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Chapter 18

Games Children with Autism Can Play With Robota, a Humanoid Robotic Doll

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18.1 Background

This paper discusses the potential use of a small, humanoid robotic doll called Robota in autism therapy. Robota was specifically designed for engaging children in imitative interaction games. This work is associated to the Aurora project where we study the potential therapeutic role of robots in autism therapy. This section provides the necessary background information on autism (18.1.1), and motivates the application of interactive technology in autism therapy (18.1.2). Section 18.1.3 discusses the important role of imitation and interaction games in the development of social skills. Section 18.2 introduces the Aurora project. Sections 18.3 and 18.4 briefly describe the humanoid doll Robota and its potential use in autism therapy. Observations from preliminary trials are discussed in section 18.5 before section 18.6 concludes this chapter.

18.1.1 Autism

The autistic disorder is defined by specific diagnostic criteria, specified in DSM-IV (Diagnostic and Statistical Manual of Mental Disorders, American Psychiatric Association, 1994). Individuals with autism present a broad spectrum of difficulties and abilities, and vary enormously in their levels of overall intellectual functioning. However, all individuals diagnosed with autism will show impairments in the following areas: Qualitative impairment in social interaction, communication, and restricted repetitive and stereotyped patterns of behaviour, interests, and activities. At the higher functioning end of the autistic spectrum we find people with Asperger Syndrome. Some of them manage to live independently as adults and succeed in their profession, but only by learning and explicitly applying rules to overcome the ‘social barrier’ (e.g. Grandin, 1995) which demonstrates the benefit of explicitly learnt/taught social knowledge. Instead of picking up and interpreting social cues 'naturally' they can learn and memorise rules about what kind of behaviour is socially appropriate during interaction with non-autistic people.

Many theories exist trying to explain and understand the primary causes of autism at the psychological or cognitive level of explanation. Much attention has recently focussed on the significance of early impairments in imitation (e.g. Rogers & Pennington, 1991) and shared attention (e.g. Baron-Cohen, 1995). Results by Jacqueline Nadel have shown very positive responses when children with autism were imitated by other children (1999). These results are confirming Nadel's view of imitation as a *format of communication* (see section 18.1.3), a means to express interest by imitation, and a means to engage others in interaction. Based on this paradigm, our working assumption is that an interactive, doll-shaped robot that can imitate will be able to engage children with autism in playful behaviour that can be used to teach basic imitative interaction skills.

18.1.2 Interactive Technology in Autism Therapy

For over thirty years researchers have been investigating the usage of robots in education (Papert 1980; Druin & Hendler, 2000). The potential use of computer and virtual environment technology in autism therapy is increasingly studied (e.g. Colby *et al.,* 1971; Strickland 1996; Powell, 1996; Blocher, 1999). People with autism often interact very 'naturally' with computer technology and use it in an exploratory and creative manner. A few projects have also investigated robotic devices (Weir & Emanuel, 1997; Michaud *et al.,* 2000; Plaisant *et al*., 2000), and it has been proposed that a humanoid robot might be used as a therapy aid for children with autism (Kozima & Yano, 2001). Teaching methods for children with autism are often based on highly structured teaching sessions (Watson *et al*., 1989) where the children are explicitly encouraged to make eye-contact, take turns in a social setting, associate facial expressions with emotions etc. (Howlin *et al*., 1999). Generally, computer technology in education and therapy has the big advantage of *putting the child in control*, under possible guidance of and feedback from the teacher, but with the child learning at his/her own pace.

A humanoid robot, i.e. a robot that can match at least to some extent basic behaviours of human beings (e.g. arm, head and eye movements) is an interesting tool for studying robot-human interaction, and in particular social interaction dynamics. However, research with humanoid robots to date is severely limited by the effort required in terms of required funding, development time, and the necessity to have a large team of highly qualified researchers and technicians maintaining the robot and keeping it operational.

Additionally, humanoid robots are usually not 'mobile', i.e. they can only be studied in the laboratory and cannot be transported easily to different sites, a necessary requirement if such systems are to be used in educational or therapy applications where it is desirable to study people in a familiar environment rather than bringing them to the laboratory. Research into robot-human interaction is often using a commercially available mobile robotic platforms (such as the Pioneer from ActivMedia Robotics, or RWI's indoor robots such as B21r, B14r and

Magellan Pro), systems that were historically developed for tasks such as navigation and planning, and therefore have a highly restricted behaviour and interaction repertoire. Robotic toys have become very popular during the past five years (cf. Sony's Aibo, LEGO Mindstorms, Furbys, My Real Baby). As commercial products such toy robots are robust, relatively inexpensive (in comparison to research platforms), and specifically designed for robot-human interaction. Usually, their behaviour and appearance is designed to mimic real biological systems, so as to be ‘cute’ and popular with people, by appealing to human's tendencies to anthropomorphise. However, such robots are usually limited in terms of their capabilities and provide little freedom for the user to improve those. Either the robot’s behaviour is fixed (Aibo, My Real Baby, Furbys) or the complexity of the behaviour that one could program remains very limited because the platform has little computational power (hence affordable by the great public), e.g. LEGO Mindstorms with very few sensors (6) and actuators (3).

In this chapter we discuss possible therapeutic contributions of a humanoid robotic doll to autism therapy. Our approach is based on the assumption that bodily interaction in imitative interaction games is normally an important factor in a child's development of social skills (see next section), and that teaching of such skills (in a playful and exploratory context but nevertheless from an educational point of view focussing explicitly on specific types of interactions) could help children with autism in coping with the normal dynamics of social interactions.

18.1.3 Homo imitans: Imitation Games People Play

Growing up in a human family means that a lot of time is spent on social interactions. Infants, in particular, receive an important amount of attention. Imitative and rhythmic interaction games (comprising e.g. vocalisations and body movements) between infants and caretakers, such as imitation and turn-taking, play an important part in the development of social cognition and communication in the young human animal (Bullowa, 1979; Piaget 1962; Nadel & Butterworth (Eds.), 1999). Infants are born ready to communicate by being able to reciprocate in rhythmic engagements with the motives of sympathetic partners.

Imitation plays an important part in play and social learning in humans, including adults and children. It is necessary for the individual's social acquisition of a variety of skills, ranging from vocal imitation in language games to imitation of body movements (*e.g.* when instructed how to tie shoe laces). Similarly, research in robotics and software agents is trying to employ imitation as a means of social learning, using machine learning approaches such as neural networks. Importantly, the *social function of imitation* in human-human interaction is increasingly recognised as a means to engage others in interaction, to express interest, and to develop coordinated interaction that is central to verbal and non-verbal 'dialogues'.

From a neurobiological perspective, given recent discussions on 'mirror' neurons and the neurobiological origin of imitation in primate evolution, one might speculate that *mirror neurons* are nature's solution – at least in some primates – to solving the correspondence problem, namely in creating a common shared context and shared *understanding* of actions and affordances (see below) between two agents (see discussion by Arbib, 2002). Recently a connection between an impairment in the mirror neuron system, imitative skills and autism has been suggested (Williams *et al*., 2001). However, discussions on deficits of children with autism with respect to imitation are controversial (e.g. Rogers in Nadel & Butterworth, 1999; Charman *et al*., 1994) and often depend on the particular psychological theories on the nature of autism that particular research groups support. Generally children with autism seem to imitate less frequently, in particular they seem less able to imitate actions and gestures, cf. Jordan (1999).

Although the work that we discuss in this paper focuses on autism therapy, rather than trying to understand the nature of autism, we would like to point out that robots could also serve as interesting tools for investigating theories and models proposed by autism researchers. Similarly, in biology and cognitive science the usage of robots as research tools in the quest for understanding intelligence has already been widely recognised.

In human culture imitation is an important cultural and social *medium of communication*. Imitation is an important mechanism of social learning in human culture, but also a powerful means of signalling interest in another person, used for purposes of communication. According to Nadel *et al*. (1999) immediate imitation is an important *format of communication* and milestone in the development of intentional communication, linking the imitator and the imitatee in synchronised activity that creates intersubjective experience, sharing topics and activities. Even unconscious temporal synchronisation and rhythmic coordination of movements between people play an important role in communication and interaction in human culture, cf. proxemics (the study of humans' perception and use of space, *cf.* Hall, 1966). Temporal synchronisation of behavioural dynamics has also been implemented in studies with robot-human interaction (Dautenhahn, 1999).

Our work focuses primarily on the *social role of imitation* (Dautenhahn, 1994), i.e. imitation as a format of communication that creates intersubjectivity in human-human interaction. We propose that the important link between the dynamics of imitation and social interactions can be explored in using a humanoid robot.

18.2 The Aurora Project

The work discussed in this paper is associated to the Aurora project which has been studying how a non-humanoid mobile robot with very simple interaction skills can be used as a teaching device (a 'toy') in autism therapy. Here, robot-human interactions are unconstrained and unstructured, allowing full-body interactions (see figure 18.1). Our motivation is that children can explore and 'discover' interaction skills rather than being taught explicitly. For more background on the project's robotic and therapeutic issues see (Dautenhahn, 1999; Werry & Dautenhahn, 1999; Dautenhahn & Werry, 2000, 2001; Werry *et al*., 2001a,b,c; Dautenhahn *et al.*, to appear). Results are generally encouraging. In a series of trials with 8-12 year old autistic children it was found that a) the robot is safe for the children to use, 2) the large majority of children are not afraid of the robot and show great flexibility in coping very well with the new context, 3) the children are very motivated to interact with the robot over a period of five to ten minutes or longer, 4) the children are usually more interested in the robot in 'interactive' mode in comparison to the robot showing rigid, repetitive, non-interactive behaviour, 5) the children have no problems coping with the robot behaving reactively but not completely predictable. In these trials the robot showed a few basic behaviours of approach and avoidance. Results also indicate that the children generally showed more interest in the robot (in terms of gaze, touch etc.) and were more engaged in interactions with the robot than with another non-robotic toy. The results showed large individual differences among the children, but it is safe to say that we showed that the robot was able to engage children with autism in interaction dynamics that are important to social interactions in general, and that we can further explore, e.g. in the work described in this paper. In previous work we studied and adapted different analysis techniques (quantitative and qualitative). The former is based on micro-behaviours (Tardif *et al.*, 1995), the latter uses Conversation Analysis (CA). Such analysis techniques (see Dautenhahn *et al*., to appear) can also be applied to interactions of children with a humanoid robot.

Figure 18.1. A child with autism playing "chasing" games with the mobile robot used in the Aurora project.

The main limitation of the (non-humanoid) robot currently used in the Aurora project lies in that it offers only a very small number of interactions with the child, i.e. the type of interactions that can occur are limited to spatial approach/avoidance turn-taking games. The humanoid robot Robota, described in the next section, can complement this work by offering a much larger range of multi-modal imitative interactions, in this way providing new means of interaction such as mimicking movements of body parts (e.g. hands, head), as well as more complex interactions (sequences and combinations of actions). Because of its small size and relatively low price it is also ideal for long-term studies in which the children are regularly exposed to and interact with the robot.

18.3 Who is Robota?

Robota is a doll-shaped robot 50 cm tall, weighing 500 grams, see figure 18.2. The arms, legs and the head of the robot are plastic components of a commercially available doll. The main body contains the electronics (PIC 16F870, 4MHz and 16F84, 16MHz) and mechanics (5 motors, legs, arms and head, 1 DOF each)[1]. For a complete description of Robota's hardware, see http://www-slab.usc.edu/billard/robota.html. Through a serial link connection to a PC, the robot uses speech synthesising and video processing (based on a QuickCam camera). Using a motion tracking system, Robota can copy upwards movements of the left and right arm of the user when the user faces the camera. This game can be used to teach Robota to dance to a specific music, played on the PC. The robot reacts to touch: it detects passive motion of its limbs through its potentiometers and responds with a little jerk of the touched limb. In the present trials, the robot uses speech synthesising to tell its name and describe its behaviour. This is meant to attract the child's attention. In other games, the robot can be taught by the user how to speak (Billard, 1999, 2000, 2002), see below.

Figure 18.2. Robot, the humanoid robotic doll. The robot's dress is removed in order to show the robotic parts that control its movements.

Robota was designed as an interactive toy for children. The multimedia type of interactions which Robota offers makes it a non- (not immediately at least) boring toy. In (Billard & Dautenhahn & Hayes, 1998), we reported initial tests with (typically developing) children of 5 and 6 years old, which showed the potential of the robot as a game for children. The children enjoyed playing with the robot because they could interact with it in different ways. The robot would respond to the children touching specific parts of its body, by making small movements or some sounds. It would mimic the child's head and arm movements. It would speak words that are part of the child's every-day vocabulary (e.g. "food", "hello", and

[1] Planned extensions include one motor to drive the two eyes in coordinated sideways motion.

"no"). The level of complexity of the game with Robota can be varied. One can restrict the interactions to built-in behaviours of the robot (a 'baby-like' robot).

18.4 Possible Usage of Robota in Autism Therapy

The previous section discussed Robota's range of behavioural capabilities. In future, the behavioural repertoire will need to be adapted in order to meet the specific needs of children with autism. In particular the 'baby behaviours', which encourage 'caring' behaviour in typically developing children are not very likely to have the same impact on children with autism. Pretend play, imagination and fantasy which are necessary in order to 'suspend disbelief' and treat the robot doll like a 'baby', are often impaired in children with autism. Thus, a doll that is too appear confusing and unpredictable, too similar to human social behaviour. In our work we start with a small behaviour repertoire of the robot. Over time we plan to incrementally change it depending on the children's reactions.

Potentially, a number of different types of robots might be successful in autism therapy. However, the specific nature of autism poses particular requirements and constraints on the robot and its behavioural capabilities. Most importantly:

- **Safety and ethical issues:** It is vital to provide a safe environment where the child can explore as unconstrained as possible the robot's capabilities in an enjoyable and relaxed atmosphere. Since the child should learn through playing, any aspects of the robot that might upset or scare the child need to be avoided by all means. For these reasons we decided to use small, lightweight, toy-size robots.
- **Predictability and control:** Although it is desirable that the child adapts to complex and often unpredictable behaviour, as humans show them, children with autism can easily get overwhelmed by sensory stimuli, e.g. as they occur in human social interactions. Thus, we believe that an important advantage of using robots in autism therapy is not to provide an 'artificial human', but to provide a tool that is *clearly much simpler* than any human being, and that can guide the children through increasingly more varied and complex types of interactions in which they exercise skills (such as turn-taking and imitative skills) that play an important role in human-human interactions. This approach is supported by empirical data which shows the preference of autistic children to 'social' (doll-like) objects with low complexity, in a predictable environment (Ferrara & Hill, 1980).
- **Generalisation:** Any autism therapy method faces the problem that people with autism have great difficulties in generalising learning achievements across contexts, such as applying what was learnt in class to contexts outside the school. For this reason we believe that ultimately a variety of robot designs in autism therapy are useful. The behaviour and appearance of each robot could be tailored toward the particular developmental stage, learning needs, and individual interests of a child. Robots that can 'change

shape', i.e. that can be made more or less machine-like, or anthropo-/ zoomorphic could be interesting to study.

By using Robota, a humanoid robot that can engage children in synchronous and imitative interaction games, we hope to develop interaction skills in children with autism, skills that might help them to cope better with daily-life human-human interaction. With Robota we can systematically investigate specific design and behaviour parameters and study how they influence imitative interaction dynamics. Using an enhanced version of Robota with autistic children could address novel research questions that have not been addressed in the above mentioned previous works with robots in autism therapy. Firstly, by varying the shape of the robot from machine-like to doll/human-like one can study the role of human-like features in the social responsiveness of autistic children. In this way, the humanoid robot can be used as a tool to systematically assess the response of autistic children to some basic human features (e.g. directionality of gaze, face expressiveness) and basic social interaction behaviour. Secondly, we could study the effect of repeated and regular interaction between the child and the robot with the robot in the role of a robot 'robotic therapy aid'. Such long-term studies are vital for demonstrating any therapeutic effect or impact the robot might have on the children. Thirdly, with Robota one can study imitation and mirroring behaviour in autistic children. Imitation and mirroring play already an important role in many existing therapies for autistic children. Such behaviours could be studied systematically, intended to guide the child through increasingly complex interaction dynamics. Usually, mirroring/imitation methods are highly time- and labour-consuming and require the teacher to undergo specific training. A robotic therapy aid could provide an economical means that takes some of the strains off teachers and/or parents.

Different from existing projects that use non-humanoid robots for autism therapy, the discussed work investigates a complementary area in the interaction design space, exploring the emergence of imitative interaction dynamics and turn-taking in robot-human interaction, based on research into the social role of imitation. Group scenarios with two children simultaneously playing with the robot, similar to studies we conducted with a mobile robot (Werry *et al.*, 2001c), are also hoped to facilitate social learning and generalisations across contexts.

18.5 Preliminary Trials

The Robota dolls were developed by Aude Billard, originally for different projects (robotics and entertainment applications). In November 2001 a basic version of Robota was available for a few days. Robota was tested with eight autistic children at Radlett Lodge School and six children at Colnbrook School (three of six children played with the robot on two consecutive days). Trials were videotaped. The video data is currently being analysed, detailed results will be published in forthcoming publications. The version of Robota that was used had the following behaviour repertoire: a) it could 'dance' to one of two pre-recorded songs ('Dancing queen' and 'Rock around the clock') , b) a camera detected vertical arm movements of the child, Robota responded by lifting the right, left or both arms, c) when the child moved the limbs and the head of Robota then the robot could learn and replay the movement sequence. In order to recognise vertical arm movements reliably, the child was required to sit in front of the camera (positioned next to Robota), and s/he had to sit relatively still. Fig 18.3 shows the basic set up. A teacher (background) is sitting next to the child and encourages him to play with Robota. A typical example of such interactions (between a child, his teacher, and Robota) can be described as follows:

Figure 18.3. A six-year old boy with autism playing with Robota. In this context he seemed curious about Robota's head movements and so he touches the doll.

- Child and teacher enter the room. Robota is located on a table, an experimenter sitting next to it. Teacher and child sit down on chairs at the table. The teacher 'introduces' the child to the robot, e.g. "Look, this is Robota, you can play with her".
- The teacher demonstrates what the robot can do. For example, the teacher lifts her right arm and tries to encourage the child to do as she did. Robota responds by imitating the arm movements.
- The teacher verbally and with gestures points out the correspondence between Robota's and the child's movements: "Look, Robota imitates you". The teacher then repeats this game using the left arm or raising both arms. The teacher can also initiate a different game where the child moves Robota's arms and head, and where Robota learns this sequence and can replay it (music is used for some children who enjoy music).

Generally, and very different from previous trials in the Aurora project with a mobile robot, the children's behaviour in these trials was very much teacher-directed and teacher initiated. Since the videotapes are currently being analysed, it is at this stage very difficult to draw any general conclusions. We clearly observed many instances in which the children played imitation games with the robot, seemingly enjoying it: we observed clear signs of enjoyment such as smiling, or a boy kissing Robota goodbye before he left the room. Given that children with autism often show less imitative skills than typically developing children, we believe that this is a promising research direction, in addition to using other mobile autonomous robots used in the Aurora project.

18.6 Conclusions

In previous work we studied how a mobile robot can engage children with autism in interaction games. The humanoid robot Robota extends this work by opening up a new and larger range of possible interactions and interaction modalities (involving movements, sounds, remembering and imitating sequences of actions etc.) The games with Robota allow exploring specific therapeutic issues that are relevant to autism therapy[2]. In the long run, this study could contribute to the development of robotic tools in autism therapy, by exploring the space of possibilities offered by different robotic designs (humanoid versus non-humanoid). To this end, the latest development of Artificial Intelligence/Robotics techniques (cf. Billard, 2000; Billard & Dautenhahn, 1998) can be applied for creating games that involve cognitive challenges as well as challenges in motor coordination.

In future work with Robota it will be particularly interesting to see how the robot can be used in more 'free-form' play scenarios, without requiring extensive teacher intervention. Note, that sometimes the teacher had to intervene because the child was about to break the robot (e.g. forcefully pulling its arms). We are therefore currently seeking funding in order to develop an enhanced version of Robota that is a) more robust, b) more specifically adapted to the needs and abilities of autistic children, and c) has additional features such as moving eyes. At present only a basic version of robot is available for occasional testing.

The enhanced version of Robota would allow us to study systematically and in-depth the issues that are addressed in this paper. Most importantly, resources are needed for conducting *long-term studies* where the children are regularly and over an extended timeframe exposed to the robot. Such studies are vital in order to assess the value of the robot in autism therapy. Observing positive interactions of the children with the robot in individual trials is certainly encouraging and informative with respect to the set up of the trials and general issues of robot design and control. However, our long-term goal is to help children with autism and make a contribution to autism therapy, we therefore need to be able to demonstrate therapeutic effects. The second important role of long-term studies is

[2] We like to thank the teaching staff, parents, and children at Radlett Lodge School and Colnbrook School who participated in the trials. The robot used in the trials reported here was created under the sponsorship of the French National Science Museum, "La cite des Sciences et de l'Industrie", and DIDEL SA (CH). Aude Billard is supported by a personal fellowship from the Swiss National Science Foundation. We would like to thank Stuart Powell, Tim Luckett, Penny Stribling, Paul Dickerson and Tamie Salter for helpful comments on the project.

that the robot can be given *adaptive* abilities so that it can change its behaviour depending on the interaction histories with individual children.

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