology for people with autism. Usually, the same children are only exposed once or a few times to a robot. In contrast, the approach taken in this study was based on repeated trials over a long period of time and allowed the children time to explore the interaction space of robot-human, as well as human-human interaction. Supporting evidence was obtained for the initial hypothesis, namely that repeated exposure to an interactive small humanoid robot will increase basic social interaction skills in children with autism.

In some cases, the children started to use the robot as a mediator, an object of shared attention, for their interaction with their carers and the investigator. Furthermore, once they have become accustomed to the robot, in their own time and on their own initiative, they all opened themselves up to include the investigator in their world, interacting with him, and actively seeking to share their experience with him as well as with their carer (see figure 4.9).

Figure 4.9: Autistic children sharing with an adult their experience with the robot.

In Figure 4.9, the photo on the right, taken from a trial conducted during the

longitudinal study, is a still shot taken out of a sequence where, for the first time, the child acknowledged the presence of the investigator (in prior trials the child completely ignored him) and came and sat on the investigator's lap for few moments before standing up and moving toward the robot while holding the investigators hand. It is believed that this event, too, can be contributed to the longitudinal approach taken in this investigation where the child had enough time to familiarize himself not only with the robot, but also with the unfamiliar person (the investigator) who was present during the trials (a comprehensive analysis of the joint attention skills exhibited in this sequence of actions is presented in chapter 6). It is important to note that the investigator did not initiate any part of this interaction. The photo on the left, from a trial that took place during an extension to this study, some months later, depicts a moment when the child (who has very limited verbal communication skills) turned his head toward his carer and said: "toy fun...fun...fun".

It is believed that this sharing of experiences is an important aspect of the work, since human contact gives significance and (emotional, intersubjective) meaning to the experiences with the robot.

Chapter 5

The Robot's Design (appearance)

This chapter studies the effects of the robot's appearance on facilitating and encouraging interactions of children with autism with a humanoid robot. As described in section 2.1 above, one of the main impairments of children with autism refers to their inability to relate to other people in meaningful ways. Peter Hobson (Hobson 2002) studied the behaviour of children with autism when greeted by a stranger and found that they did not seem to react with feelings to his presence and his orientation towards themselves. The children appeared not to be interested in the stranger and often didn't even look at him. It is not just that children with autism might demonstrate a preference to interacting with objects rather than with other people, but, as Hobson suggests, children with autism often seem to relate to a person as an object.

If some children with autism demonstrate a preference to interact with objects rather than people how would they interact with a humanoid robot? What aspects in the robot's appearance can facilitate interactions which might encourage basic social interaction skills? Ferrara and Hill (1980) reported that children with autism prefer

simple designs and a predictable environment in their interaction with toys, and that they approached social objects (they used various types of dolls in their study) more readily if they were simple in appearance. They concluded that these are more appropriate starting points for therapeutic intervention where the complexity of the therapeutic toys can be slowly increased.

An important implication of the investigation reported here, for the use of robots as assistive technology for children with autism, relates to the question of whether or not one should use humanoid robots that closely resemble human beings (e.g. possessing a lot of facial features such as eyes, mouth, nose, eye brows, hair etc.). Although robots equipped with human-like features appear more like ordinary humans, the complexity of their appearance might be overwhelming or even frightening to autistic children.

Two types of robots were used in two studies in this investigation, a life size 'Theatrical Robot' (a person who was dressed and acted like a robot) and a small humanoid robotic doll. The chapter compares the children's levels of interaction with and response to the robots in two different scenarios: one where the robots were dressed like a human, and the other when the 'robots' appeared with plain clothing and with a featureless, masked face. The two studies were as follows:

A. A study with a life size 'robot'- the humanoid robot used in previous studies within the Aurora project and thus far in this research is a small, 45 cm tall doll with a pretty, detailed face and girl's clothing (see section 3.2). Bearing in mind the social interaction impairment of autistic children, and their reaction to other unfamiliar people, or 'strangers', one of the questions posed by the current research is how children with autism may react to a *life size* robot with a full range

of possible interactive movements. At present, controlling a humanoid robot with many degrees of freedom requires state-of-the-art computing and engineering skills, which lies outside the scope of a project in assistive technology. Full-sized humanoid robotic platforms are also highly expensive and beyond the scope of a project that is aimed at school children where safety and ethical issues are of primary concern. In order to address this lack of the availability of an easy to control, safe, full-sized humanoid robot that can be used in these studies, a novel approach was developed by using a Theatrical Robot - a professional mime artist - a person who was dressed and acted like a robot. The Theatrical Robot is a life-size, embodied, simulated robot which allowed the investigation of the requirements of robot design even prior to any hardware and software development (Robins, Dautenhahn and Dubowski 2004). The Theatrical Robot consists of a human instructed to behave and/or appear like a robot. The human should be a professional or a person trained to perform pre-scripted behaviours, as needed for experimental protocols, reliably and with high precision. In this study, the children's level of interaction with and response to the mime artist were compared in two different scenarios, one when he was dressed like a 'robot', and the other when he was dressed as an 'ordinary human'. The trials with the two scenarios took place on the same day, approximately one hour apart. The set-up of the trials in both scenarios were identical, i.e. they took place in the same room, and the mime artist performed an identical, pre–scripted repertoire of movements in both cases, closely mimicking the movements of the small humanoid robot. This whole study with the mime artist performing in two scenarios was repeated again for the second time, two months later, with very similar results.

B. a study with a humanoid robotic doll - the study with the theatrical robot described above took place alongside the longitudinal study with the humanoid

robot described in section 4.2. Inspired by the results of the trials with the theatrical 'robot'(i.e. the response of the children toward the plain/robotic appearance of the robot was notably more social and pro-active), it was felt important to continue this investigation, with the humanoid robot used in the longitudinal study, as it might yield similar results. An additional costume for the robot was prepared – plain clothing with featureless head, and some of the trials of the longitudinal study were conducted with two different appearances of the robot, namely a 'pretty girl' and a 'plain' robotic doll. This longitudinal study was extended six month later, with additional trials with three of the four children, at the same location and with the same set-up. These trials focused specifically on the issue of the robot's appearance, and provided additional data to the results which are presented in this chapter.

5.1   The Hypothesis

The investigation focused on how the children respond in two experimental conditions with different appearances of the robot. Autism research has shown that children react with avoidance towards novel stimuli in general, and strangers in particular which are rather treated as objects than people. However, as discussed in earlier chapters, they appear to respond positively to the simplified environments provided by computer systems and robots. Thus, it is hypothesized that the children will react (socially) more proactively toward a plain/robotic version than toward a more human-like appearance that includes e.g. a range of facial features.

5.2   The Trials: Approach, Set Up & Analysis

The approach in all the trials (trials with the humanoid robotic doll and trials with the mime artist) in this investigation is the same approach taken throughout the research (see section 3.1) and has been designed to allow the children to have un-constrained interaction with the robot and with the mime artist with a high degree of freedom, on their terms to begin with (providing it is safe for the child and safe for the robot). In all trials, those with the theatrical robot, and those with the humanoid robot, four behavioural criteria (including Eye Gaze, Touch, Imitation and Near) were evaluated, using mainly quantitative analysis techniques based on the video data of the interactions, which provided the basis of the discussion here.

The children who participated in these trials are the same four children who participated in the longitudinal study. The set–up used in the trials, and the data processing and analysis methods are the same as those used in the longitudinal study. Please refer to section 4.2 for more details.

5.3   Study with the *Theatrical Robot*

5.3.1   The 'Robot'

The mime artist who performed the Theatrical Robot role was a white male, 175 cm tall with average build. The 'robotic' costume included a complete head cover, mask, shirt, gloves trousers socks and shoes – all painted in the same light gray colour (see figure 5.1 below). The ordinary human costume included brown shoes, dark trousers, an open brown jacket, and a light colourful shirt. The mime artist's

movement repertoire progressed from stillness, through simple robotic movements to more human like interactional gestures, including simple robotic movements similar to the movements of the humanoid robotic doll (i.e. arms up and down, legs up down, head side to side). The mime artist performed the same movement repertoire in the same order in all the trials (including the trials where he was dressed as an ordinary person- a stranger).

Figure 5.1: The theatrical 'robot' in its various interactional modes. The figure on the right shows the same person wearing ordinary human clothing.

5.3.2 Trials Setup & Procedures

Before each trial, the mime artist was standing still in the far end of the room, ready to start his movement repertoire as soon as the child entered the room. The investigator was standing behind a set of curtains, at the other end of the room, operating one of the cameras. He was not visible to anyone in the room. The other camera, operated by remote control, was set to 'standby' mode ready to record. The children were brought to the room by their carer, one at a time. The carer, staying near the entrance, did not intervene in the trial procedures, nor did she give any instructions to the child, except for drawing the initial attention of the child to the mime artist, if it was needed. The child then, was left to observe and interact

with the mime artist, should he choose to do so. The mime artist continuously performed his repertoire of movements, which included approximately one minute of stillness, two minutes of simple robotic movements and a further two minutes of human gestures. He was not responding to the children, and during the whole trials his eye gaze was directed straight forward. Figure 5.1 shows different interaction modes. The trial, lasting approximately five minutes, stopped at the end of this sequence of movements.

5.3.3 Quantitative Analysis of the Results

Quantitative methods have been used to analyse the data, as described above, and yielded various graphs that compare the children's response to the mime artist in his two different appearances - i.e. as theatrical 'robot' and as a ordinary person. The graphs in figure 5.2 & 5.3 compare the response of all the children to the two appearances of the mime artist (plain robot and human) in terms of Touch, Gaze and Near.
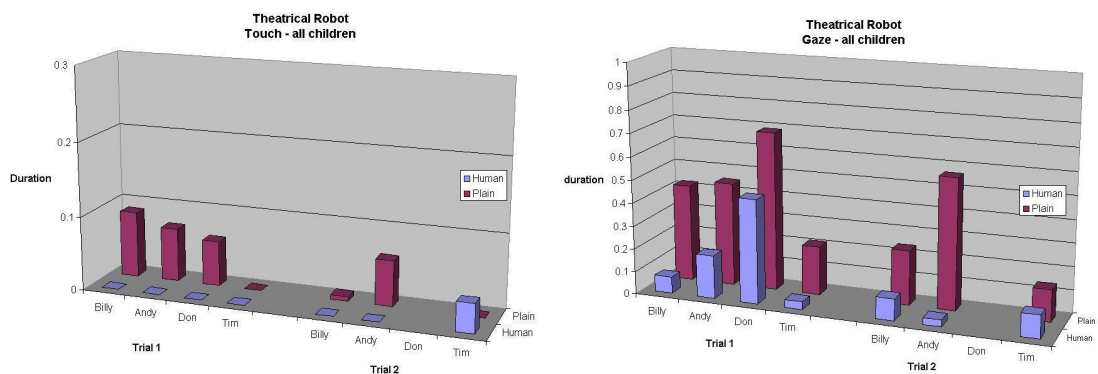
Figure 5.2: Scores for the behavioural criteria of Touch and Gaze as observed during the two different mime artist appearances (robot & human) in two sets of trials.
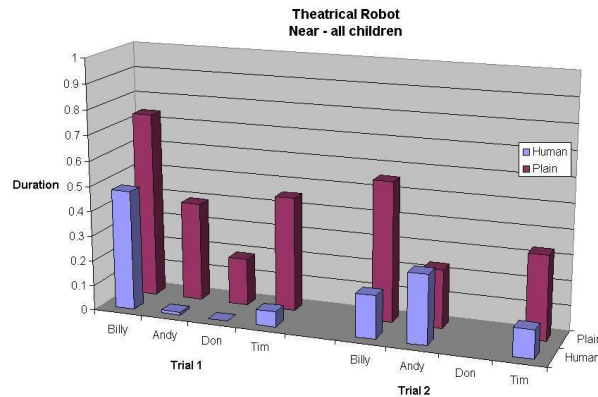
Figure 5.3: Scores for the behavioural criteria of Near as observed during the two different mime artist appearances (robot & human) in two sets of trials.

As can be seen from these graphs, there is a remarkable difference in the amount of time the children interact with the mime artist when he appeared in his theatrical robot costume, and when he appeared as an ordinary human. All children showed a significantly higher level of interaction for Gaze, Touch and Near when the mime artist appeared as a theatrical 'robot'. Moreover, the second set of trials that took place two months later (trial 2 in the graphs) shows very similar results. Figure 5.4 give two examples of how individual children responded to the mime artist in the two scenarios of appearing as a robot and as an ordinary human.

5.3.4 Qualitative / Observational Analysis

The observation of the video recordings of the trials with the mime artist showed a striking difference in the children's behaviour and attitude towards the mime artist when he was wearing an ordinary person's clothes (figure 5.5) and when he was in his Theatrical Robot costume (figure 5.6). Note, that the trials took place with the same children and in the room with the same experimental settings.
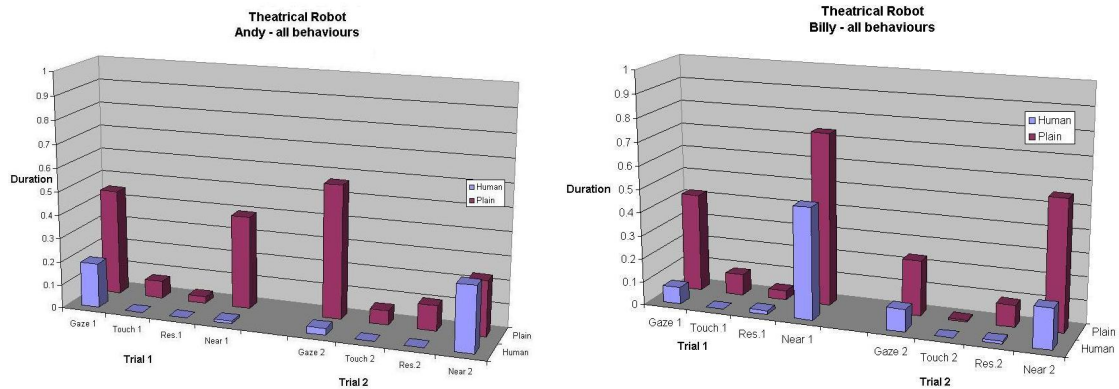
Figure 5.4:   Andy's and Billy's interaction graphs.

Figure 5.5: Mime artist as an ordinary person. Children from left to right: Andy, Billy, Chris.

When the mime artist presented himself as an ordinary person - a stranger, he was being avoided or ignored. Typically, distance is maintained and eye contact avoided. What is sometimes described as 'aloofness' but is a form of avoidance behaviour in children with autism, can be observed in figure 5.5. The photo on the right shows an even more extreme variant of this behaviour.

In the trials with the theatrical 'robot', as soon as the 'robot' is noticed, he, (it) is approached by the child who in most cases immediately makes physical contact as can be seen in figure 5.6. The child's attention is maintained and when the theatrical

Figure 5.6: Andy (left) and Billy (right) making physical contact with the theatrical 'robot'.

'robot' begins to go through his 'robotic movements' the child becomes even more bold in his interaction. The child begins to mimic the robot's movements and even maintains the physical contact with the 'robot' as it is moving (figure 5.7).

Figure 5.7: Andy (left) and Chris (right) interacting with the 'robot' whilst it is moving.

The image in Figure 5.8 derives from the repeated trial that took place two months later. Here we can see the same child, Andy, reacting in a very similar way. As soon as Andy noticed the 'robot', he approached and made physical contact. Moreover, we can see that Andy's gaze during this interaction is often being directed to the 'robot's' face.

Figure 5.8: Andy in a repeated trial two month later.

5.4   Study with a Humanoid Robot

The result from the study with the theatrical 'robot' above showed that the children responded notably more socially towards the life-size robot when it had a plain/robotic appearance, as compared to an appearance with full human features. As stated earlier it was important to see whether these results could be confirmed in the longitudinal study with the small humanoid robot that took place alongside, as it could potentially enhance its results (see chapter 4). The robot is described in section 3.2. The plain appearance of the robot consisted of a grey/silver costume (shirt & trousers) and a plain featureless mask that covered the whole head of the robot. The human appearance of the robot was that of a 'pretty girl' and consisted of a pink costume and a head with a full featured face and brown hair (see figure 3.1). Being part of the longitudinal study which expanded over several months, the robot operated either in its 'dancing' mode or puppeteering mode, depending on the phase of the trials, which were designed to progressively move from very simple exposure to the robot to more complex opportunities for interaction (see chapter 4).

The set of trials where the children were given the opportunity to have free interaction with the robot was repeated a few months later (referred to here as the

extension study) with the focus being on the different appearances of the robot (see figure 5.9).

Figure 5.9: Free interaction during the extension study.

5.4.1   Quantitative Analysis and Results

The quantitative analysis of the data yielded various graphs showing the different responses of the children to the robot's appearance (i.e. the different duration of interaction). We can see in figure 5.10 examples how one child (Don) has a different level of interaction with the robot, in terms of behavioural criteria of Touch and Near, depending on the robot's appearance. These data were taken during the longitudinal study when the child had many exposures to both robot's different appearances.

Extension Study: As mentioned earlier, six months later the trials were repeated twice again (weeks 1&2 in the graphs below) with exactly the same set up, with the specific aim of studying the children's reaction to the different appearances of the robot. The graphs show samples of the results. Figure 5.11 show individual children's level of interaction for all four behavioural criteria (Gaze, Near, Touch, Imitation), and how it differs according to the robot's appearance.

Figure 5.12 gives an example of how the robot's appearance during the Extension
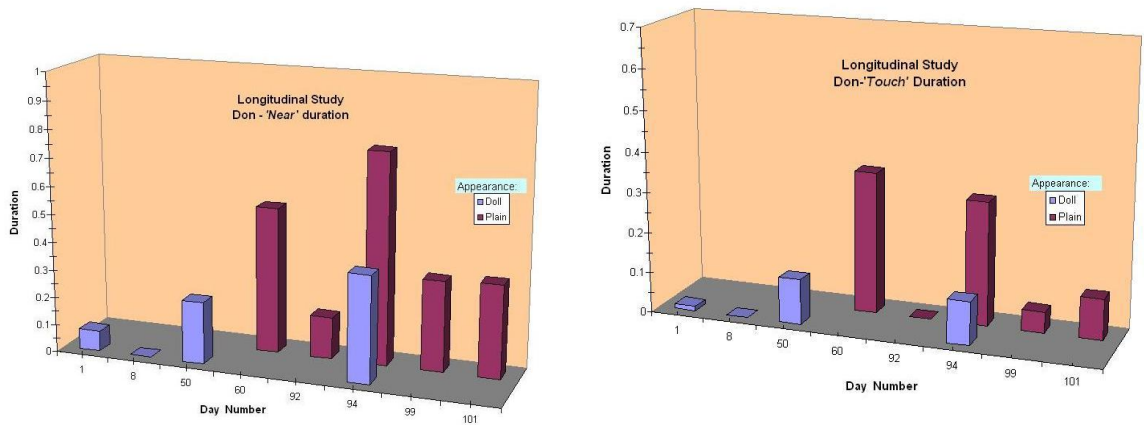
Figure 5.10:   Don's duration of Near and Touch in both scenarios (The vertical axis is a proportional representation of the duration of behaviour relative to the duration of that specific trial).
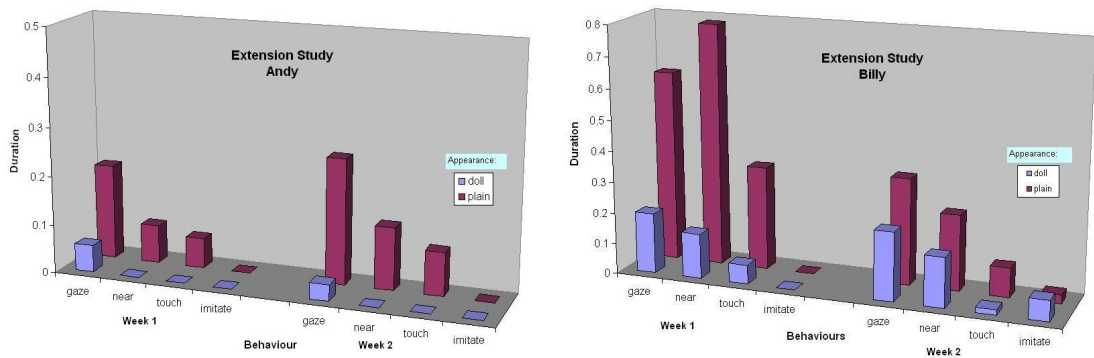
Figure 5.11: Billy's and Andy's behaviour during trials of the *Extension Study*.

Study affected the level of eye-gaze towards the robot in all children.
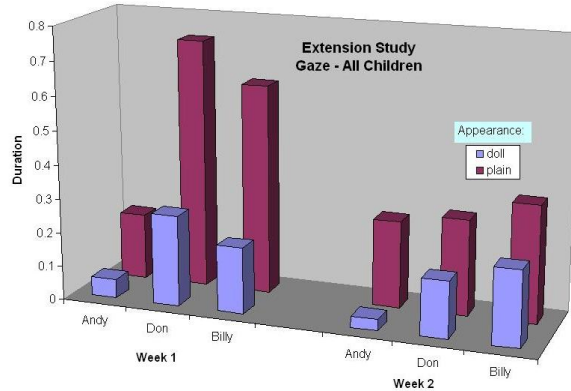
Figure 5.12: Eye-Gaze levels of all children during the *Extension Study*.

5.4.2 Qualitative Analysis

Our approach of carrying out repeated trials over a long period of time allowed the children time to explore both the interaction space of robot-human, and also human-human interaction. As mentioned earlier, in some cases the children started to use the robot as a mediator, an object of shared attention and it seemed as if they were actively seeking to share their experience with the investigator as well as with their carer (figure 5.13). In addition, the stress free environment, with a high degree of freedom, facilitated the emergence of spontaneous and playful interactions, that included at times, elements of social behaviour directed at the robot.

Although this is a very small sample base, it is interesting to note that in most of these cases of social behaviour (both, toward the investigator and toward the robot) it happened when the robot wore its plain robotic costume, and in the case of two of the children, joint attention with the investigator occured when they saw this costume of the robot for the very first time (after seeing the 'pretty-girl' costume several times before). Billy, for example, after completely ignoring the investigator

for the first few weeks, as if he didn't exist in the room at all, surprised everyone when he took the initiative and came and sat on the investigator's lap (figure 5.13 center). Billy also surprised his teacher and the investigator when the last trial of the longitudinal study was ending, by running around the room and 'dancing' in–front of and directed towards the robot each time he passed it (figure 5.13 right). He also repeated this behaviour with a very similar dance during the extension study two month later.
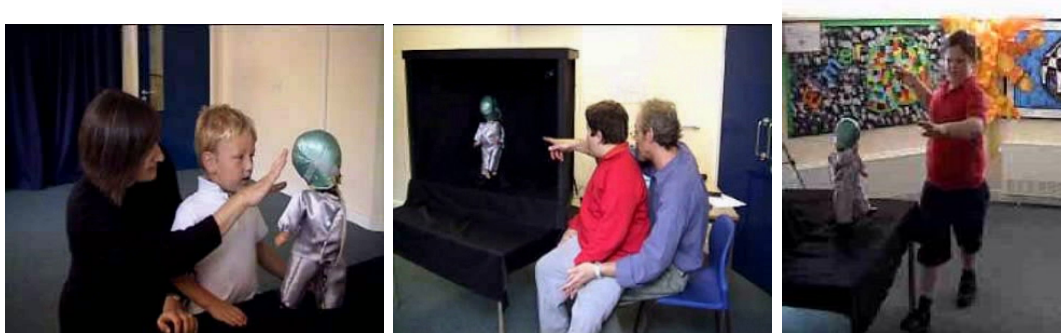
Figure 5.13: Children displaying social behviour.

As it is such a small sample base, it is impossible to decide if and to what extent the children's behaviour in these cases can be attributed solely to the robot's plain appearance. However these results might be a good basis for further longitudinal studies. A comprehensive qualitative analysis of some of these segments of trials, where the children used the robot as a mediator and object of shared attention, can be found in chapter 6. The social behaviour of Billy which was directed toward the robot is further discussed in section 7.2.

5.5   Discussion of Results

All four children with autism showed notable differences in how they interacted with the robots in the two experimental conditions: as a robot with robotic, plain appearance, or with ordinary human appearance. This applies to the experiments conducted with both types of robots tested i.e. the full size theatrical 'robot' and the small humanoid robotic doll. Results confirm the hypothesis, which was formulated based on research in psychology on how people with autism interact with other people. Note, that the study comprised four children who were exposed to the two conditions for the mime artist only twice. Possibly, after repeated exposure to the children, the mime artist in his ordinary human appearance would no longer be a stranger, but become a familiar person. Similarly, experimenters who work regularly with the same children become, over time, more and more familiar to a child who is then likely to change behaviour toward that person. In this case the experimenter or therapist can develop a meaningful relationship with the children, which is very different from what can be expected of a robot. Further in-depth studies into the role of robots and 'strangers' in the therapy and education of children with autism might shed more light on these issues and provide additional experimental evidence. However, the results at present are nevertheless striking in showing notable differences in the two experimental conditions studied.

An important implication of these findings for the use of robots as assistive technology in the therapy and education of children with autism relates to the question of whether one should use humanoid robots that closely resemble human beings (e.g. possessing a lot of facial features such as eyes, mouth, eyebrows etc.) as suggested e.g. by (Breazeal and Foerst 1999), or rather utilize machine-like, clearly

non-humanoid robots, as argued e.g. in (Dautenhahn 1999). The preliminary evidence presented in this paper clearly supports the case of using simple robots with few features. This has also been confirmed by the results of the two studies (i.e the longitudinal study and the extension study) with Robota- the small humanoid robotic doll. These studies showed very similar results and clearly indicate that initially the children showed a preference for interaction with the robot in its plain robotic appearance over the 'pretty doll' appearance (although over time, during the longitudinal study, they became accustomed to both appearances of the robot). The images in figure 5.9, taken during the extension study, show examples of pro-active behaviour towards the robotic doll with a plain dress, as opposed to the reactions towards the same robot in a 'pretty girl dress' (image on the right). This result is striking insofar as children with autism (different from other children) can be expected to avoid novel stimuli. However, once a robot becomes familiar, it might be possible to gradually change the appearance toward a more human-like appearance, which could also assist the children in generalizing experiences from interactions with robots to interactions with people, in line with the analysis presented by Ferrara and Hill in their studies with different toys for children with autism (Ferrara and Hill 1980).

Chapter 6

Robots as Social Mediators

This chapter focuses on the investigation into which ways and to what extent a robot can assume the role of a social mediator. In early work in the Aurora project where children with autism were exposed to a mobile non-humanoid robot once or twice, results indicated the ability of the robot to provide a focus for shared attention (Werry, Dautenhahn, Ogden and Harwin 2001c). Based on these positive indications, this research investigated how a humanoid robot can mediate interaction in multiple exposures by children with autism over a longer period of time, and how the robot, being an object of joint attention, might encourage them to interact with an adult (the investigator) as well as with each other whilst playing with the robot.

6.1 Joint Attention & the Case of Autism

From infancy, children use non-verbal interactive actions such as eye-gaze and protodeclarative pointing to share their attention and interest in an object or a third person with others. These triadic referencing activities are referred to as joint at-

tentional skills and play a crucial role in the development of autistic children. In typically developing children joint attention skills emerge between about 9 and 18 months of age and impairment in these skills are among the earliest abnormalities noticed in autism (Charman 2003, Leekam 2003, Siller and Sigman 2002).

This impairment, often referred to as *joint attention deficit*, described in the Diagnostic & Statistical Manual of Mental Disorders (DSM) as "a lack of spontaneous seeking to share enjoyment, interests or achievements with other people (e.g. by a lack of showing, bringing or pointing out objects of interest" (American Psychiatric Association, 1995, p.70). There has been ongoing debate about the significance of this 'deficit' in relation to social skills in autism. Research has suggested that children with autism (particularly those with a low verbal mental age) are impaired in following the gaze and head direction activities of others (Leekam, Hunnisett and Moore 1998). More recently, Siller and Sigman noted that in autism "nonverbal communication is characterised by a lack of joint attention" (2002, p.77). Other research has suggested that older and verbally higher functioning children with autism are better (though still somewhat impaired) in initiating and following joint attention (Leekam, Lopez and Moore 2000, Travis, Sigman and Ruskin 2001).

6.2 Robot Mediated Joint Attention in Child–Adult Interactions

This section analyzes in great detail occurrences of joint attention that emerged spontaneously in natural interactions between the author and children with autism, in a playful context where a humanoid robotic 'toy' served as a focus of attention, a salient object in the environment that mediates the interactions. It explores how

children with autism initiate and orientate to joint attention bids in interactions involving a robotic device. The qualitative approach adopted here, using in part *Conversation Analysis* (CA), brings to light the children's gaze initiating and gaze following behaviour with reference to what other participants in the interaction (an adult and a robot in this case) are doing at the time, and provide information on details of their communicative and social competencies.

6.2.1   Data Selection and the Analytic Perspective

The data presented in this section was recorded during the trials of the longitudinal study described in chapter 4 (please refer to that chapter for the description of the robot, the children and the trials' set-up and procedures).

During the analysis of the video recordings of this set of trials the author noticed several occasions when the children interacted with him (he was the experimenter in the trials) and with their carer who also was present in the room. Sometimes this occurred in relation to the robot, when the robot acted as a mediator or an object of shared attention, and at other times these interactions were not robot related. The author carefully selected, from a total of 115 minutes of video data, three short sequences where the robot mediated interaction between the children and himself and in which joint attention issues became relevant. The first sequence is of a child securing joint attention with the experimenter with the use of gaze initiation activities. This sequence was analyzed using CA scripts. The other two sequences are illustrations (using photo stills) of children displaying gaze following activities during interaction with the experimenter where the robot was the focus of joint attention.

6.2.1.1   About Conversation Analysis

Conversation Analysis (CA) seeks to provide an accurate description of the actions in interaction through the vocal and non-vocal activity of participants. It focuses on what is being done at any given moment in any form of interaction. This is achieved by considering the participant's response to each other's talk. In this way all interactional activities (vocal and non-vocal) can be understood as being responded or orientated to in terms of their *contextual relevance* (Shegloff 1968). One of the key findings of CA research is that in day to day interaction participants are sensitive to the co-participants in their design of their talk (Sacks, Schegloff and Jefferson 1974). The term *recipient design* is used here to highlight the observation that speakers design their conversations, e.g. the allocation of 'turns', by orienting toward the other recipients. This analysis of everyday talk has been expanded to include gesture and body movements as examples of the ways in which co-participants can skilfully orientate to each other (Goodwin 2003). A basic finding of CA is that skillful participants arrange their actions (talk, body movement, gaze, gesture etc) in such a way that they attend to the activities undertaken by their co-participant(s).

These findings are of direct relevance to the study of interaction involving children with autism and a robot. CA consists of the detailed transcription and analysis of all vocal and non-vocal activities that are available and potentially relevant to the participants. These include the movements or gestures of a non-vocal robot which might be relevant and influential to the action of other participants. CA may help to highlight both the deficits in social interaction skills that children with autism might have and the competencies of children with autism in skills that might otherwise go unnoticed.

6.2.2 Initiating and Securing Joint Attention by the Use of Gaze

This example of child–adult interaction took place in one of the trials where the child (Andy) acknowledged the presence of the experimenter for the first time, and to everyone's surprise, he came to the experimenter, pulled him off his chair, and started to play with him on the floor. After a short game on the floor, the experimenter and the child positioned themselves in front of the table where the robot was located and where the interaction sequence that described here took place. CA was chosen as the analysis method for this sequence, in order to focus in depth on specific interactional competencies on the part of the child. With its attention to the autistic child's activities in their interactional context, CA can help to understand subtle details of the events that take place in such interactions. Note, CA is a very time consuming technique that requires highly specialist skills of the coder. The author therefore requested the help of an expert[1] who taught him the basic principles of CA coding and analysis, and who provided the transcript and its analysis of the example presented here.

6.2.2.1 The Physical Surroundings

Andy (A) is sitting on the experimenter's (Exp.) lap (see image 1 below) who is crouched on the floor facing toward the robot (which is placed on a table directly in front of them). The robot moves its arms, hands and legs as indicated but between lines 1 and 11 the robot's left leg does not move but is instead fixed in a slightly protruding position relative to the other leg (due to a temporary technical fault).

---

[1]The CA transcript and its analysis in this example have been provided by Dr. Paul Dickerson, a senior lecturer in the School of Human and Life Sciences, Roehampton University, London.

6.2.2.2   How the Transcript is Organised

The transcripts are a simplified version of the vocal and non-vocal activities of the participants **A** (Andy, an autistic child), **Exp.** (the experimenter) and the robot. A teacher is also present in the room but remains silent and off camera throughout the interaction. The transcript is an amended form of Jefferson's (1984) conventions (details of which are available at: http://www-staff.lboro.ac.uk/ ssca1/trans4b.htm; see appendix B for CA notation). To read the transcript, first note that moving from left to right and from one line number to the one below provides the sequence in which the activities occurred. Because so many activities might occur at any one time sometimes several lines are taken up to note what occurred at that precise point in the sequence. All vocal utterances are comprised of bold letters which capture the sound produced. Where these occur simultaneously the left square bracket symbol '[' is used to denote the onset of the overlap. Where there is doubt about the vocalisation produced it is placed in single round brackets. Any explicit description of behaviour is placed in double round brackets. A large number of arrows are used in the transcript to pinpoint the moment of onset or cessation (sometimes both) of a given action. This moment is measured against any vocalisation (if present) or the timed interval between vocalisations (measured in tenths of a second) indicated by hyphens. Hence the arrows will point to the precise moment during an articulation of a sound at which the indicated event occurred or the precise moment in time after the end of the last vocalisation. In this way the vocalisations, and intervals between them, provide a time-line on which all of the interactional activity recorded is mapped and which provides the reader with a sense of the sequential arrangement of the interaction. Additionally photo stills from the video are indicated by means of the following composite symbol: #1↓ the number indicating the image captured

at the precise moment indicated by the arrow.

6.2.2.3 Analytic Observations

The following analytic observations focus on body movements and vocal expressions. As an anecdotal remark, all children showed laughing, smiling, giggling etc. during the trials which seems to indicate enjoyment. This is important to the general aim to create an enjoyable environment where children with autism can play with robots. However, the affective nature of the interactions was not a focus of our study and was therefore not evaluated in detail.

Conspicuous Noticing:

Data transcript – lines 1-3:

```
                              ((robot moves left arm out and back))
                                   ↓         ↓
1      A      [aah  aah  ah   ah   ah  ah  ((melodically))
                  T__ ((gaze at T))R>_ ((gaze at Robot's left foot until line 10))
               ↑((head rotating))    ↑  ↑((leans in towards robot's left foot and back))
       Exp.   [(huh huh huh)
              ((face obscured)) ↑A_>((Exp. gazing at A from behind until line 2, 0.5))
                                           ((robot's right leg moves out and back))
                                   #1↓         ↓                    ↓
2      (- - - - - - - - -1- - - - - - - - -2- - - - - - - -3- - - - - - - - -4)
       A      ↑      ↑ ((leans back))
                                              ↑              ↑
                                     ((A flicks right leg out and back))
                             ↑ ((right hand raised towards robot))
                                   ↑>((touches robot's left foot
                                         until line 3, 6.4))
       Exp.         ↑((Exp.'s face obscured from view until line 3))     ↑
                                                                   ((leans back))
```

In this extract Andy demonstrates visually, in a variety of ways, a concern with or interest in the robot's temporarily static left leg. In line 1 Andy leans in to the left leg momentarily, in line 2 (image 1) of the transcript Andy touches the robot's
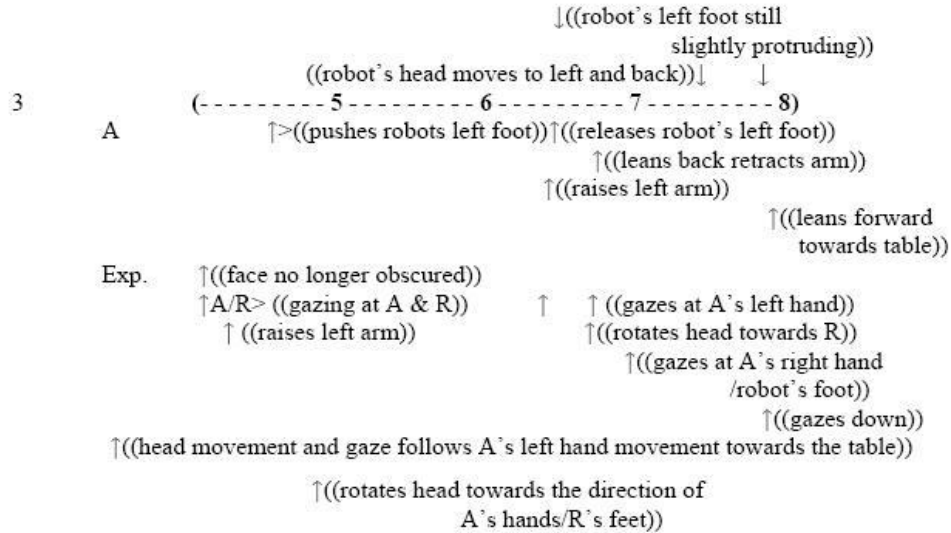
left foot. This is followed by a push against the foot (line 3) and Andy's leaning in towards the robot (line 3) and eventual near contact between Andy's face and the robot's left foot (lines 5 to 8, image 2). These activities on the part of Andy can possibly be interpreted as simple expressions of inner cognitive concerns (such as his interest in or awareness of a problem with the robot's left leg movement) however they are also made available both for our inspection analysing the data and for his co-participant Exp. who is gazing from behind.

image 1   image 2

Note that the child's attention to the robot's leg takes various forms; from the relatively indirect leaning in towards it in line 1, to the manual contact with and manipulation of it in lines 2 and 3, through to a still more overt near face contact with it in lines 5 to 8.

<u>Data transcript – lines 5 -8:</u>

```
5        Exp.     (°which way°) ((°three syllables°))
                         ↑((head leans in closer to A))
         A           ↑(face low on the table near to robot's left foot))
                  ↑ ((moves closer to robot's left foot))
                           ↓#2
                  ((robot rotates head right and then back to starting position))
                       ↓                   ↓
6                 (- - - - - - - - - 1 - - - - - - -)
         A                   ↑((face almost touching robot's left foot))
         Exp.        ↑((glances slightly up in direction of robot


                         -    A within likely field of view))
                            ↑((starts to raise right hand))
                            ↓((robot moves left hand up))
7        Exp.     hEy >what you↑doing<
                  ↑A>((gaze at A>))
                           ↑A>((gaze down at A>))
                  ↑((right hand movement towards A))
                      ↓((robot moves left hand down))
                             ((robot raises then lowers right hand))
                         ↓              ↓           ↓((raises right leg))
8                 (- - - - - - - - - 1 - - - - - - - - - 2 - - - - - - - - - 3 - - - - - -)
         Exp.     ↑((leans to his right))
                  ↑R/A((gaze at robot's left foot/ A's face))
                  ((Exp.'s gaze follows A's head as he starts to get up))↑
         A                                             ↑((starts to get up))
                                                        ↑
                                             ((standing facing robot))
```

These activities seem to involve an escalation of intensity prior to Exp.'s overt orientation to the robot's leg in line 8 after which Andy stands up whilst producing a vocalisation oriented to Exp. It may be that there are grounds for understanding

Andy as producing increasingly obvious orientations to the robot's left leg until the time that Exp. displays an orientation to the robot's leg himself. At this point Exp. is producing a visual display of Andy's body orientation and once this possible instance of joint attention has been accomplished Andy no longer escalates the intensity of his attention to the leg but instead orientates to Exp. If Andy's behaviour was intended to achieve joint attention with the experimenter without the use of speech, then the increased intensity of orientation to the robot's left leg was a successful strategy, as it attracted the attention of the experimenter to the leg, which was then followed by mutual gaze between the experimenter and Andy (Goodwin 2000).

Organisation of Vocalisations and Gaze

This section examines the organisation of vocalisations and gaze of the child and the experimenter.

Data transcript – lines 9-11:

```
9       A       (n:yA:rhk)
                ↑((rotates around towards Exp.))
                            ↓#3
                ↓((robot right leg lowered to initial position))
10              (- - - - - - -)
        A                ↑ Exp.>((gaze at Exp.'s face until line 11))
        Exp.             ↑ A>((gaze at A's face until line 13)
                ↓((robot's left leg starts to move -previously being static))
11      A       [(nyim:a))
                ↑Exp.__ ((gaze at Exp.))
                        ↑((starts to look down - but able to monitor Exp.'s face
                                                    and his own feet))
        Exp.    [(°good°)
                ↑ A>((continues to gaze at A's face)
```

In lines 9 and 11 Andy produces vocalisations. Whilst these vocalisations cannot readily be decoded into recognisable words (by those unfamiliar to Andy's talk at least) they do show certain interesting properties in the organisation of Andy's body orientation and gaze, coinciding with their production. In line 9 Andy's vocalisation starts whilst standing facing the robot - but as it begins Andy rotates away from the robot and toward the adult (the experimenter- Exp.). This very action could be understood as referencing the first articulation to a particular physical space (the robot) by virtue of its onset whilst gaze is at the robot. Furthermore the onset of Andy's rotation treats the vocalisation as designed for Exp. (as a recipient) as Andy rotates to Exp. whilst the vocal sound is produced. Andy produces his second and final articulation in line 11 having secured mutual gaze (gaze at each other's eye area) with his adult co-participant (Exp.). Note, that an interval of 0.8 seconds occurs between the two vocalisations and that Andy produces the second vocalisation very soon after mutual gaze is established. In this way Andy is displaying a design in the timing of his second vocalisation such that it occurs only after Exp.'s gaze at Andy has been secured (image 3, line 10). This accomplishes some important interactional work, in that securing mutual gaze confirms that Exp. is an intended recipient of the vocalisation, (Heath 1984). This is particularly important given that the earlier vocalisation (necessarily) involved Andy's gaze being directed away from Exp. and at the robot. Furthermore, the placement of the gaze is such that it occurs with the ending of Andy's vocalisations - a transition point when speaking participants routinely gaze at their co-participants (Heath 1984).

image 3

By bringing his gaze to Exp. at this precise moment Andy designedly selects Exp. as the intended recipient of his vocalisation, he is able to monitor Exp.'s responses to his vocalisations, and makes his own activities, including the cessation of speakership available to Exp.

Establishing mutual orientation to and through gesture:

In line 10 (cf. image 3), as noted above, Andy establishes mutual gaze. After this is achieved Andy starts to gaze down (initially towards the end of line 11 and more markedly in line 12, image 4, and especially line 13, image 5). The placement of Andy's gaze downwards after establishing mutual gaze provides an example of Andy designing his actions for his co-participant Exp. such that he can follow Andy's gaze direction. That is, in endeavouring to design our actions such that a co-participant gazes where we are gazing, it is particularly helpful to achieve mutual gaze with that co-participant and then proceed to direct our gaze to the referent we wish our co-participant to gaze at.

Data transcript lines 12-13:

```
                                ↓#4
12      Exp.        >°yes°<
                    ↑ A>((continues to gaze at A's face))
        A           ↑((continues to look down))
                        ↓#5
                        ↓#6         ↓#7
                                    ↓((robot's head rotates to the left))
13                  (- - - - - - - - - 1 - - - - - -)
        A           ↑((starts to flick right leg out))
                        ↑((gazes down very conspicuously at leg -
                            still able to monitor Exp.))
                            ↑((starts to gaze up at Exp.))

                            ↑Exp.>((gazing directly at Exp.))
        Exp.        ↑((gazes down in the direction of A's leg))
                            ↑((gazes more directly at A's leg))
                            ↑A>((gazing directly at A's foot))
```


image 4   image 5

After achieving mutual gaze (line 10, image 3) and having started to direct his gaze downwards (line 12 image 4) Andy produces a leg flicking movement (line 13 image 5). It can be noted that Andy flicks his right leg whilst it is the robot's left leg which he had paid conspicuously close attention to and which had been temporarily motionless - however this may be accounted for in terms of the mirror arrangement of the experiment (the child's right leg corresponds to/mirrors the robot's left leg

96

when the child is facing the robot). More important for our current considerations is the fact that Andy does not even start to produce the leg movement until after he has both achieved mutual gaze and started to gaze down slightly towards his leg. That is, rather than being produced without regard for Exp.'s orientations, Andy designedly places his leg movement to occur after activities which enable Exp. to visual orientate to it. Furthermore, Andy's gaze remains at his leg until he has secured Exp.'s overt orientation to it (line 13, image 7) at which point Andy gazes at the face of Exp.

image 6   image 7

In this way Andy has designed his actions to maximise Exp.'s opportunities for joint attention to Andy's leg movement. This is made still more possible by the size and spatial placement of Andy's leg movement - which is large and as far as possible made available for Exp.'s visual scrutiny. Thus, Andy's leg movement is a gesture that serves as a skilful means by which interactants get their recipients to visually orientate to their gestures. Furthermore, Andy produces a still more marked visual orientation to his own gesture (line 13 image 5) which cannot readily be dismissed as him merely being interested in looking at his own leg movement. The placement

of Andy's pronounced visual orientation and its overt production make available to Exp. that Andy is gazing at his leg and provide a means of securing visual joint attention towards Andy's leg. This joint attention is successfully accomplished in line 14 image 6 at which point Exp. begins to gaze down in the direction of Andy's leg, and line 14 image 7 where Exp. gazes more directly at Andy's leg. In this way the participants themselves display the work that each others actions have accomplished. Exp.'s orientations to the leg movement of Andy display Exp.'s treatment of the sequence of body, gaze and leg movement that Andy has executed. Visual joint attention has been achieved in line 13 image 6. A careful analysis of the prior sequence allow to see the design features on the part of Andy that have enabled this to be accomplished.

Andy's feet were in movement, but not gazed at, as he rotated to face Exp. - the shift of gaze to his moving foot occurs as that foot is moved to convey an important meaning (by forming a kicking gesture). Andy's gaze shift to his foot gesture can be seen as highlighting its importance and directing the recipient's attention (i.e. the experimenter's attention) toward that gesture when they weren't directly looking at it. Andy is thus doing what competent communicators (both adults and children) can be found to do in a number of quite different situations, i.e. he orientates to those movements that are designed to be communicative by either placing them in the recipient's line of vision or directing the recipient's attention to them by gazing at them.

6.2.3   Following the Gaze of Others

The above analysis has explored how an autistic child can initiate joint attention in response to the immediate interactional circumstances he is confronted with. Thus the child was found to move his gaze to his own (communicative) leg gesture at a time when it could not be assumed that the adult recipient was already noticing it. The examples below briefly illustrate how two other children, Don and Billy, responded to joint attention activity on the part of the adult. In particular these examples show how the children appropriately follow the adult's gaze and point towards the robot.

Don's example:

image 8   image 9

Images 8 and 9 show that Don moves from looking at the adult (who is gazing at Don) to following the adult's gaze and pointing, by directing his gaze and body orientation towards the robot.

image 10   image 11

Images 10 and 11 show Don developing his attention to the robot by reaching out to touch it. It can be noted that Don's right hand begins to move to touch the robot as the robot lowers its arms. This action on the part of the child may therefore be responsive not only to the gaze direction and pointing of the adult but also to the unfolding activity of the robot.

Billy's example:

The images below illustrate Billy's orientation to the gaze and pointing activity of the experimenter (Exp.) as well as what might be understood as his own attempt to initiate further scrutiny of the robot through pulling Exp. towards the robot.

image 12   image 13   image 14

In images 12, 13 and 14, Billy redirects his eye gaze from the laptop screen to the robot. This is done in response to the gaze and pointing of the experimenter (Exp.). Note that image 14 captures Billy stepping in closer to the robot and pulling the Exp. towards him - this could be understood as a means of initiating action to bring the experimenter towards an object that currently Billy is gazing at. This pulling action coincides with arm movements of the robot and can be understood as a way in which Billy seeks to initiate heightened levels of joint attention (on the part of Exp. towards the currently moving robot).

image 15   image 16   image 17

Image 15 indicates that Billy's gaze remains on the robot rather than merely following Exp.'s hand itself. That is, Billy orientates to (or responds to) the pointing and gaze of Exp. as indicating an object of joint attention other than Exp.'s hand itself, namely the robot. Billy's gaze stays with the robot during a very brief glance by Exp. from the robot to the laptop screen and back, which occurs in between images 15 and 16. By the time shown in image 16 however, Billy does follow Exp.'s gaze direction by gazing at the object of scrutiny that Exp.'s gaze has now selected

101

- the laptop screen. It can be noted that this re-orientation in image 16 occurs during a phase in which the robot is relatively stationary and hence produces fewer behaviours to elicit scrutiny on the part of both Exp. and Billy.

image 18   image 19   image 20

Images 17 and 18 show another instance of Billy appropriately following the gaze and pointing behaviour of Exp. Exp.'s pointing occurs after both Billy's stepping back away from the robot and the robot raising its left arm. Billy again follows the pointing and gaze direction of Exp. by re-orientating to the robot. Image 18 is again suggestive of renewed scrutiny which occurs with, and might be responsive to, the robot's movement of its left arm. In image 19 Billy brings his gaze to Exp. achieving mutual gaze before stepping away from the scene smiling and moving his arms (possibly in response to the robot's arm movement) as shown in image 20.

6.2.4   Summary

This analysis has revealed subtle details and qualities of joint attention skills in children with autism. In many respects it is the children who were impressive in

the interactions analysed, as they exhibited a capacity for recipient design and used their joint attention skills to do what all skillful interactants do.

First, Andy not only attended to the robot's (temporarily) dysfunctional left leg but this attention was done in an overt manner (leaning obviously in next to the faulty leg), possibly to ensure that the adult will notice it. This body orientation did get the adult's attention to the region of the robot's left foot and having done so Andy then rotated towards the adult. Furthermore, the conspicuous attention to the robot might be understandable as being built upon the subsequent vocalisations, gaze and gesture activities of Andy. Second, Andy produced vocalisations with some concern for recipient design, when he rotated towards the experimenter in the production of the first vocalisation achieving mutual gaze immediately before and during the production of the final vocalisation.

Additionally, in exploring the interaction of the other children, Don and Billy, it was found that the children moved their gaze to look at what the adult gazed and pointed at. The photo stills further indicated that the children followed the pointing and gaze of the adult to locate the correct object for joint attention (the robot). Once this attention was given to the robot the children were found to develop additional activities which can be interpreted as responsive to the movement of the robot - such as touching the robot in the case of Don, and possibly the arm movement at the end in the case of Billy.

6.3 Robot as a Social Mediator in Child–Child Interactions

This section continues the research into joint attention skills in triadic interactions involving a robot, a child, and a second person. In the previous section (6.2), the second person involved was an adult (the experimenter). Extending the findings from that investigation, this section includes a scenario where not only the adult experimenter, but also a second child with autism was present. It provides a case study evaluation of segments of trials where four children with autism interacted with a robot as well as with each other. The emphasis here is on the interactions amongst the children themselves, where the robot was a salient object in mediating these interactions. Results are presented using an analysis of interaction informed by conversation analytic principles (see section 6.2.1.1). The analysis is focused primarily on the ways in which the autistic children were found to skilfully orientate and re-orientate their bodies in a way that was sensitive to the activities of the adult (such as requests and adjustments to the robot), the robot (its position and movement) and the other child. Such issues of body kinesics on the role and timing of nonverbal behaviour, including body movements, in communicative and interactional dynamics, play a fundamental part in human-human interaction. The analysis showed how the children exhibited interaction skills where the robot served as a salient object mediating joint attention and interactions with other children.

6.3.1 The Trials

The trials took place in Middleton school, a special school for children with moderate learning difficulties, which also has a small base for children with autism. As stated

above, the aim of the current study was to investigate how the robot can mediate interaction amongst children with autism. The trials were designed to allow pairs of children to play with the robot at the same time, with the hope that the robot, being an object of shared attention, will mediate and encourage the children to interact with it and with each other. In order to minimize any possible anxiety that the children might experience, being in a novel situation with a new and unusual toy (the robot) and a new person (the investigator), each child participated in a few preliminary trials with the robot, on their own, without a second child present. These pre-trials were designed to allow the children to get used to the presence of the investigator and get familiar with the robot during unconstrained interactions. This approach was continued in the main part of the study, where the children continued to have opportunities for free and unconstrained interactions with the robot and with each other.

6.3.1.1   Special Observation Sessions

It was important for the investigator to gather information about the children's social behaviour to help in the process of choosing the specific children to participate in the study, and to help in designing the trials. Therefore the investigator, in consultation with the Head of Autism Provision at the school, arranged special visits to the school in order to observe the children during their normal and varied school activities. The activities chosen were specifically those that contained social interaction elements. These included:

- eating lunch around the table in the dining hall

- art and craft class

- story telling class

- music class

- dance and movement class

- watching a movie (when it was too wet to go outside at lunch break)

- play time in the school-yard during breaks

In some of these visits the investigator generally observed all the children in that activity. In other visits he followed a specific child throughout his or her various activities. The visits were followed by discussions with the teacher and influenced the selection of the children for the study, with a focus on the less able children with the greater social difficulties[2].

6.3.1.2   The Children

The four children who were selected, in consultation with the head of Autism Provision unit in the school, to participate in the main investigation are Rob (age 6), Adam (age 8), Henry (age 7) and Jack (age 7). According to their QCA assessment of their level of interaction and working with others, Rob and Adam were assessed at a level where they might engage in activities alongside others in parallel. Henry was assessed at a level where he might take part in work/play with one other person and take turns in simple activities with adult support. In the subject of attention, Rob and Adam have been assessed at a level where they focus their attention to their own choice of activities, while also can attend to an adult directed activity but

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[2]The motivation to focus on less able children in the Aurora project is elaborated in Dautenhahn and Werry (2004)

require one-to-one support to maintain their attention. Henry has been assessed at a level where he maintains attention to his own choice of activity while also responding to other pupils or adults. Jack had joined the school only a short time prior to the start of the trials and no assessments were available.

6.3.1.3   The Robot

The robot used in these trials is the same robot used in all previous trials in this research (see section 3.2) but with slightly modified appearance. Based on the results of the study into robot appearance presented in chapter 5 the robot was dressed in a plain costume, and initially with the same featureless head-cover. During the preliminary trials some of the children showed interest in the cover of the robot's head, and took it off several times, exposing the 'pretty girl' face for a short while and put it back on. When asked by the investigator, these children (who had some limited language skills) explicitly expressed their preference of the plain head cover. The investigator, in order to make a face with human features more acceptable to them, presented them with the robot without the head-cover but with simplified head features i.e. a short simple hair style, plain lips (painted in 'skin' colour) and paler eye-lashes (see image on the right in figure 3.1). As the modification was acceptable for the children, the robot remained with this appearance for the rest of the trials.

6.3.1.4   Trials set-up & procedures

The trials were conducted in a familiar room often used by the children for various activities. The room size was approximately $2.5m^2$ with a carpeted floor. The room is an internal room and had one door and one window overlooking an open plan area

with other class activities. The robot was positioned on a table and connected to a laptop. The investigator was sitting next to the table operating the laptop when necessary. Two stationary video cameras were used to record the trials. The children were brought into the room two at a time, by the investigator who collected them from their classroom. Each trial lasted as long as the children were comfortable with staying in the room. The trials stopped if the children indicated they wanted to leave the room or if they had stopped all interactions and got bored after spending at least 3 minutes already in the room. The average duration of each trial was approximately 5 minutes. In total the study comprised 20 visits to the school (14 sessions with the robot and 6 special observation sessions) over a period of nine months. The trials were designed to progressively move from very simple exposure to the robot to more complex opportunities for the children to get engaged in interactions with each other. During the later trials, the investigator verbally encouraged the children to show each other how they could interact with the robot. This was necessary in order to bootstrap the engagement of the children with the robot. In previous trials (see chapter 4) this same effect was achieved without such explicit verbal instructions, but it required a longitudinal approach where the children could discover interactions with the robot in their own time. Since the current work was intended to focus on the robot's role of a mediator, it was decided to use the explicit means of verbal encouragement, including a simple 'game' scenario, which was applicable to the particular group of children that took part in the current investigation.

6.3.2   Robots as Embodied Beings – A Context for Autistic Children to Display Sophisticated Embodied Actions

This section studies ways in which the autistic children orientated and re-orientated their bodies as a response to the activities of the adult (e.g. giving the children requests or instructions) and to the robot's position and movement. The children's response involved unexpected *initiation* of new actions as well as *physical contact* between the children.

The robot demonstrated its role as a *social mediator*, an *embodied being*[3] in the sense of providing an interactive context where social skills in children with autism were facilitated and encouraged. The robot, operating in its puppeteering mode (i.e its actions, unknown to the children, were controlled by the investigator), was sensitive to even subtle changes in the children's behaviour. This sensitivity, as well as its physical presence and interactivity, provided a social play context where the children displayed sophisticated embodied actions and interactions.

6.3.2.1   Responsiveness to Adult Requests

The following example is taken from a trial where the investigator tried to encourage the children to play a game whereby the robot will not move unless the children together show a movement similar to the robot's. Note, the typical interaction pattern with the robot usually involved lifting the arms or legs. Images 1-5 in figure 6.1 show the activities of the children during 4 seconds whilst nothing further was

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[3]Note, the use of the term embodied 'being' for the robot is referring to the situational, social context, and it is not implied that the robot possesses any cognitive, emotional, or physiological properties characteristic of biological systems.
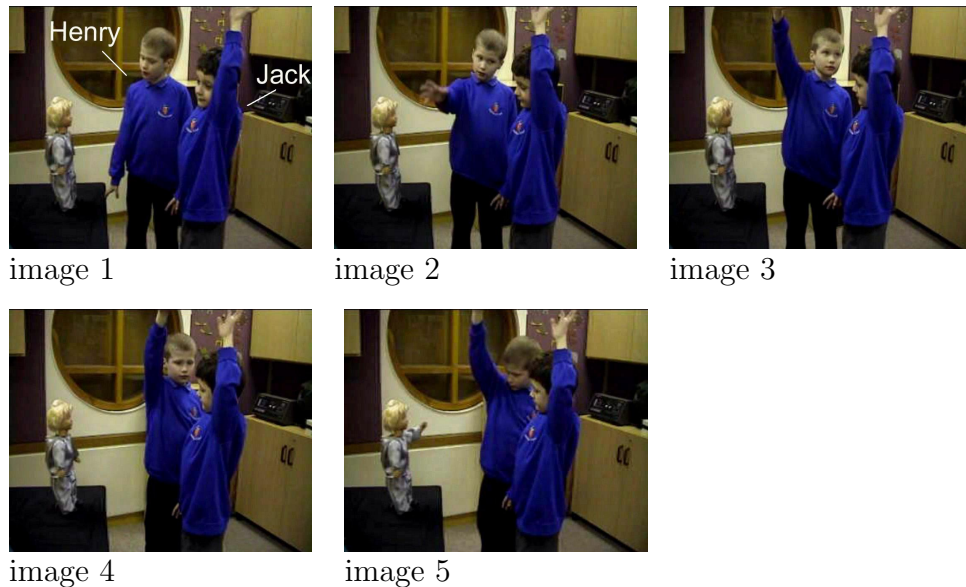
said by the investigator.

Figure 6.1: Images 1–5 show the robot mediating interaction among the children – example one.

We see how Jack (on the right of image 1) made the first movement - whilst Henry first looked at the robot (1), then gazed at Jack (2) and started to imitate him, then he looked at the top of Jack's hand to ensure he is doing the same (3), then he gazed again at Jack's face (4) before looking to see if or how the robot responded (5) (and by then, the robot's arm was raised). This sequence shows the ways in which, following an adult's request for the production of the same behaviour, one child has co-joined the action of the other - with gaze playing a particularly important part in the synchronisation of their body movements.

6.3.2.2 Responsiveness to the robot

(i) Responsiveness to the robot's position

In addition to moving appropriately in response to a request the children are also shown to position themselves appropriately even when not asked to do so by an adult. In figure 6.2 image 6, for example, Adam (right) positions himself such that
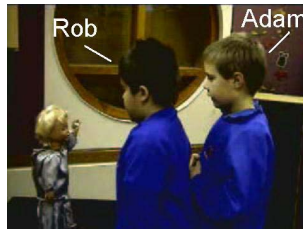
image 6

Figure 6.2: Adam positions himself

he is aligned with Rob (left) facing the robot with his right side protruding - such that he is able to see the robot and raise his right arm without colliding with Rob. In this way both Adam and Rob are positioned such that they can monitor and interact with the robot without colliding with each other for the predicted range of activities which may follow.

(ii) Responsiveness to the robot's movement

As well as responding appropriately to requests and positioning their bodies appropriately vis a vis the robot and each other, the children were also found to respond to (or orientate to) the actions of co-present others (robot and child). Thus the movement of the robot - in particular the movement of its arm - is responded to

by repositioning of body orientation and the enactment of gestures (figures 6.3 and 6.4 below).

image 7
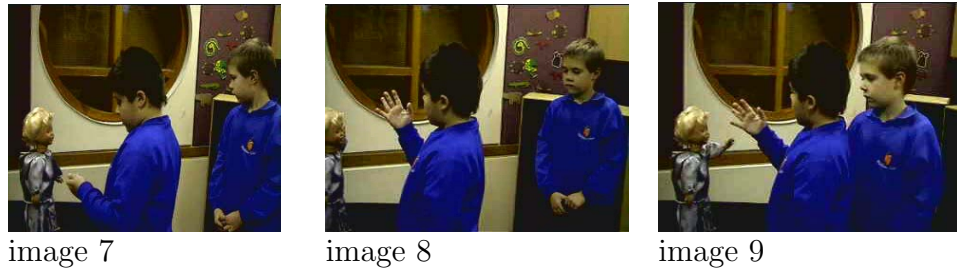
image 8

image 9

Figure 6.3: Adam positions himself

In figure 6.3 image seven Adam is momentarily not attending to the robot, he is gazing to one side away from the direction of the robot. Rob is orientated in the general direction of the robot but is gazing specifically at his own hand. In image eight the robot has raised its hand and Rob has raised his hand. Adam now gazes at (or attends to) the area occupied by the robot and Rob. In image nine the robot and Rob are lowering their arms. Adam has moved closer to the robot.

image 10

image 11

Figure 6.4: Adam and Rob 'mirroring' the robot

In figure 6.4 image ten the robot has started to raise its arm and Adam has swiftly straightened his arm. In image eleven the robot's arm is straightened and

Adam and Rob both hold their 'mirrored' hands up.

6.3.2.3   Robot mediated initiated actions

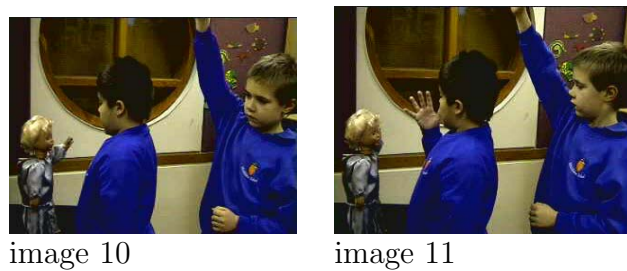In this example (figure 6.5) the investigator tried to prompt both children to raise their hands at the same time. Henry pointed with his finger to his leg (image 12) wanting to include also the legs in the interaction game with the robot. Jack responded with a stretch of both, a leg *and* an arm, whilst Henry gazed at him (image 13). Henry then imitated Jack and looked at the robot (image 14), possibly to see if the robot responded in the same way.

Henry and Jack then tried a few stretches of hands and legs (e.g. image 15) and then

image 12   image 13   image 14
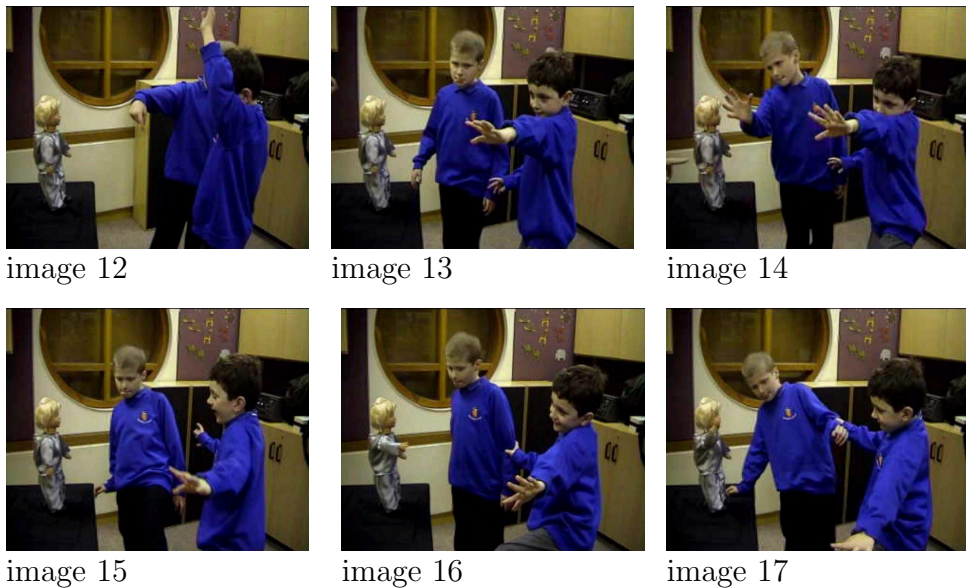
image 15   image 16   image 17

Figure 6.5: Stills 12-17 show a second example of the robot mediating interaction among the children

they interacted with each other - using each other to balance themselves (images 16 & 17).

113

Stills 12-17 in figure 6.5 show also how the embodied form of the robot differs in the possibilities it provides, from a two dimensional representation (e.g. on a computer screen). In the example above the robot encouraged and provided an opportunity for a full body experience for the children, stretching themselves and exploring their own balances, as well as experiencing each other in their interaction.

6.3.2.4   Robot mediated physical contact between the children

The sections above showed examples of how the robot provided a context in which the autistic children displayed embodied sophistication in three separate aspects:

- how they orientated their body as a response to an adult's request (the investigator).

- how they positioned and repositioned their own body in relation to the static and moving robot.

- how they initiated actions (such as leg movement) in the context of interacting with the robot and each other.

The following sections analyse how, when putting all these three aspects together, the embodied robot provides a context that might encourage one child to interact with another in a physical way (touch). This behaviour is very common amongst typically developing children - but is very unusual amongst children with autism, and even more so with the particular child concerned. The focus in the following example is on Adam, who during previous trials showed a keen interest in the robot. It is also important to know that information gathered by the investigator during the special observation sessions (see section 6.3.1) and which has also been confirmed

114

by his teachers, suggests that Adam doesn't show much interest in other children in his class, nor in their activities. During class activities Adam constantly tries to avoid the rest of the children - positioning himself, at any opportunity he has, in the corner of the room standing with his back to the rest of the children, or trying to escape from the room altogether. This repeats itself in the playground during breaks, where Adam can always be found at the perimeter of the play area, most of the time standing, or pacing a few steps, but with his back to the rest of the children. In contrast to what appears as a lack of interest in his class mates, Adam showed a keen interest in the robot. In a previous trial where he was alone with the robot (only the experimenter present) he interacted with it for nearly the whole duration of the trial. In a different previous trial where he was with another child, he sat at the side: watching the robot and what was done to the robot when the other child interacted with it.

The following examples (figures 6.6 – 6.12) are different sections of one trial where Adam had been brought together with Rob to the room and both were encouraged to interact with the robot and with each other.

(i) Example 1

As Adam initially stayed at the back of the room, the investigator called him (image 18) saying "Adam come closer and look what Rob is doing".

Adam responded to the request and came closer. Rob, at that time, was not actively engaged with the robot and the investigator prompted him to show Adam what the robot is capable of doing. Immediately following this request Adam *held*

115

image 18

Figure 6.6: Adam stayed at the back

Rob's hand (image 19) - an action which at a bare minimum can be seen as in some way responsive to the proximity of Rob. Rob in turn responded by coming closer to the robot (image 20), and Adam followed him (image 21).

image 19   image 20   image 21

Figure 6.7: Adam held Rob's hand during the interaction

(ii) Example 2

After a while, when Rob still did not demonstrably engage with the robot, the investigator encouraged Adam to show Rob how to interact with the robot. In an action which appears responsive to this request Adam moved closer to Rob and *put his arm on Rob's shoulder* (image 22). Rob at this point started to imitate the

116

robot's hand movement, and Adam, noticing this, turned towards the robot and touched the robot's hand (23).

image 22   image 23

Figure 6.8: Adam taps Rob's shoulder during the interaction

(iii) Example 3

Adam and Rob continued to interact with the robot, following the investigator's prompts. A little bit later, after watching Rob's response, and when the investigator stopped prompting - Adam turned his back to the robot, (image 24) an action which if taken out of context might confirm notions regarding the asociability of autistic children in general and Adam in particular. However what is particularly striking is the way in which Adam's position still enabled him to monitor both Rob and the robot by turning his head - which he did at crucial moments, such as when the robot's motor made a noise indicating movement (image 25). Such monitoring actions occurred at crucial moments in terms of the robot's activities (images 25 & 27) and occurred within the context of Adam's body being positioned such that it faced away from both Robot and Rob - yet sufficiently close to both to hear the robot and (as is shown in image 28) to touch Rob.

117

image 24   image 25   image 26

Figure 6.9: Adam is able to monitor Rob and the robot

In image 28 Adam engages in an action that would not be possible had his body been positioned further away - that is, with his back to the robot, Adam *put his hand on Rob's shoulder*, paused at this position for about 4 seconds and moved away (29).

image 27   image 28   image 29

Figure 6.10: Adam put his hand on Rob's shoulder

(iv) Example 4

Immediately after the above, the investigator called Adam to return. Adam oriented himself towards the space behind Rob (image 30) and then positioned himself directly behind Rob and paused there for several seconds to watch Rob interacting with the Robot (image 31).

Adam then *touched Rob on both shoulders* (image 32) – in a way which could be seen as responsive to the alignment of Rob and the robot that he was facing. Next, Adam stepped to one side such that both children were now facing the robot and could monitor and respond to its movements and Adam could (as he subsequently did) monitor Rob interacting with the robot using simple imitative movements (image 33). Adam stayed in this position for a while before moving away.

It is important to point out here that, according to the teachers, the behaviour of Adam displayed in these examples – e.g. not only being so physically close to another child, but touching, and leaning against another child, was very unusual, and they could not recall any prior occasions where he had behaved in this way towards any other child.

image 30   image 31

Figure 6.11: Adam watching Rob's interaction with the robot
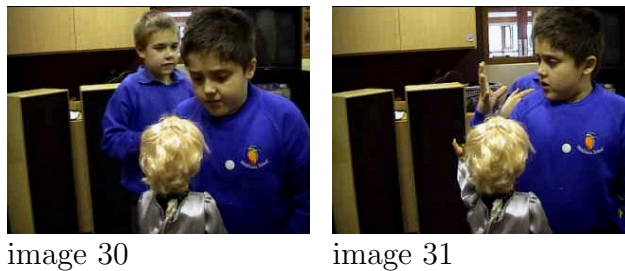
6.4   Discussion of Results

The analysis of the examples presented in this chapter has identified skillful actions on the part of children with autism during interactions with a robot, with an adult and with other children. They demonstrated an orientation to their co-participant, arranging their vocal and non–vocal actions such as talk, body movement, gaze and

image 32   image 33

Figure 6.12: Adam touching Rob on both shoulders

gesture during the interaction, according to and in response to actions of the other participants.

In the examples presented in the first section, the children displayed recipient design skills where the robot served as a salient object mediating joint attention with an adult. Note, it is at present unclear whether this behaviour was caused by and therefore is attributable to the robot; other objects (e.g. toys widely used in assessments of children's social communication skills, such as mechanical toys, ballons or bubbles etc.) might possibly serve the same role. However, as described in section 2.3.2, previous research in the Aurora project by Werry et al. showed that when interaction with a passive toy was compared to interaction with a mobile robot, the children directed statistically significantly more eye gaze and attention towards the robot (Werry, Dautenhahn and Harwin 2001a). The robot's autonomy, and the fact that it never reproduces exactly the same behaviour but rather variations of behaviours might have played a role in these results. Further research might shed more light on why and how a robot provides an interesting focus of attention for children with autism.

Whilst the data does not allow for speculation about whether the joint attention skills presented by the children might or might not have occurred without a robot

present, it can be noted that in this instance the skillful interaction on the part of the children occurred not just in the presence of a robot but was specifically concerned with features of the robot's behaviour. The autonomous and predictable pattern of the robot's moving arms, legs and head caused Andy, for example, to notice the temporarily faulty left leg. Similarly, the robot's arm movement attracted Don's and Billy's attention. In all these cases the robot provided an environment for noticing on the part of the autistic children, and it served as a salient reference point against which certain actions of the children (and adult) might be understood.

The second section presented a case study evaluation of trials where the children interacted with the robot and with each other. Results highlighted different ways where the robot provided a context in which the autistic children displayed an embodied sophistication - they orientated their bodies a) in response to a request from the investigator, b) to the robot with regard to its position and its movement c) to initiate new body movements and d) to each other's bodies using touch.

The findings in both sections highlight the advantage of using an *embodied* robot rather than a computer simulation - the embodied nature of the robot allowed for the displays of such body orientation and *full body experience* in ways that a two-dimensional display on a computer screen is unlikely to evoke. In addition, the robot's role as an object of shared focus of attention was displayed throughout the actions of the children. The robot became an embodied entity which allows for an exploration of how children position themselves with regard to it and each other - and as such an excellent tool for exploring how they might interact with other embodied entities such as humans (e.g. other children and adults).

Importantly, the results of this investigation highlight that a robot can serve as a 'social mediator', an object and focus of attention and joint attention, that children

with autism can use to communicate with other people.

Chapter 7

Summary of Experimental Results

The longitudinal approach, together with the unconstrained scenarios with a high degree of freedom, facilitated the emergence of spontaneous, proactive and playful interactions with the robot and with other people, that revealed further aspects of social interaction skills (imitation, turn-taking and role-switch) and communicative competence in the children. It also revealed the children's initial preference in respect of the robot's appearance.

The results showed how a small humanoid robot can provide an enjoyable focus of (joint) attention and serve as a salient object mediating interaction between the children and other people (peers and adults).

The methods used in conducting the trials and the results of these trials demonstrate the potential benefits of robots as assistive technology for children with autism, as well as inform HRI research about aspects of robot design suitable for this specific application. In addition, these results highlight certain aspects of the nature of autism (e.g basic aspects of social interactions and communication), and with the positive indications shown here it can also potentially lead to benefits in

autism research, education and therapy.

7.1   Lessons Learnt

Studying robotic assistants for encouraging social interaction skills in the specific domain of autism is a challenging aim that presents an additional level of complexity not usually experienced in 'mainstream' HRI research. The following section discusses some of the expected and unexpected issues the author had to face and overcome during this research.

As explained earlier, given the nature of autism as a spectrum disorder, this implies huge differences among the subjects, and their therapeutic/behavioural/educational background, so this work is guided by the individual needs and preferences of the children. Given this specific context, the main approach adopted was to explore the social interaction space (involving children with autism, a robot and adults) in *its contextual environment* e.g. during school activities, in a familiar environment. This presented at times the following difficulties:

<u>Practical issues:</u>

- difficulties in planning in advance trials that require the participation of specific children. Despite the school adhering to a pre-set time table, there were occurrences of unforeseen changes in the schedule of the children's activities, and therefore specific children were not always available to take part in the trials (or when they were absent from school). The investigator should come prepared with alternative plans (which might include different set-up scenarios, possibly different robot programs etc).

- any unplanned changes in their schedule of activities that happens prior to a trial can significantly affect the children's behaviour because of the change in their routine (e.g. they could be very 'moody' or upset). A child who might have done very well in previous trials may show totally different behaviour in a current trial for reasons unrelated to the trial. The investigator should be sensitive or 'tuned' to the child's behaviour, and at the same time on-goingly liaise with the child's teacher in order to find out whether any trial related parameters, or external parameters are affecting the child's behaviour.

- some people with autism have hypersensitive sensory conditions. Touch , smell sound or light can all be overpowering or distorted at different times. Any change in the environment, such as a bright light from a lamp or from outside, or the volume of music (if used), or even the colour of the investigator's clothes, all potentially might affect their behaviour. Again the investigator needs to be very sensitive and tuned to the children's behaviour, especially when working with children that have very little or no language skills at all and are unable to verbally express any difficulties they face.

- The robot should be built and presented in a very robust way, firstly to be safe for the children that may handle it in various ways (sometimes forcefully), and secondly to keep it intact. The author found the autistic children that took part in the trials, to have very enquiring minds, and as they are even more interested in mechanical 'toys' such as the robot – they will try to explore it in many and often unexpected ways, from licking it, to lifting and dropping it, from pulling any protruding parts (like the hands and legs), to pushing its moving parts against the direction of the motors and beyond the robot's range

of movement. Again, the experimenter needs to be very alert in this situation, especially when the overall approach is to encourage spontaneity and provide maximum freedom for the children to interact with the robot.

Methodological issues:

- the work in assistive robotics is strongly guided by the needs and preferences of individual subjects. Given the nature of autism and the difference between the individuals large scale experimental user studies are not suitable, nor the use of control groups. Instead, in order to evaluate the potential of any particular assistive robot, the investigation should be designed as a long-term one with a small group of individuals.

- again, due to the nature of the target user group (children with autism) experiments cannot be duplicated, as the children's behaviour might vary given the very same experimental conditions. In addition, because the research investigates any interaction in its contextual environment, the investigator's actions (or the robot's actions via the investigator) should not follow a pre-specified script but respond to the changing behaviour of the child.

- in generic HRI research the experimenter usually avoids any relationship with the users. When investigating the potential of a robot to act as a social mediator specifically with a user group that is known to have social impairment, the investigator should adopt a contrary approach. If the subjects show any attempt to socially interact with the investigator, these attempts should not be ignored, but encouraged.

- further to the above point - the investigator should come to the trial prepared

126

with a planned procedure, but at the same time he/she should be versatile and flexible enough to be able to change the plan on 'the spur of the moment', and to 'sieze the opportunity' if it arises. From the author's experience during the trial in the research presented here- some of the important interactions between the autistic children and himself, mediated by the robot, were in such unexpected circumstances.

- Any application of computer technology for education or therapy of children with autism faces the problem of generalization: the child needs to be able to transfer what is learnt in the classroom or specific learning environment to other contexts and ultimately to everyday situations outside the classroom. Based on the results presented in this thesis one cannot claim yet that the robot has improved social interaction skills in children with autism. Providing such evidence will remain a future target.

7.2 A Cautionary Tale

As can be seen throughout the investigation, during all trials the robot was initially the main focus of the children's attention. This was the case during the child-robot imitation and turn-taking games, as well as during the trials when the robot was the object of joint attention mediating interaction between the children and other people. This section focuses on some cautions in this respect which have arisen during the course of the data analysis. These cautions concern two specific but frequently related behaviours, *social isolation* and *stereotypical behaviour* which is often exhibited in children with autism. In addition, the section also exemplifies interaction where social behaviour was directed at the robot, which raises awareness of the goal

of the research, namely to help the children increase their social interaction skills *with other people* and not simply create relationships with a 'social' robot, which would isolate the children from other humans even further.

7.2.1   Social Isolation

Often, children with autism are described as socially isolated, ignoring other people near them, and often treating them as if they were objects (Hobson 1993, Hobson 2002, Siegel 1998, Tustin 1990). Tustin in her review of the external descriptive diagnostic features of autism, provides a quote from Kanner that illustrates it very well: "the people, so long as they left the child alone, figured in about the same manner as did the desk, the bookshelf, or the filing cabinet." (Tustin 1990, Page 2). In some trials in which small groups or pairs of children with autism were exposed to the robot we have noted occasions where the children seek to have an 'exclusive' relationship/interaction with the robot ignoring their peer and the experimenter. Examples of these behaviours from two different trials with different children can be seen below.

Example one:

Figure 7.1: Henry (left) interacting with the robot whilst Martin (right) waits for his turn.

Figure 7.1 shows the beginning of the trial where Henry (a child with autism) is interacting with the robot, in a very similar way to how he did in a previous trial (simple imitation game). Martin (a child without autism) is standing nearby awaiting his turn.

Figure 7.2 shows that whilst it is Martin's turn for interaction (the robot and the experimenter directed their attention to Martin), Henry won't 'let go' and continued with his imitation movement, trying to get the robot's attention; and even got annoyed when this did not happen (figure 7.2 –right).

Figure 7.2: It is Martin's turn for interacting with the robot, whilst Henry won't 'let go'.

In figure 7.3, we can see that whilst Martin is still interacting with the robot, Henry has stepped forward, ignoring Martin, and touches the moving hands of the robot, seeking exclusive interaction.
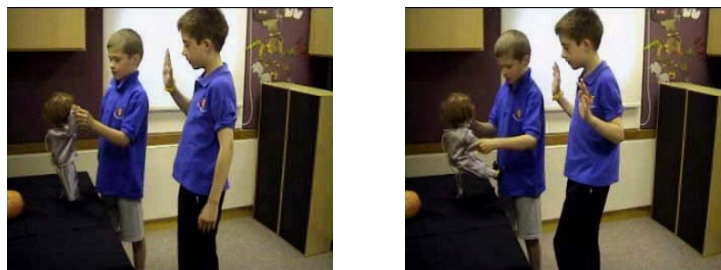

Figure 7.3: Henry seeks exclusive interaction with the robot.

Example 2:

In this example, two children with autism are playing with the robot 'together' for the first time. Each of them played with the robot individually many times in the past but here they are both exposed to the robot simultaneously.
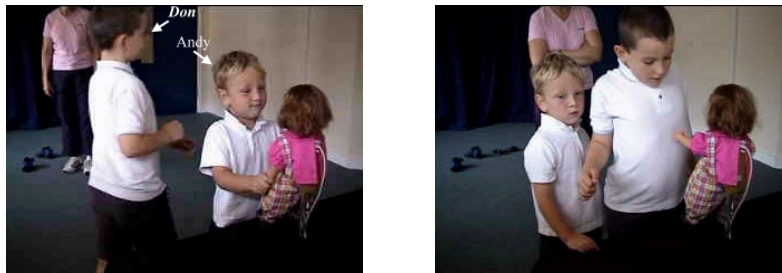

Figure 7.4: Andy (left picture) and Don (right picture) both seeking exclusive interaction with the robot.

During this session, Don was asked by the teacher to show Andy how to play with the robot. Each time Don went to interact with the robot he actively ensured that he had exclusive interaction, blocking out Andy with his hands. This behaviour repeated itself on different occasions during the session, as can be seen in figures 7.4 (right), 7.5 (left), 7.6 (left).

Andy, on his part, was trying to ignore Don and constantly needed 'encouragement' from his teacher to look at what Don was doing (e.g. figure 7.5–right). He was often looking away altogether, as can be seen in figures 7.4 (right) and 7.5 (right). Andy interacted with the robot only when he had exclusive access to it, i.e. when Don had stepped away (figures 7.4–left, 7.6–right).

These situations highlight the fact that interactions in these trials need to be

Figure 7.5: Don interacting 'exclusively' with the robot, whilst Andy tries to ignore Don.
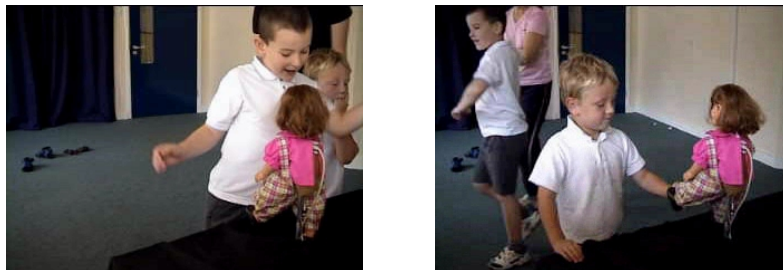
Figure 7.6: Don actively seeks exclusive interaction with the robot, whilst Andy waits for exclusive opportunities to interact.

carefully monitored and taken into consideration when programming the robots and creating the scenarios and games to be played with the robot, to ensure that the robots encourage interaction and become social mediators and do not reinforce existing behaviours and become social isolators.

7.2.2   Stereotypical Behaviour

The second caution relates to the highly stereotypical behaviour also frequently noted in children with autism. These highly repetitive forms of behaviour increase social isolation and frequently become self-injurious (Van-Hasselt and Hersen 1998,

White-Kress 2003, Hudson and Chan 2002, Jenson, McConnachie and Pierson 2001). The work so far has been limited to the use of robots to develop basic interaction skills through simple imitation and turn-taking activities between the robot and the children. Currently, the robots available for this kind of mediation and suitable for the experiments are only capable of a relatively limited and repetitive range of movements, leading to the caution that this might increase rather than decrease the incidence of these kinds of behaviours. The following images (figures 7.7&7.8) were taken during various trials (described in early chapters) where the children played simple imitation games with the robot. The robot as mentioned earlier, had a very limited range of movements, i.e. the four limbs were capable of moving up and down, and the head could move sideways. This robot's behaviour is far more stereotypical, i.e. shows little variation, as compared to e.g a mobile robot that can move in any direction (as presented in (Werry et al. 2001c)).

Figure 7.7: Billy during a simple imitation game with the robot.

Figures 7.7&7.8 show how Billy and Rob engaged in a simple turn-taking and imitation game with the robot. The robot's movements were simple and highly repetitive, and Rob and Billy responded to them each time with almost identical movements, in a very 'mechanistic' manner. Using well-defined, salient features, i.e. easily recognizable 'mechanistic' movements seems advantageous e.g. in early stages

Figure 7.8: Rob during a simple imitation game with the robot.

when children with autism are first being introduced to a robot. These stereotypical movements reduce the complexity of interaction (which is difficult for the children to deal with). However, in later stages, in order not to teach the children to behave like robots and to learn 'robotic movements', robots with more naturalistic, 'biological' movements would be beneficial and a suitable next step in the process of learning. One of the advantages of using robots, as mentioned earlier, is that the complexity of interaction can be controlled. Bearing in mind the stereotypical nature of the movements of the humanoid robot used here, the investigator needs to ensure that, over time, more complex scenarios are introduced in child-robot interactions as well as in robot mediated child-child interactions. After the initial phases of introduction and learning, natural movements are clearly preferred over mechanistic, 'robotic' movements.

7.2.3 Social Behaviour: Bonding with the Robot

The approach taken in this research of providing a relatively stress free environment, with a high degree of freedom, facilitated the emergence of spontaneous, proactive, and playful interactions with the robot. These interactions included, in some cases, elements of social behaviour directed at the robot. One example of these behaviour

elements occured during the last trial of a longitudinal study (see section 4.2). Here Billy ended the session running around the room and 'dancing' in front of and directed towards the robot each time he passed it (figure 7.9).

Figure 7.9: Billy is 'dancing' to the robot.

Billy repeated this dance in a very similar fashion six months later during the next trial he participated in (figure 7.10).

Figure 7.10: six month later, Billy is 'dancing' again.

Another example of social behaviour displayed by Billy, is when he performed his own unique sign for good-bye to the robot. His teacher said at that time that it was as if he was waiting for the robot to say good-bye back to him (figure 7.11).

The question that must be asked throughout this research is how the children benefit from the interaction with the robots. Are they increasing their social interaction skills (with other people) or are we simply encouraging relationships with a

Figure 7.11: Billy says 'goodbye' to the robot.

'social' robot? Billy's behaviour was clearly directed towards the robot. In non-autistic children, pretend play or play primarily targeted at other humans present in the room could serve as a possible explanation for this behaviour. However, since children with autism have impairments in these specific domains, it is unlikely that it applies to Billy. Billy very much enjoyed the interactions with the robot, he laughed and smiled during his dance. From a quality of life perspective, this enjoyment is in itself a worthwhile achievement. However, it must be asked whether this sign of 'attachment' or 'bonding' with the robot is worthwhile to pursue, reinforce, or to avoid.

For any child that is usually withdrawn and does not participate in any interaction with other people, 'bonding' with a robot could serve as leverage, and a stepping stone that could provide safety and comfort, opening the child up towards the possibilities of 'human' interactions that are far more unpredictable and complex. Thus, 'bonding with robots' could be beneficial to a child with autism, but only if it is not the ultimate goal, but an intermediate goal on the long path towards opening up the child towards other people.

Chapter 8

Conclusions and Outlook

The approach taken in this research of repeated exposure of the children to the robot over a long period, in a stress free environment, allowed the children, as hoped, to have unconstrained interactions, which facilitated imitative and turn-taking behaviour to emerge. In addition, the robot provided an enjoyable focus of (joint) attention that revealed communicative and social competencies of children with autism and encouraged social behaviour, in some cases in a manner never displayed before. Some of the examples of interactions discussed in this thesis also point out how human contact (with the experimenter) provided meaning and significance to otherwise mechanical interactions (with the robot).

8.1   Socialization theories - revisited

Section 2.2 has shown how social interaction, collaboration and direct personal relationships play a fundamental role in the development of cognition, it is a critical component of learning and helps to establish personal growth. The meaning of

things are learnt in a social way within a particular context, and play that is socially constructed can provide social and cultural experiences where this can take place. The literature has shown how the range of skills that a child can develop with guidance from an adult, or when interacting with other children (e.g. during play), is more than the child can achieve alone (see section 2.2.2).

For people with autism, the skills for iconic and symbolic representation and the skills for social learning are severely impaired, whilst play in a social context as well as having personal relationships might even be non existent, all of which may cause a delay in their mental, emotional and personal growth.

As explained in section 2.2.4 - an interaction with the environment provides stimuli that influence and control the behaviour of the child and that are crucial to child development. The basic assumption of the research was explained in section 2.4, namely that for children with autism, having the opportunity to play simple turn-taking and imitation games with a robot, where the robot can also act as a social mediator when other children are present, might provide the social setting that encourages the much needed social interaction skills. This assumption was maintained as the core drive and motivation of this work.

Results from the research presented in this thesis showed examples of how, by playing with a humanoid robot in a social context, the robot (together with its operator) provided the stimuli and reinforcement, in a controlled manner, that helped the children to learn elements of basic social behaviour skills (such as simple imitation, turn taking, and some aspects of non-verbal communication). This was evident to a certain degree in the interactions between individual children and the robot as described in chapter 4 (e.g. section 4.2.5) as well as in child- child interactions where the robot assumed the role of a social mediator (see chapter 6). In addition, the use

of a physical robot supported a variety of interactions, where the robot encouraged and provided an opportunity for a full body experience for the children, e.g. stretching themselves and exploring their own balances, as well as experiencing each other in their interactions (see e.g. interactions described in section 6.3.2). Overall, it can be said that the social setting where a child, a 'social' robot and another person (child or adult) could play together did encourage social interactions.

8.2   The role of the robot

The results showed that with the robot being the focus of joint attention, it mediated the interactions between the autistic children and other people - children and adults. This role of the robot as a social mediator can be further enhanced when the robot is used as a tool in the hand of an experienced operator/therapist. As explained in chapter 1, the approach adopted in this research is one where the experimenter *includes himself* as part of the trial, adopting the stance of being available and ready to respond to the children and able to 'seize the opportunity' for any further interactions, should the possibility arise, even if it means changing the pre-planned procedure of the trials. Having had years of experience working with people with special needs, I could recognize such opportunities that arose during the trials, where I could use the robot to secure a triadic mode of interaction between a child, the robot and myself. In some cases the children used the robot as the channel for indirect communication/interaction with me. The following examples illustrate the role of the robot and of the experimenter in such circumstances:

Example a - The robot became the channel for communication and *indirect inter-action* with the experimenter.

In one of the preliminary trials the child (Jack) engaged in an imitation game with the robot where the robot mirrored the movements of Jack's limbs. Unknown to Jack, I was operating the robot and responding to Jack's movements as accurately as I could. However, it just happened, on one occasion, that I unintentionally moved the opposite arm of the robot. Jack giggled and mentioned (to the robot) that this was wrong. After a few turns of correct imitation, I then introduced, *deliberately* this time, another mistake in the robot's imitation of Jack's movement - Jack giggled again talking to the robot with affection that this is wrong. I then introduced more deliberate mistakes, and Jack's laughter and affection directed to the robot grew. Then an important point arrived when Jack realized that I was operating the robot from my laptop and that it was me who was making the mistakes, so this became *our* game, and whilst Jack still continued to play the imitation game with the robot, after each mistake that the robot made in mirroring Jack's movements (which were deliberately introduced by me), Jack turned to me laughing saying "mistake", "mistake", this time diverting his affection towards me. It was very clear at this stage that Jack was actually knowingly *playing with me* and sharing his enjoyment with me, whilst standing in front of the robot, initiating movements for the robot to mirror. Jack was using the robot as a mediator to indirectly interact and play a game with me.

Example b - Unexpected *direct* interaction between the child and the experimenter. This is an example of a child who had participated in many trials before, but had never acknowledged the presence of the experimenter (me) who was sitting next to the robot during the trials. However, during the 10th trial, the child, Andy, who has no language skills, unexpectedly came to me, held my

hand and pulled me off my chair to play with me on the floor. Although this was not part of the trial's planned procedure, and was seemingly not a robot related activity, I supported the child's initiative and decided to participate in this play. After a few mutual giggles whilst kneeling on all fours I transformed this into a turn-taking game of chasing and retreating (*imitation* and *turn-taking* were part of the overall theme of this investigation). We played on the floor for several minutes, after which I gradually directed the child toward the robot. I set the robot to operate in its autonomous 'dance' mode and, while I was kneeling on one leg in front of it, Andy was sitting on my lap watching the robot moving its head and limbs to the bit of pre-recorded music. I started to teach Andy a simple imitation game by gently moving his head and limbs in response to the robot's movements. The autonomous and predictable pattern of the robot's moving arms, legs and head caused Andy to notice the temporarily faulty leg, and he initiated a sequence of non-verbal communication behaviours aimed at conveying this to me (see section 6.2.2.3 for detailed analysis of this segment).

Clearly, the opportunities for interaction, as described in the above examples, could be used as a tool for intervention, for example if they happened as part of a therapy programme, and could form a platform for subsequently building valued interactions directly between the child and the therapist.

8.3   Selection and rejection of tools

- **Quantitative and Qualitative analysis -** Quantitative and Qualitative analyses have been used to create an interactional profile for the individual

children that took part in the first set of studies (the longitudinal study described in chapter 4 and the study about the robot appearance described in chapter 5). The *quantitative* analysis was aimed at a more general level in order to find out the overall effects of repeated exposure to the robot on the children's social interaction skills. It helped to show the extent of the interactions and the trend of the children's behaviour over a period of time. In addition, *Qualitative/Observational analysis* revealed further social interaction skills and communication competencies which otherwise would have been overlooked.

- **The use of conversation analysis (CA) -** The results mentioned above suggested that, for the analysis of the role of the robot as a social mediator in interactions between the children and other people, it is important to use a method that focuses on each and every participant (robot, children and adult) in their *interactional context*. CA was used here as it can provide not only an accurate description of the participants' actions during the interactions, but it also provides a mechanism by which to understand all the interactional activities in their *contextual relevance*. Using CA to analyse the children's activities in their interactional context helped to highlight the role of the robot in these interactions, and also highlighted competencies of the children in skills that otherwise might have gone unnoticed. CA was found to be a very useful tool and could have been used to analyse any of the data collected during the trials. However CA is a *very* time consuming technique (a CA practitioner aims to analyse *each 10th of a second* of a sequence of data) and one that requires highly specialist skills of the coder, (which the author had to seek help with from a CA specialist) and thus could realistically only be applied to

a very small corpus of the total video data collected. For this reason, only one specific highly 'meaningful' sequence was identified and analysed in great detail using CA, in order to focus in depth on specific interactional competencies, i.e. joint attention. For the rest of the data collected in the study of the role of the robot as a social mediator (sections 6.2 & 6.3), although not analysed in such great detail, the results were presented using an analysis of interaction informed by conversational analytic principles.

8.4 Future Work

It is not clear yet whether any of the social and communicative skills that the children exhibited during interaction with the robot would have any lasting effect and whether they could be generalized and used in the children's day to day life outside the trial scenario. Providing evidence of therapeutic effects goes beyond the scope of this thesis and could be explored in future work. More longitudinal studies are required, together with continued monitoring of the children in their classroom and home environments. However the evidence does point in a positive direction, namely that children with autism might have some of their very special needs met through the mediation of robots.

A potential future 'robot therapy' could offer a space that helps children with autism, whilst keeping their personal autonomy, build the confidence to explore social relationships with other people. Robots could be used to facilitate children in therapy or education, helping them to develop communication skills in a social context. By playing with inanimate objects rather then directly with other people, *as an interim step*, children with autism might feel safe enough and be encouraged

142

to explore social interactions. The robot could assume the role of a social mediator, where the child, using natural means of communication e.g joint attention with another person, could play with a toy (the robot) that he/she is familiar and comfortable with.

The research presented in this thesis provided evidence for the potential use of a humanoid robot in encouraging social interaction skills in children with autism. This has been achieved so far:

1. with the use of simple imitation and turn-taking games between the children and the robot,

2. by the use of the robot as a social mediator mediating the interactions between the children and other people,

3. by investigating the children's preference for the robot's appearance.

The experience gathered so far in the research strongly suggests that any further study with the robot should be done on a long term basis (e.g. longitudinal repeated measure design). Future work could continue to investigate the possible role of a humanoid robot as assistive technology for children with autism in all these three areas. Further longitudinal studies could address specific therapeutic/educational goals and address specific social skills e.g. imitation, joint attention, eye-contact and body awareness. Further research could study:

- The design and testing of possible new scenarios with the humanoid robot for robot/child interaction aimed at teaching imitation skills, adapting the Two-Trainers modelling technique applied to children with autism by Pepperberg and Sherman (Pepperberg and Sherman 2000). This training system, based

on the Model/Rival procedure is a technique using three way interactions amongst two trainers and a student. It was used initially to train Grey parrots to produce and comprehend elements of human language, and was later adapted successfully as an intervention program for children with autism. Future work could investigate whether a robot could function as a participant in this training method.

- The design and testing of new scenarios with the humanoid robot and children with autism, focusing on the role of the robot as a social mediator and object of shared attention, encouraging interaction with peers. Evidence in current research showed one of the advantages of using an embodied robot is that it encourages a variety of full body interactions in the children (e.g. leaning on each other, stretching, 'dancing' etc). Specific scenarios could be designed to further encourage body awareness and sense of self specifically in a social context (amongst and with the help of peers).

- The design and testing of new scenarios that combine teaching imitation skills and mediating social interactions in scenarios with two children and two robots, adopting the models explored by Jacqueline Nadel, who studied the communicative function of imitation in pre-verbal children (Nadel 2002). Nadel's work showed that providing two identical sets of toys encourages imitation games as a means of communication among pairs of pre-verbal children. It would be interesting to investigate whether using two robots with pairs of children with autism might yield similar results.

- The investigation into the robot's appearance showed an example of a child directing his eye-gaze towards the theatrical robot's face attempting to make eye

144

contact with the robot, which wore a simple mask with apertures suggesting features such as eyes and mouth. This was in sharp contrast to the response of the child to the same mime artist when he appeared as an ordinary person. Could it be that a person's actual eyes could give so much information that it becomes overpowering for the autistic child, inducing the eye-gaze avoidance behaviour? The results from this study, albeit with a very small sample, does raise some questions regarding what level of complexity of facial features is sufficient to trigger a response and further research into this question may inform us about the nature of autism as well as robotic design. Future research could utilize a methodology developed by ethologists looking at eye-gaze in primates (Ferrari, Kohler, Fogassi and Gallese 2000) and could throw light on how eye gaze and the avoidance of eye gaze effect areas such as reciprocity and imitation in communication and socialisation.

8.5   Concluding Remarks

It is not clear if any social behaviour skills that might be encouraged in a child towards the robot, will be generalised and applied to interaction with other people. One of the three main areas of impairment common to all people with autism is imaginative skills. This poses a major problem in all therapeutic approaches to autism. As the imaginative skills are often impaired, so is the generalisation ability. Skills might be improved in one environment but the autistic person will have a great difficulty in generalizing the learning experience and applying these skills in different situations outside the specific learning environment.

Future research, using the robot as a social mediator in the interaction of autistic

children with peers or adults, as described above, might show a way how to overcome the generalization deficit and help these children acquire basic interaction skills.

Autism does not occur to the same degree and in the same form in all cases, so, as robotic systems are developed to aid in the therapy and education of children with autism, it is unlikely that they can be used generically to satisfy all needs. Various types of virtual or robotic interactive systems are likely to fulfil different roles in the spectrum of possible applications for children with autism. In the quest to assist people with autism researchers are using different designs of robotic systems, from animal-like robots to humanoid robots to robots with more abstract shape.

Previous study within the Aurora project presented the potential benefits of a mobile, *non-humanoid* robot (see section 2.3.2), and the work described in this thesis complements and extends this work by demonstrating the potential benefits of a *humanoid* robot in encouraging communication social interaction skills in children with autism.

Particular goals and particular social and cognitive needs might require specialised designs and will dictate the specific robotic system to be used, and as Dautenhahn said: "....the design space needs to map onto the niche space, the space of requirements posed by the particular application domain, taking into account specific needs of groups of users as well as individuals" (Dautenhahn 2002, page 196).

Appendix A

The robot's appearances used in the longitudinal study

The two different robot appearances used in the longitudinal study:

G - robot with a 'pretty girl' appearance.

P - robot with a Plain appearance.

G&P - combined results. On these days two sessions were conducted with the children, one using the robot with a 'pretty girl' appearance, and a second session with the robot in plain appearance. The average behaviour scores for that particular day were computed by averaging the scores for both sessions.

Note, on certain days sessions with particular children were not possible (empty entry in table below).

	Day No.							
Child	1	8	50	60	92	94	99	101
Andy	G	G	G	G	P	G&P	G&P	P
Don	G	G	G		P	G&P	P	P
Tim	G		G		P	G&P	G&P	
Billy	G	G	G	G&P	P	P	G&P	G&P

Table A.1:

Appendix B

CA Notation

(The following is taken from http://www-staff.lboro.ac.uk/ ssca1/notation.htm)

Conversation Analysis Notation

"These notation symbols are based on the system invented by Gail Jefferson and now well established in CA..."

(.)	Just noticeable pause
(.3), (2.6)	Examples of timed pauses in seconds
↑word,↓word	Onset of noticeable pitch rise or fall *(can be difficult to use reliably)*
A: word [word B: [word	Square brackets aligned across adjacent lines denote the start of overlapping talk. Some transcribers also use "]" brackets to show where the overlap stops
.hh, hh	in-breath (note the preceding full stop) and out-breath respectively.
wo(h)rd	(h) is a try at showing that the word has "laughter" bubbling within it
wor-	A dash shows a sharp cut-off
wo:rd	Colons show that the speaker has stretched the preceding sound.
(words)	A guess at what might have been said if unclear
( )	Unclear talk. Some transcribers like to represent each syllable of unclear talk with a dash or an "x"
A: word= B: =word	The equals sign shows that there is no discernible pause between two speakers' turns or, if put between two sounds within a single speaker's turn, shows that they run together
word, WORD	Underlined sounds are louder, capitals louder still
°word°	material between "degree signs" is quiet
>word word< <word word>	Inwards arrows show faster speech, outward slower
→	Analyst's signal of a significant line
((sobbing))	Transcriber's attempt to represent something hard, or impossible, to write phonetically

Appendix C

Consent Letter

University of Hertfordshire

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

Dear Parent,

Myself and Dr Kerstin Dautenhahn of the University of Hertfordshire are involved in the Aurora project to research ways in which toy-like robots can be used as tools to help in the development of communication and social interaction skills of children with autism.

We have run trials in the past at a number of the National Autistic Society's schools, and with the agreement of Mr. Patrick Draper, we will be running more trials at Bentfield school. These will involve sessions of around 15 minutes long, where the children could play with the robots, individually, or using the robot as a focus during interaction with other children.
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.

Further information on the project may be found on the internet at 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

Ben Robins

Day telephone no. - 01707 281150
Eve telephone no. - 01279 813322

- -

I give permission for my child _____ to take part in trials
of the Aurora project at Bentfield 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 Ben Robins

152

Appendix D

Publications

The work described in this thesis has been published in relevant conferences and journals as follows:

Chapter 4

1. Robins, B., Dautenhahn, K., te Boekhorst, R. and Billard, A. **Effects of repeated exposure of a humanoid robot on children with autism[1].** In Keates S., Clarkson J., Langdon P., and Robinson P. (eds): *Designing a More Inclusive World,* pp 225-236. Springer- Verlag, London. 2004

2. Robins, B., Dautenhahn, K. te Boekhorst, R. and Billard, A. **Robotic assistants in therapy and education of children with autism: Can a small humanoid robot help encourage social interaction**

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[1]This paper was presented at the 2nd Cambridge Workshop on Universal Access and Assistive Technology (CWUAAT) 22nd - 24th March 2004 and won the best formal paper award at the conference.

skills? *Universal Access in the Information Society* (UAIS), Springer-Verlag, July 2005. This Journal article is an expanded version of the CWUAAT workshop paper.

Chapter 5

3. Robins, B., Dautenhahn, K., te Boekhorst, R. and Billard, A. **Robots as assistive technology - Does appearance matter?** *In proc. 13th IEEE International Workshop on Robot and Human Interactive Communication - RO-MAN '04*, Kurashiki, Japan, 20-22 September 2004, pp 277-282.

4. Robins, B., Dautenhahn, K. and Dubowski, J. **Investigating autistic children's attitudes towards strangers with the Theatrical Robot- A new experimental paradigm in Human-Robot Interaction studies?** *In proc. 13th IEEE International Workshop on Robot and Human Interactive Communication - RO-MAN '04,* Kurashiki, Japan, 20-22 September 2004, pp 557-562.

Chapter 6

5. Robins, B., Dickerson, P., Stribling, P. and Dautenhahn, K. **Robot-mediated joint attention in children with autism: A case study in a robot-human interaction.** *Interaction studies: Social Behaviour and Communication in Biological and Artificial Systems,* (journal) John Benjamins Publishing Company, Amsterdam 5(2), pp 161-198. 2004.

6. Robins, B., Dickerson, P. and Dautenhahn, K. **Robots as embodied beings - Interactionally sensitive body movements in interactions**

among autistic children and a robot. *In proc. 14th IEEE International Workshop on Robot and Human Interactive Communication - RO-MAN '05,* Nashville, USA, 13-15 August 2005.

Chapter 7

7. Robins, B., Dautenhahn, K. and Dubowski, J. **Robots as isolators or mediators for children with autism? A cautionary tale.** *In proc. AISB05 convention, Symposium on Robot Companions: Hard Problems and Open Challenges*, 12-15 April, 2005. University of Hertfordshire, Hatfield, UK. pp 82-88.

In addition, the author contributed a summary of the work presented in this thesis to the following publications

Summary:

8. Billard, A., Robins, B., Nadel, J. and Dautenhahn, K. **Building Robota, a mini-humanoid robot: A tool, for testing of developmental psychology and evaluating the possible role of robots in education of children with autism.** Submitted to the special issue of the *Assistive Technology Journal on Intelligent Systems in Pediatric Rehabilitation,* 2005.

9. Davis, M., Robins, B., Dautenhahn, K., Nehaniv, C. and Powell, C. **A comparison of interactive and robotic systems in therapy and education for children with autism.** *In proc. Assistive Technology,*

from Virtuality to Reality - 8th European Conference for the Advancement of Assistive Technology in Europe AAATE'05, Lille, France, 6-9 September, 2005.

10. Robins, B. and Dautenhahn, K. **Interacting with robots: Can we encourage social interaction skills in children with autism?** *ACM SIGACCESS Accessibility and Computing archive* Issue 80, pp 6-12, ACM Press, New York, USA, September 2004.

11. Dautenhahn, K., Werry, I., Billard, A., Robins, B. and Salter, T. **Robots that autistic children can play with.** *In proc. 7th International Congress on Autism Europe*, Lisbon, Portugal, November 2003.

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158

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166

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167

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168

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