**Universidade do Minho**
Escola de Engenharia

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# Affective Robotics for Socio-Emotional Development in Children with Autism Spectrum Disorders

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Tese de Doutoramento
Programa Doutoral em Engenharia Eletrónica e de Computadores

Trabalho efetuado sob a orientação de
**Professora Doutora Filomena Maria da Rocha Menezes de Oliveira Soares**
**Professora Doutora Cristina Manuela Peixoto Santos**

Outubro de 2014

## STATEMENT OF INTEGRITY

I hereby declare having conducted my thesis with integrity. I confirm that I have not used plagiarism or any form of falsification of results in the process of the thesis elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

University of Minho, ______________________________

Full name: ______________________________________________________________

Signature: ______________________________________________________________

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"Learn from yesterday, live for today, hope for tomorrow. The important thing is to not stop questioning."

**Albert Einstein, Relativity: The Special and the General Theory, 1920**

I believe we should never stop questioning. We need to question the world around us, our methods, or our beliefs. During the years I pursued my PhD I had the opportunity to meet or build stronger relationships with a handful of people who led me to search, to want to know more, and to accept the challenge of questioning everything.

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"Aprende com o passado, vive para hoje, espera pelo amanhã. O mais importante é não parar de questionar."

**Albert Einstein, Relativity: The Special and the General Theory, 1920**

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# Abstract

Autism Spectrum Disorders (ASD) are a group of complex developmental disorders of the brain. Individuals affected by this disorder are characterized by repetitive patterns of behaviour, restricted activities or interests, and impairments in social communication. The use of robots had already been proven to encourage the promotion of social interaction and skills lacking in children with ASD. The main goal of this thesis is to study the influence of humanoid robots to develop socio-emotional skills in children with ASD. The investigation demonstrates the potential benefits a robotic tool provides to attract the attention of children with ASD, and therefore use that focus to develop further skills.

The main focus of this thesis is divided into three topics. The first topic concerns the use of a robot to encourage learning appropriate physical social engagement, and to facilitate the ability to acquire knowledge about human body parts. The results show that the robot proved to be a useful tool, attracting the children's attention and improving their knowledge about human body parts. The second topic regards the process of designing game scenarios to be used with children with ASD, targeting the promotion of emotion recognition skills. Three game scenarios were developed based on the expertise of professionals and they were successfully tested in pilot studies. Finally, the last topic presents two child-robot interaction studies with a large sample. They examine the use of a humanoid robot as a tool to teach recognition and labelling of emotions. The first study focuses on verbal and non-verbal communicative behaviours as measures to evaluate the social interaction and children interacting with the robot displayed more non-verbal behaviours indicating social engagement. The second study analyses the children's attention patterns, and the children's performance in the game scenarios previously designed. Along the sessions, the children increased their eye contact with the experimenter and in the study comparing the use of the robot with a traditional intervention, children who performed the game scenarios with the robot and the experimenter had a significantly better performance than the children who performed the game scenarios without the robot.

The main conclusions of this research support that a humanoid robot is a useful tool to develop socio-emotional skills in the intervention of children with ASD, due to the engagement and positive learning outcome observed.

**Keywords**: Autism Spectrum Disorders; Socially Assistive Robots; Human-Robot Interaction; Socio-Emotional Skills Development.

# Resumo

As Perturbações do Espectro do Autismo (PEA) são um distúrbio complexo do desenvolvimento do cérebro. Os indivíduos afetados por esse transtorno são caracterizados por padrões repetitivos do comportamento, atividades ou interesses restritos e dificuldades na comunicação social. A utilização de robôs já provou ser um estímulo promovendo a interação social e competências em falta nestes indivíduos. O objetivo principal desta tese é estudar a influência de robôs humanoides para desenvolver competências sócio emocionais em crianças com PEA. A investigação demonstra os potenciais benefícios de uma ferramenta robótica para atrair a atenção de crianças com PEA e utilizar esta atenção para desenvolver outras competências.

O foco principal desta tese está dividido em três tópicos. O primeiro tópico consiste na utilização de um robô para incentivar a aprendizagem sobre a interação físico-social apropriada e para facilitar a aquisição de conhecimento sobre partes do corpo. Os resultados mostram que o robô provou ser uma ferramenta útil, atraindo a atenção das crianças e melhorando o seu conhecimento sobre partes do corpo. A segunda parte refere-se ao processo de construção de atividades para serem utilizadas com crianças com PEA, promovendo competências de reconhecimento de emoções. Três atividades foram desenvolvidas com base na opinião de profissionais e foram testadas em estudo piloto com sucesso. Finalmente, o último tópico apresenta dois estudos de interação criança-robô examinando a utilização de um robô humanoide como ferramenta para ensinar reconhecimento e identificação de emoções. O primeiro estudo foca a comunicação verbal e não-verbal como medidas de avaliação da interação social e as crianças que interagiram com o robô mostraram mais comportamentos não-verbais que indicam interação social. O segundo estudo analisa os padrões de atenção e o desempenho das crianças nas atividades concebidas anteriormente. Ao longo das sessões, as crianças aumentaram o contacto ocular com o experimentador e no estudo que comparou a utilização do robô com intervenção tradicional, as crianças que realizaram as atividades com o robô e o experimentador tiveram um desempenho significativamente melhor do que as crianças que realizaram as ativdades sem o robô.

As conclusões principais desta investigação suportam que um robô humanoide foi uma ferramenta útil para desenvolver competências sócio emocionais na intervenção de crianças com PEA, devido à interação e resultados positivos de aprendizagem observados.

**Palavras-chave**: Perturbações do Espectro do Autismo; Robôs Socialmente Assistivos; Interação Humano-Robô; Desenvolvimento competências sócio emocionais.

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# Abbreviations

| | |
|---|---|
| **ANOVA** | **AN**alysis **O**f **VA**riance |
| **API** | **A**pplication **P**rogramming **I**nterface |
| **ASD** | **A**utism **S**pectrum **D**isorders |
| **DoF** | **D**egrees of **F**reedom |
| **FACS** | **F**acial **A**ction **C**oding **S**ystem |
| **FSR** | **F**orce-**S**ensing **R**esistors |
| **GUI** | **G**raphical **U**ser **I**nterface |
| **HD** | **H**i-**D**efinition |
| **HRI** | **H**uman **R**obot **I**nteraction |
| **JAT** | **J**oint **A**ttention **T**ime |
| **M** | **M**ean |
| **PAD** | **P**leasure **A**rousal **D**ominance |
| **PDD-NOS** | **P**ervasive **D**evelopmental **D**isorder-**N**ot **O**therwise **S**pecified |
| **PANA** | **P**ositive **A**ctivation - **N**egative **A**ctivation |
| **QR** | **Q**uick **R**esponse |
| **RQ** | **R**esearch **Q**Question |
| **SA** | **S**uccessful **A**nswers |
| **SD** | **S**tandard **D**eviation |
| **TD** | **T**ypically **D**eveloping |
| **TEACCH** | **T**reatment and **E**ducation of **A**utistic and Related **C**ommunications Handicapped **CH**ildren |
| **ToM** | **T**heory **o**f **M**ind |
| **UUP** | **U**nsuccessful and **U**nanswered **P**rompts |
| **ZECA** | **Z**eca **E**ngaging **C**hildren with **A**utism |

*Dedicated to Antoine*

# Chapter 1

# Introduction

A social interaction consists in a societal exchange between two or more individuals. Social interaction can be observed between groups of two (dyads), three (triads) or larger social groups. According to Weber (1978), "an action is 'social' if the acting individual takes account of the behaviour of others and is thereby oriented in its course". The field of social robotics comprises the dynamic interaction with an embodied entity. Generally, social robots bring into focus social rather than physical interaction to help humans. This interaction promotes the collaboration and communication focusing on the use of the robot's embodiment to interact with users in an engaging way, instead of primarily focusing on the physical capabilities of the robot such as navigation and object manipulation.

Assistive robotics endeavours to help users with special needs in their daily activities. Assistive robots offer an exceptional occasion for quantifying social behaviour, since they are designed to identify, measure, and react to social behaviours, being repeatable and objective (Tapus *et al.*, 2007). Particularly, the purpose of socially assistive robotics is to improve the quality of life of their users, such as individuals with Autism Spectrum Disorders (ASD). The challenge lies in the high individualisation of each user's special needs (Tapus *et al.*, 2007).

Children with ASD may benefit from assistive robotics in the contexts of special education, training social and academic skills. Several studies have showed that robots produce a high level of encouragement and engagement in individuals with ASD, including individuals who are not likely or willing to interact in a social manner with human therapists. Scassellati (2007) defined possible areas in which social robotics may be a helpful tool to diagnose, treat, and understand ASD. The robot can represent a social support to engage children, educate them socially and incrementally help

transferring the acquired knowledge when interacting with other partners (Tapus *et al.*, 2007).
The embodiments of the assistive robots used until now with children with ASD vary greatly, from four-wheeled mobile robots (Dautenhahn & Werry, 2004; Ferrari *et al.*, 2009), anthropomorphic robotic dolls (Dautenhahn & Billard, 2002), expressive snowman-like devices (Kozima *et al.*, 2009), animal-like (Stanton *et al.*, 2008) to humanoid robots (Feil-Seifer & Mataric, 2011; Huskens *et al.*, 2013; Robins *et al.*, 2009). Researchers have been discussing the most appropriate features of a robot to be used in intervention for children with ASD. Robots shaped as animals, cars, and toys are often simpler and affordable, and the fact that they do not have a humanoid form may encourage interesting and engaging interactions. In addition, mechanical parts often attract the attention of children with ASD. On the other hand, humanoid robots promise a great potential for generalisation. For example, imitation and emotion recognition activities are harder if the robot does not present a human form (Ricks & Colton, 2010).
The two robots used in the research presented in this thesis are both humanoid. The interaction is as simple and predictable as possible, based on a prompt-answer-reward process, using simple verbal commands from the robot. When communicating with a person, the interaction can be complex and intimidating, and the process mentioned above provides a safer and more pleasant atmosphere for the child with ASD (Gillesen *et al.*, 2011).

## 1.1 Motivations, Scope and Problem Statement

Facial expressions are used in the identification of feelings and state of mind of others, and they permit human beings to adjust their behaviour and react suitably. Consequently, understanding facial expressions correctly and extracting the pertinent social information from them is important for social interactions and communication (Nachson, 1995).
Baron-Cohen & Wheelwright (2004) defined empathy as the aptitude to attribute mental states to others, responding with a suitable emotion to the other person's mental states. This suggests that empathy is formed of cognitive and affective components. The cognitive component is also called the "theory of mind" (ToM) (Dennett, 1989). Mental states include thoughts and emotions. Thoughts are divided into beliefs, desires, intentions, goals and perceptions (Baron-Cohen, 1997; Dennett, 1989). Ekman

(1971) defined the six "basic" and several "complex" emotions. The "basic" emotions are described as being universally recognized and expressed. Moreover, "complex" emotions are more dependent on the context and culture and they involve attributing a cognitive state (Griffiths, 1997).

Some individuals with ASD have a delayed development of empathy, having difficulties in putting themselves into someone else's perspective and to be aware of how to react to another's feelings, in real time. Deficits may have a crucial influence on their social behaviour raising the challenge of whether aspects of empathy can be taught to individuals with ASD (Baron-Cohen *et al.*, 2009).

Individuals with ASD have difficulties in recognizing emotions from facial expressions, vocal intonation, body language, separately (Hobson, 1986; Yirmiya *et al.*, 1992) and in context (Golan *et al.*, 2008; Klin *et al.*, 2002). The difficulties in recognizing emotions are to a certain extent the result of modified face processing (Dawson *et al.*, 2004; Klin *et al.*, 2002), which may be due to a failure to interpret the information conveyed by the eyes (Baron-Cohen *et al.*, 1997).

Problems with affect processing in individuals with ASD have been identified in the literature (Celani *et al.*, 1999; Hobson, 1986; Law Smith *et al.*, 2010; Tantam *et al.*, 1989), but other studies did not identify unusual difficulties in emotion recognition skills by individuals with ASD (Kuusikko *et al.*, 2009; Prior *et al.*, 1990; Teunisse & de Gelder, 2003; Tracy *et al.*, 2011; Wright *et al.*, 2008). Differences in the sample, participants' characteristics, task demands, and stimuli may be at the root of these differences (Harms *et al.*, 2010).

The performance of individuals with ASD appear to be markedly impaired for negative, more subtle, more complex emotions (Baron-Cohen *et al.*, 1997; Law Smith *et al.*, 2010; Wallace *et al.*, 2011) or expressions embedded in a social context (Da Fonseca *et al.*, 2009; Speer *et al.*, 2007).

Distinct strategies have been used to investigate emotion processing abilities in children with ASD, with or without intellectual disabilities: sorting, (cross-modal) matching, and labelling tasks (Harms *et al.*, 2010; Uljarevic & Hamilton, 2013).

Baron-Cohen *et al.* (2009) investigated the possibility of teaching emotions to children with ASD. For that, he and his team presented to children with ASD, aged 4 to 7 years old, an animated series called *The Transporters* which was designed to enhance emotion comprehension. The children watched the different episodes every day for four weeks. The researchers measured the emotional vocabulary and emotion recognition at three levels of generalisation before and after the intervention. The group who watched the animated series improved significantly compared to a clinical control

group on all task levels.
The motivation for the research presented in this thesis consists in assessing the impact and benefits of the use of humanoid robots for socio-emotional skills development in children with ASD. One study focus on developing an understanding of the children's body in relationship to the environment and if the robot can help children with ASD to learn appropriate physical social engagement. If a humanoid robot can help children with ASD to identify, label, and imitate facial expressions is also tested. Moreover, another game scenario implies the skill of identifying the other's perspective in a social story. Additionally, this research aims to understand if and how a humanoid robot can promote triadic interactions between a child with ASD and another person, measuring and analysing eye gazing patterns, joint attention behaviours, verbal, and non-verbal interaction.

## 1.2 Overview of the Research

The physical embodiment of a social agent intensifies its social presence, contributing to positive social responses from the person interacting with the agent (Lee *et al.*, 2006). The goal of using robots as social assistants is to elicit positive and productive interactions, possibly with a targeted learning outcome. Robots occupy a particular niche between motionless toys, which do not elicit novel social behaviours and animate social beings, which can be the cause of confusion for children with ASD (Scassellati *et al.*, 2012).
Researchers have been presenting results suggesting that robots are used effectively as tools to improve social skills for children with ASD, such as joint attention, i.e., the shared focus of two individuals on the same object (Moore & Dunham, 2014). Robots are greatly appealing to children belonging to this spectrum and they have been used to encourage communication with the therapist or adult interacting with the children. However, the generalisation of skills from the robot to the human being is challenging and seen as one of the hardest obstacles to overcome (Giullian *et al.*, 2010).
One important aspect to have into consideration is the autonomy of the robot. It should have a certain level of autonomy to allow the experimenter to interact with the child rather than to have to focus his/her attention to control the robot. With this specific target group and in intervention context, a completely autonomous robot is not desirable to allow the experimenter to determine how and when the robot should respond to certain actions of the children, and to change the activity they are involved

(Giullian *et al.*, 2010). In the research presented in this thesis, autonomy is introduced in the robot's behaviours using tactile sensors to identify gentle and harsh touches from the child on the robot (Chapter 3) and using image processing techniques to identify the answer from the children in the game scenarios (Chapter 5).
The robot used in Chapter 3 is a child-sized, humanoid robot with a minimally expressive face and arms able to produce gestures. The robot used in Chapter 5 has a higher level of sophistication compared to the robot in Chapter 3 especially regarding facial expressions, and finer arms movements. Based on research of Paul Ekman, the facial expressions corresponding to anger, happiness, sadness, fear, and surprise were modelled on the robot and a perceptual study was performed to evaluate the produced facial expressions. This robot was especially chosen to develop emotion recognition skills in children with ASD. It has a cartoon-like appearance, resembling human characteristics but not being ultra-realistic as androids are, which can be least engaging to children with ASD (Ricks & Colton, 2010). Equally important is that the robot's body which is not covered with clothes allowing the children to observe the movements of the joints.

### 1.2.1 Research Questions and Goals

The main goal of this thesis is to verify the application of affective robotics for socio-emotional skills development in children with ASD. To perform this verification several intermediate studies were designed with specific goals, research questions, and hypotheses which are detailed in each chapter. To summarise, this research pursues the following research goals:

**Goal 1:** to verify if a humanoid robot can help children with ASD to learn appropriate physical social engagement, facilitating the ability to acquire knowledge about human body parts;

**Goal 2:** to create a set of game scenarios using a humanoid robot as the main tool to develop socio-emotional skills in children with ASD;

**Goal 3:** to evaluate the use of a humanoid robot, as a tool to teach recognition and labelling of emotions;

**Goal 4:** to understand if and how a humanoid robot could promote triadic interactions between a child with ASD and another person.

Hence, the main research questions (RQ) to be investigated are the following:

**RQ 1:** Can the robot elicit the ability to acquire knowledge about human body parts and help teach children with ASD appropriate physical (tactile) social engagement?

**RQ 2:** How can a humanoid robot contribute to develop emotion recognition skills in children with ASD using game scenarios about labelling, imitation and inference of emotions?

**RQ 3:** Does the verbal and non-verbal communication of children with ASD change in an interaction with a humanoid robot and another person?

**RQ 4:** How does the use of a humanoid robot influence eye gaze and joint attention time in children with ASD in an interaction with another person?

Thus, the following hypotheses are proposed:

**Hypothesis 1:** The use of a robot helps children with ASD learning the name of different body parts and encourages them to show appropriate physical behaviours, i.e, in accordance with social norms;

**Hypothesis 2:** Children with ASD will perform better when participating in game scenarios aiming to promote socio-emotional skills with a robot and an adult comparing to children who only interact with an adult;

**Hypothesis 3:** Children with ASD will interact verbally and non-verbally more often and for longer when performing activities with a robot and an adult comparing to children who only interact with an adult;

**Hypothesis 4:** Children with ASD will participate in joint attention behaviours for longer periods of time and more frequently when performing activities with a robot and an adult comparing to children who only interact with an adult.

### 1.2.2 Methodological Considerations

The research carried out in this thesis has a humanoid robot as the central technological tool. Having in mind the target group of this research, it is not expected to test the technology in dyadic child-robot interactions, but to promote a triadic interaction between the child with ASD and an adult using the robot as an object of joint attention. This research is multidisciplinary involving areas such as affective robotics, assistive technology, robot-assisted play, social robotics, child's development, ASD research, and developmental psychology.

The impairments of children with ASD are characterized by repetitive patterns of behaviour, restricted activities or interests and are related to difficulties in social communication (Association, 2013). With this in mind, the methodology and the study design used in this research aim to obtain generalisations, giving emphasis on data and behavioural changes. Whenever it is possible the results are presented as quantitative data and using their statistical analysis to describe and assess the final results.

Between the research strategies available, case studies and experiments are used in this investigation for qualitative and quantitative research, respectively.

Case studies are used to test theories and in this thesis they are applied in the exploratory studies of Chapter 4. Yin (2014) defined the case study research method as an empirical investigation that examines contemporary events within their real-life context, when the boundaries between phenomenon and context are not distinctly obvious and in which multiple sources of evidence are used. Case studies provide an understanding of a complex issue or object and support what is already known through previous research. This research method highlights specific contextual analysis of a restricted amount of events or conditions and their relationships (Gerring, 2007). Case studies offer insights that might not be achieved with other approaches and have been used for the preliminary stage of a research project, as a foundation for the development of 'more structured' tools that are necessary in surveys and experiments (Eisenhardt, 1989; Rowley, 2002). Case studies were conducted in the research performed in Chapter 4.

The experiments are studies where the researcher handles at least one variable while quantifying at least another variable. This research method may lead to answering cause-effect questions and the participants are normally randomly assigned to different groups. The group receiving the independent variable is called the experimental group and the other group treated in the same manner but not receiving the independent variable is called the control group. In the research presented in this thesis, the participants have a pre-existing characteristic due to their clinical diagnosis. Because of this, there is no random assignment and this investigation is considered as differential research (Shaughnessy & Zechmeister, 1985; Taylor, 1999). Experiments were conducted in the research performed in Chapters 3 and 5.

The studies presented in this thesis have in common an experimental procedure which allows the structured collection of data. The experiments' preparation includes establishing a formal protocol of collaboration with the school or clinic where the experiments took place, a meeting with the professionals who interact with the children daily, and the completion of a questionnaire to characterize each child. The second part of this phase consists in scheduling the experiments according to the goals of the study, including one day where the experimenter has the opportunity to get acquainted with the children. This familiarisation is necessary due to the difficulty of the children to accept new persons in their routine.

According to the goals of the studies, a task without the robot is designed to evaluate the children's knowledge in a pre-test and their potentially acquired knowledge in a post-test. The children are evaluated both for the duration and for their performance in the task.

The design of the game scenarios is based on the literature and on the expertise of teachers, therapists, psychologists, and doctors who were consulted using questionnaires and focus groups. The activities elaborated in this research involve the implementation and testing of interactive learning environments, with various modalities of interaction with a robot. The chosen learning activities include the exploration of sensory and motor skills and the opportunity of communication using technology as a mediator. The technology is directly applied in this particular case to special education of children with ASD, developing different modalities of social interaction. When the experiments took place, observational grids were used to register modifications in the children's behaviours but video recordings were the main source of information and data. Afterwards, all videos were coded using a predetermined list of behaviours built according to the specific goals of the study. A second rater coded 10% of the videos to insure the quality of the obtained data, evaluated by an intra-rater reliability test.

### 1.2.3 Ethical Considerations

Chapters 3, 4, and 5 present studies involving more than fifty children with ASD. This research was approved by the Ethics Committee of the University of Hertfordshire, United Kingdom (Chapter 3) and by the Ethics Committee of the University of Minho, Portugal (Chapters 4 and 5). In addition, in the work developed in the United Kingdom, the researcher applied for an Enhanced Disclosure, and an Enhanced Criminal Record Certificate was issued by the Criminal Record Bureau. In Portugal, the procedures

were approved by the Portuguese National Committee for Data Protection.
The following issues were ensure to meet all the ethical concerns:

- **Protocols:** The schools and clinics which participated in the studies established a protocol with the University where the research was developed. Prior to the experiments, a meeting took place in each school and clinic to clarify any questions from the professionals who interact daily with the children. The professionals were also asked to fill in a questionnaire to characterize the children's profile (e.g. name, date of birth, diagnosis, characteristics of the child, among others);
- **Parents' consent:** The children's parents/tutors signed an informed consent in which they allowed the participation of their children in the research. This consent was accompanied by a document clarifying the objectives, risks and benefits of the research, as well as the full freedom to accept participating in the study and withdraw their child at any time;
- **Privacy:** As demanded by the Ethics Committee of the University of Hertfordshire and by the Portuguese National Committee for Data Protection, the personal data of the participants in the research is enclosed and all the private information collected during the investigation is confidential and dealt according to the rules on data protection and private life. Anonymity is guaranteed at any time of the research project, since only the researcher and the professionals who follow the children on a daily basis have knowledge of this data. The videos are only made public on science communication events, such as scientific conferences and with prior authorisation from the parent or guardian of the children.

## 1.3 Contribution to Knowledge

This thesis provides evidence supporting the beneficial use of robots in the intervention with children with ASD. A tool which manages to attract the children's attention gives an excellent opportunity to develop social skills that are deeply impaired in children with ASD. Promoting social interaction skills in this target group is challenging but the research presented in this thesis indicates that this tool may facilitate the learning process.
The main contributions of this thesis are:

- A new methodological approach in robot-assisted play targeting children with ASD aiming to promote social interaction with an adult and focusing on the introduction of a new object in an intervention session. This methodology is based on four phases (familiarisation, pre-test, practice, and post-test) and triadic interactions where the robot is the object of joint attention;
- A list of well-defined observational codes for video analysis with the objective of studying tactile interaction, verbal and non-verbal communication, eye gazing behaviours, and the performance of the children in game scenarios in individual context;
- The structured game scenarios aiming at the promotion and learning of tactile interaction and emotion recognition skills. These scenarios followed a rigorous experimental procedure, are fully documented and hence stand for a first step in the design of reliable behavioural tools for the development of potential future robot interventions;
- An original study with 45 children with ASD compared the use of a robotic tool to traditional intervention aiming to promote emotion recognition skills;
- An extended database of videos with child-robot interaction coded regarding the following social behaviours: eye gaze, tactile interaction, and verbal and non-verbal communication;
- The children's performance provide strong evidence of the robot being a valuable tool to encourage the acquisition of emotion recognition skills by children with ASD. This knowledge was attained at three different levels either by identifying and labelling facial expressions and the corresponding gestures, imitating facial expressions and inferring the affective state of another person;
- A game scenario focusing on imitation of emotional facial expressions provided strong proof of the engagement of the children in the interaction, validated by their non-verbal behaviours;
- Strong indication that the identification of the affective state of a character in social stories by children with ASD was facilitated by a expressive humanoid robot.

## 1.4 Publications resulting from this research

The research presented in this thesis was disseminated in the following publications:

**Journal Articles:**

- Costa, S., Lehmann, H., Dautenhahn, K., Robins, B., & Soares, F. (2014). Using a Humanoid Robot to Elicit Body Awareness and Appropriate Physical Interaction in Children with Autism. International Journal of Social Robotics, 1-14, DOI: 10.1007/s12369-014-0250-2.

**Conference Papers:**

- Costa, S., Soares, F., Pereira, A., & Moreira, F. (2012). Constraints in the design of activities focusing on emotion recognition for children with ASD using robotic tools. Paper presented at the Proceedings of the 4th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob), (pp. 1884-1889), Rome, Italy;
- Costa, S., Lehmann, H., Robins, B., Dautenhahn, K., & Soares, F. (2013). "Where is your nose?": developing body awareness skills among children with autism using a humanoid robot. Paper presented at the Proceedings of the ACHI 2013, The Sixth International Conference on Advances in Computer-Human Interactions, Nice, France;
- Costa, S., Soares, F., Pereira, A., Santos, C. (2013). Facial Expressions and Gestures to Convey Emotions with a Humanoid Robot. Paper presented at the Proceedings of the ICSR 2013, International Conference on Social Robotics (pp. 542-551). Springer International Publishing, Bristol, United Kingdom;
- Costa, S., Soares, F., Pereira, A., Santos, C. & Hiolle, A. (2014) Building a Game Scenario to Encourage Children with Autism to Recognize and Label Emotions using a Humanoid Robot. Paper presented at the Proceedings of the Ro-man 2014, 23rd IEEE International Symposium on robot and human interactive communication, Edinburgh, Scotland;
- Costa, S., Soares, F., Pereira, A., Santos, C. & Hiolle, A. (2014) A Pilot Study using Imitation and Storytelling Scenarios as Activities for Labelling Emotions

by Children with Autism using a Humanoid Robot. Paper presented at the Proceedings of the IEEE ICDL-EPIROB 2014, The Fourth Joint IEEE International Conference on Development and Learning and on Epigenetic Robotics, Rome, Genoa.

## 1.5 Overview of Thesis Content

The thesis is organized as follows:

- **Chapter 2** provides background knowledge in the areas of emotional processes, autism spectrum disorders, and the use of social robots with children with ASD. This chapter starts with an overview of theories of emotional processing in human beings. Consequently, the problematic related to ASD is highlighted, focusing on the difficulty in social interaction, imitation, and emotion recognition. A brief overview regarding the TEACCH (Treatment and Education of Autistic and Related Communication Handicapped Children) methodology for intervention with children with ASD is presented. The last section concerns studies using robots to interact with children with ASD discussing their application to promote social and tactile interaction, and emotion recognition. The information from this chapter was used as basis for the research implemented in the remaining chapters. A gap was found since very few projects focus on promoting emotion recognition skills in children in ASD;
- **Chapter 3** presents a study where the robot was used to encourage learning appropriate physical social engagement, promoting interactions between a child with ASD and another person, and verifying if the robot facilitates the ability to acquire knowledge about human body parts. Quantitative and qualitative results of the evaluation of the observational data are discussed and they indicate that children who initially were not able to identify some of the body parts showed an improvement of their knowledge. Additionally, the children touched the robot mostly in a gentle way;
- **Chapter 4** focuses on the process of building game scenarios to be used with children with ASD, targeting the promotion of emotion recognition skills. The chapter starts with the results from a questionnaire and two focus groups with professionals who interact daily with children with ASD. With this information,

three different game scenarios were designed and tested in two exploratory studies, indicating that these game scenarios were suitable to be used with children with ASD. Additionally, the hardware is described and the methods common to the game scenarios are presented, such as the ethical concerns, the robot, the room setup, the evaluation tools, the robot's input, and the software architecture.

- **Chapter 5** presents two child-robot interaction studies aiming to investigate the use of robots for socio-emotional skills development in children with ASD. This chapter examines the use of a humanoid robot as a tool to mediate triadic interactions and to teach recognition and labelling of emotions. The first study focus on verbal and non-verbal communication as measures to evaluate the social interaction. The results showed that children interacting with the robot displayed more non-verbal behaviours indicating social engagement than children interacting only with the adult. The second study analyses the children's joint attention behaviours through their eye gaze, and the children's performance in the game scenarios designed in the previous chapter. The results revealed that the children showed significantly more gaze directed towards the robot and increasing joint attention over sessions. In addition, the children interacting with the robot and the experimenter performed in general better than the children who only interacted with the experimenter;

- **Chapter 6** draws conclusions of the work described in this thesis and provides some outlook for the future use of robots in intervention of children with ASD. The research presented in this thesis highlights the potentialities of the use of humanoid robots to elicit the acquisition of socio-emotional skills contributing to areas such as robot-assisted play, developmental psychology, assistive technology, and ASD research.

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# Chapter 2

# Literature Review

To frame the research questions and goals presented in section 1.2.1, this chapter starts by presenting the existing theories on emotional processes in humans (section 2.1). Then, the Autism Spectrum Disorders (ASD) are presented in section 2.2, dedicating special attention to the difficulties in social interaction (section 2.2.1), in imitation (section 2.2.2), and in understanding the child's own emotions and emotions in others (section 2.2.3). In section 2.2.4 the TEACCH methodology for intervention in children with ASD is presented since this method is used with the children who participated in this thesis' studies.

Research projects involving social robots and individuals with ASD are presented in section 2.3.1. The remaining sections present specific literature which supports the research presented in Chapter 3 (section 2.3.2 - studies focusing on tactile interaction) and Chapter 4 and 5 (section 2.3.3 - projects using robots displaying emotional facial expressions).

## 2.1 Emotional Processes

According to Frijda (1986), "(1) an emotion is usually caused by a person consciously or unconsciously evaluating an event as relevant to a concern (a goal) that is important; the emotion is felt as positive when a concern is advanced and negative when a concern is impeded. (2) The core of an emotion is readiness to act and the prompting of plans; an emotion gives priority for one or a few kinds of actions to which it gives a sense of urgency - so it can interrupt, or compete with, alternative mental processes or actions. Different types of readiness create different outline relationships with others.

(3) An emotion is usually experienced as a distinctive type of mental state, sometimes accompanied or followed by bodily changes, expressions, actions".

Charles Darwin proposed that emotions evolved because they had an adaptive worth, for instance, fear evolved to help humans and animals to survive (Darwin, 1998). Darwin's intention was to show how expressions of emotions in humans were analogous to those in animals, supporting his hypothesis of the existence of a common ancestor for man and animals. Darwin considered that emotional facial expressions are innate and allow the quick judgement of someone's hostility or friendliness, communicating intentions to others (Darwin, 1998).

In the 19$^{th}$ century, William James and Carl Lange claimed a hypothesis about the nature of emotions and feelings (James, 1884; Lange, 1887). They pointed out the existence of a basic mechanism in which certain stimuli in the environment excites a specific reaction pattern of the body, through an inflexible and predetermined mechanism at birth.

In 1927, Walter Cannon claimed that the James-Lange theory had many flaws, since in his experiments, he discovered that in specific animals, such as cats, emotion still occurs even if the brain was cut off from the information about bodily responses, such as heart rate or blood pressure (Cannon, 1987). In addition, he argued that the same bodily responses accompany many different emotions, as when fast heart beats may indicate anger or excitement. Bard (1928) agreed with this hypothesis and through his research, he concluded that the experience of an emotion does not depend on the input from the body and how it is responding. Both the experience of the emotion and the bodily response occur at the same time independently of each other.

The Schachter-Singer theory proposed that experiencing an emotion needs both bodily response and its interpretation, considering the particular situation the person is in at the moment (Schachter & Singer, 1962). If someone is trying to escape a fierce animal and his/her heart rate is accelerated, it can be interpret as fear. If someone has an accelerated heart rate while looking at a loved person, it might be understood as excitement. The same bodily response may indicate different emotions depending on the type of situation.

The Opponent-Process theory suggested that experiencing an emotion, with its inherited valence (pleasant or unpleasant), is followed by a secondary opponent process (Solomon & Corbit, 1974). This motivational theory, based on opponent processes, says that when one emotion is experienced, it suppresses the opposite emotion, to balance out the two. For example, a high level of fear is felt before bungee jumping. After jumping, a high level of relief is felt, the opposite emotion of fear.

Ekman (1971) instructed typically developed individuals on how to move their facial muscles, to compose specific emotional expressions on their faces. The individuals were not informed of which specific emotion these muscle movement should correspond to. The result was that individuals experienced a feeling corresponding to the expression. For example, a happy facial expression made that individuals felt "happiness" or displaying an angry facial expression they felt "angry". They only detected fragmentary and inaccurate facial expressions, and as they were not evaluating any real situation that could trigger an emotion, their bodies could not have, at the outset, the visceral profile that accompanies a real emotion. Ekman's experiment suggested that either a fragment of the characteristic body pattern of an emotional state is sufficient to produce a feeling of the same signal or that the fragment subsequently triggers the rest of the body state leading to the feeling.

Damasio (2008) stated that in many circumstances of a humans' life as social beings, emotions are triggered only after a mental evaluation process that is voluntary and not automatic. Depending on each personal experience, a broad spectrum of stimuli and situations were innately selected to cause emotions and reactions, being filtered through a process of careful evaluation. This reflective and evaluator filter introduces the possibility of variations in the intensity and ratio of the predetermined emotional patterns and produces a modulation of the basic system of emotions claimed by James (1984).

Damasio hypothesizes that humans are programmed to react with an emotion in a pre-organized manner when certain characteristics of the stimuli, in the world or in human's bodies are detected individually or together (Damasio, 2008). Following the fear example, instances of these features are the size (large animals); large scale (eagle in flight); movement type (such as by reptiles); certain sounds (like roars); certain configurations of the body's state (pain felt during a heart attack). These characteristics, individually or together, would be detected and then processed by a component of the limbic system of the brain, triggering the activation of a body's state, characteristic of the emotion of fear and amending the cognitive processing in order to reach this state of fear. However, the mechanism of primary emotions does not describe the full range of emotional behaviours (Damasio, 2008). Damasio defines emotion as the combination of a simple or complex mental evaluative process, with predictable responses to it. This process results in an emotional state of the body enabling additional mental changes. If an emotion is a set of changes in the body state associated to certain mental images, the essence of feeling an emotion is the experience of such changes together with the mental images that initiated the cycle (Damasio, 2008).

As can be deducted from the past and current theories presented above a consensus on a global definition or interpretation of emotional processes has not yet been reached. However, most research agrees that emotions cause specific responses such as facial expressions and specific gestures. Emotions are described in psychology and philosophy as a subjective and conscious experience characterized by psycho-physiological expressions, biological reactions, and mental states.

## 2.2 Autism Spectrum Disorders

Autism was firstly defined by Kanner in 1943 as "autistic disturbance of affective contact" (Kanner, 1943). The characteristics identified by Kanner included the incapacity of relating to others, lack in the use of language, and obsessive desire of maintaining everything the same way. These individuals were also regarded as showing anxiety for having inappropriate fears and over excitement with objects or topics of interest (Ozonoff *et al.*, 2008).

In 1979, Loma Wing and Judith Gould defined the "autism spectrum". In a study with 35.000 children, Wing and Gould conclude that a large group of children had difficulties in social interaction, associated to impairments in communication and lack of interest in activities (Wing & Gould, 1979).

Until 2013, the diagnosis criteria for Autism Spectrum Disorders (ASD) were defined in the DSM-IV (Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition) by a severe and global deficit in three development areas: social interaction, communication and behaviour (Association, 2000). However, according to the current criteria in the DSM-5 (Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition), ASD are characterized by repetitive patterns of behaviour, restricted activities or interests, and impairments in social communication (Association, 2013). ASD include now the Asperger disorder, the childhood disintegrative disorder, and the pervasive developmental disorder not otherwise specified (PDD-NOS). The essential characteristics of ASD are the presence of markedly abnormal or deficient development of social communication and a repertoire patently restricted of activities and interests. The manifestations of these characteristics vary in function of the development level and of the age of the individual (Filipe, 2012).

Children with ASD show difficulty in generalisation, which is the ability to transfer the application of a certain knowledge to a different context different from the one it occurred (Myles *et al.*, 2007). This limitation makes it difficult for the children with

ASD to, for example, associate different images and different objects which designate the same concept (Lima, 2012).
There are two terms that are applied to individuals with ASD: low functioning ASD and high functioning ASD. High functioning refers to individuals with ASD who are assumed to be cognitively "higher functioning" and with an intelligence quotient higher than 70. However, these individuals still exhibit deficits in communication, emotion recognition and expression, and social interaction (Sanders, 2009).
According to the American Academy of Paediatrics, in 2007, the prevalence of ASD in Europe and in the United States pointed to 6:1000, with a great prevalence in males, with a variation between 2:1 to 6.5:1. This difference was even higher in Asperger Syndrome and in high functioning autism, where the prevalence vary between 6:1 and 15:1 (Johnson *et al.*, 2007).

### 2.2.1 Social Interaction Deficit

The qualitative deficit in social interaction for children with ASD might be characterized by a marked shortfall when using multiple non-verbal behaviours, such as eye contact, facial expressions, body postures and gestures to regulate social interaction; inability to develop appropriate relationships with peers to their level of development; the absence of the spontaneous tendency to share pleasures, interests or objectives with others; and the lack of social or emotional reciprocity (Association, 2013).
The deficit in the reciprocate interaction is marked and persistent. One important factor that can be an early sign of the deficit is joint attention, the capability children have to share attention with others about an object or an event, gazing alternatively at the object and at the peer (Johnson *et al.*, 2007). This ability appears in the first months of life and starts with the skill the child has to smile in response to a smile or verbalisation. With 8 months, children are able to follow their parent's eye gaze and follow in the same direction when they gaze at an object or person. At 10 to 12 months, the child will already be able to gaze in the same direction parents are pointing to (towards an object of interest, for instance) when they verbalise "look". The child is also able to look back at the parents to confirm that they saw the same object of interest. After 12 months, children start being able to point at an object they want. However, mainly at this age, children point but mainly to share an object/event of interest with their parents. In fact, children do not want the object, but the social sharing (Johnson *et al.*, 2007).
Children with ASD find it very difficult to establish joint attention: they do not smile in

response to their parents' smile, nor look in the same direction. They have problems following the parents' eye gaze, pointing or looking for social sharing. Given these difficulties, the strategy these children use is usually to take the adult by the hand to the intended place or object. Most of the times, children with ASD get closer to the object, and there they do not make any request, or look at the intended object, making it hard for the adult to understand what the child really wants (Siegel, 2008). The difficulty in interpreting social situations in a global way, holding up to details, makes that children with ASD lose or miss information on what is happening or happened during the social exchange. It makes the interaction with the other harder, because they do not get "the big picture" (Happé *et al.*, 2001).

Another limitation of children with ASD is related to the difficulty in understanding the perspective of others, i.e., the Theory of Mind (ToM) (Baron-Cohen *et al.*, 1985), which refers to the capacity of understanding that one can have thoughts and feelings independent of others. This skill allows the inference of the mental states on the basis of the external behaviour shown by the other. For this reason, children with ASD have difficulty in sharing, and in showing empathy.

The ToM was presented by Baron-Cohen *et al.* (1985), and according to this theory, children with ASD are not able to understand the beliefs, feelings, and intentions of others and therefore are unable to reliably predict behaviours. This skill was examined by Baron-Cohen *et al.* (1985) using the Sally-Anne test: Sally takes a marble and hides it in her basket. She then "leaves" the room and goes for a walk. While she is away, Anne takes the marble out of Sally's basket and puts it in her own box. Sally is then reintroduced and the child is asked the key question, the Belief Question: "Where will Sally look for her marble?". The correct answer to the Belief Question is that Sally believes that the marble is in her own basket. These authors compared a group of children with ASD with a group of children with Down Syndrome and one group of typically developing children. The study consisted in the application of the false beliefs paradigm, which involves the recognition that others can have beliefs about the world. The results showed that 80% of children with ASD could not perform the task. This theory could explain some of the social deficits, due to the difficulty to predict the others' behaviours and it could equally explain the difficulties in the social use of language (Baron-Cohen, 1989).

Sansosti *et al.* (2004) presents a review of social story interventions for children with ASD. According to Gray & Garand (1993): "a social story describes a situation, skill, or concept in terms of relevant social cues, perspectives, and common responses in a specifically defined style and format". The use of social stories as tools to decrease inappropriate behaviours are already validated in research (Scattone *et al.*, 2006). One study with the goal of investigating the effectiveness of social stories when used as a sole intervention, used a multiple baseline design across participants to increase the appropriate social interactions of three children with ASD. Appropriate social interactions (e.g., greeting behaviours, joining in, and sharing) were verified in two of the participants (Sansosti & Powell-Smith, 2008). In another study, a special education teacher used social stories to teach several skills to two children with ASD, such as choosing activities and playing appropriately with peers. The authors found supporting evidence for the use of social stories to teach choice-making and play skills to children with ASD (Barry & Burlew, 2004).

### 2.2.2 Imitation Impairment

Motor empathy refers to involuntarily mirroring of other's facial expressions, suggesting the stimulation of shared representations of perception and emotional sharing. Emotional empathy concerns the experience of emotions consistent with and in response to those of others. Cognitive empathy is the capacity to logically comprehend the emotional state of others, inferring for example someone is going to feel sad when receiving bad news (Blair, 2005).

Piaget noted that children begin to imitate observed actions in a period which lasted up to the first two years of life. He called this the sensory-motor stage (Piaget, 1976). Learning by imitation is fundamental to the development of cognitive and social communication behaviours, such as language, play, and joint attention. Imitation is a tool that serves two goals: learning and social function. New capabilities and knowledge are acquired, and communication skills are improved by interacting in social and emotional exchanges. However, children with ASD show deficits in imitation which are associated to impairments in the social communication skills mentioned above (Ingersoll, 2008). The difficulties experienced by children with ASD to interact socially can be explained by a deficit in specific mental modules dedicated to social cognition. This deficit also influences the high-level cognitive skill of attributing mental states in order to predict behavioural outcomes. The functional properties of mirror neurons and their responsibility in action and emotion understanding seem to define a precise mechanism which is important in primary social interaction and is impaired in ASD (Sinigaglia & Sparaci, 2008). Compared to typically developing children and children with developmental delay, children with ASD exhibit specific deficits in vocal and gestural imitation, imitation of functional and arbitrary actions with play materials or imitation tasks involving one

real object and one imaginary object (Ingersoll, 2008).
Regarding motor emotional responses, some studies have focused on motor mimicry and imitation. A detailed review by Rogers & Pennington (1991) underlines a deficit in imitative skills and behaviours in individuals with ASD. Williams *et al.* (2001) linked ASD and an impairment in imitation skills to a malfunction of the mirror neuron system. Children with ASD show a lack of interpersonal coordination of affect (Kasari *et al.*, 1990), lack of emotional expressiveness when requested to imitate affective facial expressions on instruction (Langdell, 1978), and difficulties in emotional understanding of faces (Ozonoff *et al.*, 1991).

### 2.2.3 Emotion Recognition Difficulty

The impairments in social communication in children with ASD are mostly observed in their difficulty to respond to social stimuli, to imitate behaviours, to recognize and understand mental states in themselves and in others (Clark *et al.*, 2008; Zwaigenbaum *et al.*, 2005). These differences clearly influence the adaptation of children with ASD to their natural contexts with implications for their cognitive, linguistic and emotional skills (Charman & Stone, 2006).
Children with ASD usually find it difficult to identify facial expressions and the emotions conveyed by them, to imitate or use emotional expressions, to understand and control their own emotions, and to interpret emotions or empathy with others. In a study that examined the extraction of valence from emotional expressions, images of micro expressions were presented to adults with ASD. Comparing with the control group, individuals with ASD performed worse on emotion extraction. The authors stated that the difficulty in fast emotional processing may increase problems in mimicry and empathic responses (Clark *et al.*, 2008).
In another study, three groups of ten individuals each, matched for verbal mental age and composed of children with ASD in the first, children with Down syndrome in the second, and typically developing children in the third, were tested on a delayed-matching task and on a sorting-by-preference task. In the first task, the participants had to match faces expressing an emotion which was presented briefly (750 msec). The second task involved rating the valence of an isolated stimulus, such as facial expression of an emotion or an emotional situation in which no persons were represented. Results showed a considerably worse performance from individuals with ASD than from both typically developing and Down participants groups on both tasks, shown by the mean scores of the participants (Celani *et al.*, 1999).

Another crucial aspect is the examination of the roles of the verbal and non-verbal sources of information in the ability of participants to recognize emotions (Loveland *et al.*, 1997). A study with children with low- and high-functioning ASD and typically developing children, matched by verbal and non-verbal mental age, was compared in a emotion recognition task. All participants watched video clips from which they had to identify the emotions expressed, verbally, non-verbally, or both. The presented emotions were either happy, angry, sad, surprised, or neutral, and verbal expressions of emotion were either explicit, implicit, or neutral, whereas non-verbal expressions were animated (clearly conveyed happiness, sadness, anger, or surprise) or flat (neutral face and voice). Results showed differences between higher and lower functioning groups. The performance of low-functioning participants implied they had problems understanding how a person in the video clips felt based on what the person said, if the emotion was not clearly stated. The performance of high-functioning participants suggested that they used more non-verbal than verbal information to determine a speaker's emotion, except when the emotion was explicitly named (Loveland *et al.*, 1997).

Results from Hobson (1986) showed that children with ASD were significantly impaired in choosing which of the drawings of gestures should match videotaped vocalisations and facial expressions characteristic of four emotional states, when compared to typically developing children but with learning disabilities.

The studies presented in this section summarize the research performed with individuals with ASD regarding facial emotion recognition, and they emphasize the common difficulty of this population to identify emotions. Children with ASD presented difficulties when examining the valence from emotional expressions and situations, so in this kind of tasks emotional information should be strong and marked so they can perceive them as such (Baron-Cohen, 1991).

### 2.2.4 Intervention for children with ASD

The development of children with ASD differs greatly from typically developing children and they need timely intervention that responds to all their impaired areas of development. The first goal of any intervention is to minimize the existing deficits, maximize the children's stronger skills, promoting their autonomy and quality of life (Myers *et al.*, 2007). Intervention takes action using a treatment to try to improve a particular condition or problem. In this sense, along the years several intervention methodologies have been developed. The TEACCH methodology is going to be highlighted here, since it is the methodology applied with the children participating in the research presented in this thesis. This methodology supports its intervention in:

- physical structure: organisation of the physical spaces with signalling and well defined limitations, decreasing distracting factors;
- creation of an one-on-one workspace and autonomous work inside the classroom;
- implementation of the individual work schedule with the different moments of the day;
- implementation of transition cards as a communication medium and promoter of the child's autonomy;
- definition of daily routines to promote the child's adequate behaviour through a stable and safe environment;
- introduction of small changes to break routines and to promote the capability of the child's adaptation to new situations;
- visual support to promote communication between the child and others using augmentative communication systems, such as, PECS (Picture Exchange Communication System) or communication tables (Lima, 2012; Mesibov & Howley, 2003).

Most children with ASD have alterations in the central auditory processing, which means they have difficulty processing auditory information. Because of that, they have difficulty in verbal discrimination, reacting in a hyper- or hypo-sensitive way to sounds. Vision is one of the strongest skills of children with ASD (Lima, 2012) and for this reason using a visual support is fundamental to help children with ASD to understand requests and tasks. The advantages in the use of a visual support are: to communicate to the child what is going to happen throughout the day, giving them a notion of time; to promote autonomous activities; to teach rules and alternative behaviours; to promote communication/language; to enable choices and turn-taking or to allow learning to be patient (Lima, 2012).

## 2.3 Social Robotics and ASD

Professionals working with children with emotional, cognitive and physical impairments use different props to support intervention processes. More recently, the use of robotic toys has been explored to facilitate intervention processes of children with ASD, with the robot acting as a mediator between the child and the therapist (Cabibihan *et al.*, 2013; Lee *et al.*, 2012, 2006).
The research presented in the following sections has found that interacting with robots draws these children into a range of new social behaviours. Reviews about this topic can be found in Boucenna *et al.* (2014); Diehl *et al.* (2012); Giullian *et al.* (2010); Ricks & Colton (2010) and Scassellati *et al.* (2012).

### 2.3.1 Robots as social mediators

This section presents five projects which have been reporting consistent research regarding the use of robots to interact with children with ASD in the past decade. For this reason, the methodology employed by these projects is not going to be highlighted in particular. Table 2.1 reports a summary of other studies also considered important for this literature review, and they will be used as comparison to evaluate the research presented in this thesis.
The **AuRoRA project** (AUtonomous RObotic platform as a Remedial tool for children with Autism) studied the potential role of mobile robots as therapy tools for children with ASD (Dautenhahn & Werry, 2004; Werry & Dautenhahn, 1999; Werry *et al.*, 2001).
The authors investigated how mobile robots could be used to encourage social behaviours such as eye contact, joint attention, and imitation, which are fundamental in human social cognition and development. Their long-term goal was the design of robots to be used with children with ASD by teachers and carers in schools or by parents at home. In this project, the children interacting with the robot were free to choose how they wanted to interact. Interference was reduced to minimum (only if the child was about to damage the robot or if the child switched off the robot).
In a series of trials, the mobile robot **LABO-1** (Fig. 2.1) showed a few basic approach and avoidance behaviours. Results indicated that the children usually demonstrated more attention to the robot in terms of gaze, and touch, and they were more engaged in interactions than with another non-robotic toy.

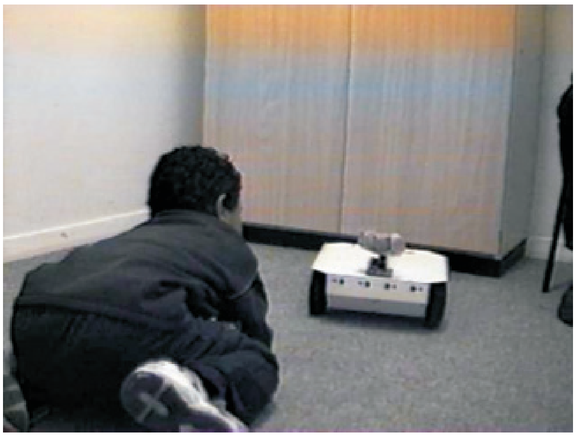


FIGURE 2.1: The mobile robot LABO-1 used basic approach and avoidance movements (Dautenhahn & Werry, 2004).

The authors concluded that the robot was safe for the children to use and they showed great flexibility in coping with new contexts. Children were motivated to interact with the robot over a period of five to ten minutes or longer and they were more interested in the robot in reacting mode comparing to the robot showing rigid, repetitive, non-interactive behaviour. However, the main limitation of the non-humanoid robot used in this project lied in the 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** (Fig. 2.2), also part of the AuRoRA Project, complemented this project offering new interactions such as mimicking movements of body parts, such as hands and head, as well as more complex interactions with sequences and combinations of actions. Robota is a doll-shaped robot which uses a motion tracking system to copy upwards movements of the left and right arm of the user (Billard, 1999, 2002a,b). In Billard *et al.* (2007), the authors presented a number of constraints on the design of the robot's mechanics and electronics, such as the setup, the robot's appearance and behaviours. Unconstrained scenarios were planned, providing additional freedom for the children to interact with the robot, facilitating spontaneous interactions. Thus, the robot needed to respond with very high precision to movements of the children, having therefore Robota been controlled via Wizard-of-Oz.

The authors aimed to study if and how simple imitation and turn taking games using humanoid robots could promote these social interaction skills in children with ASD, and how the robot could encourage social interaction with peers (typically developing children or children with ASD), assuming the role of a mediator and an object of shared attention (Billard *et al.*, 2007).

FIGURE 2.2: Robota moved its arms and head in imitation and turn-taking games (Dautenhahn & Billard, 2002)

Results from this study showed that the level of interaction with Robota in terms of eye gaze, touch and imitation increased over time (Robins *et al.*, 2004a). The results also showed that Robota elicited imitative behaviour in children with ASD. The analysis of the video data revealed aspects of social interaction skills, such as turn-taking and role-reversal. Additionally, there were occurrences where the children interacted with the robot and the investigator, using the robot as a mediator sharing joint attention with an adult (Robins *et al.*, 2004b).

The authors support the view of adopting non-invasive interfaces for interacting with the robot, suggesting that the robot's appearance plays an important role in engaging the child's "responsiveness". These studies also showed that restricting the set of behaviours of the robot to one particular behaviour would be preferable when testing with children with ASD. This restriction allowed the experimenters to better quantify the reactions of the children, especially because these children displayed varied and very individualized reactions towards the robot.

The robot **KASPAR** (Fig. 2.3) has been used in several studies with children with ASD (Robins *et al.*, 2005, 2008, 2009; Wainer *et al.*, 2010), and it has also been employed in other studies with typically developing children (Kose-Bagci *et al.*, 2009, 2010; Wood *et al.*, 2013). KASPAR is a child-sized, humanoid robot with a minimally expressive face and arms able to produce gestures.

KASPAR was designed to provide predictable and reliable interactions and to be an appropriate tool to be used by children with ASD in education and therapy. In addition, the authors intended that this robot could adapt to different degrees of the spectrum, providing a multi-modal embodied interaction depending on the child and with a variable complexity depending for example on the child's tactile interaction.

In studies with children with ASD, the authors found out that the gaze switches between a dyadic collaborative game and the other player were significantly higher when playing with KASPAR. The children were more entertained, seemed more invested in the game, and collaborated better with their partners (Wainer *et al.*, 2010).

FIGURE 2.3: KASPAR with its drum which was used in turn-taking games (Robins *et al.*, 2009)

In conclusion, the researchers showed that the use of KASPAR, not only could demonstrate important competencies of social interaction, but also showed a level of direct, physical engagement. It was also verified that children appeared to generalize this behaviour at least to the experimenter.

**Keepon** was designed to conduct non-verbal interaction with children, studying and testing psychological models of the development of social intelligence (Fig. 2.4). The authors' goals were to confirm the effectiveness of Keepon's minimal design on attentive and emotive exchange by children with ASD, and to study how the nature of these interactions changed across age, experience with the robot, and group dynamics (Kozima *et al.*, 2009). In longitudinal observations, the authors placed Keepon in a playroom at a day-care centre, children with ASD and typically developing children, their parents, and professionals interacted with each other, in an unconstrained setting or in organized group.

The experiments were conducted with Keepon interacting with children in a natural context, i.e, their playroom. The results intended to inform about robot design, cognitive theory, psychological experimental design and intervention, and pedagogical practice. As the robot alternated between making eye contact and looking at an object, it would move its body, reacting whenever the child made any significant social interaction.

FIGURE 2.4: Keepon, a spongy snowman-shaped robot focusing on non-verbal communication (Kozima *et al.*, 2009)

From longitudinal observations, the authors found that Keepon's simple appearance and predictable responses provided a spontaneous and engaging dyadic interaction. Children were able to expand the interaction into interpersonal communication where Keepon was a mediator of triadic interactions with adults and peers. Their major claims were that simple robots with minimal expressiveness can smooth natural exchanges of mental states in children with ASD.

The **IROMEC** project (Interactive Robotic Social Mediators as Companions) aimed to recognize the role of play in child's development and targeted children who are inhibited in playing (Fig. 2.5).

FIGURE 2.5: The IROMEC robot in the horizontal configuration, with a screen on top of the main body dedicated to the game and a front screen providing emotional feedback (Ferrari *et al.*, 2009)

IROMEC's educational and intervention goals focused on reducing children's limitations by taking advantage of their strengths. Regarding the child's motivation to interact, sensory development included different elements such as visual and tactile perception, spatial awareness, and proprioception (Ferrari *et al.*, 2009; Lehmann *et al.*, 2011).

In collaboration with experts, ten scenarios were created reflecting and utilising the functionalities implemented in the IROMEC robot and its various modules. For each scenario, a set of intervention and educational objectives were designed, working in an iterative process with both therapists and teachers. The IROMEC robot worked autonomously once a play scenario was selected, taking into account the children's play needs with a variety of special needs, such as cognitive, physical or/and development impairments.

This project enabled children to exercise some degree of control over their own environments and experiences. The robot changed its behaviour, helping the children exploring and reaching increasingly complex objectives needed for social interaction dynamics. In the social-emotional domain, strictly related to the previous areas, the authors wanted to use play to help the acquisition of capabilities for human relationships, emotional expression, and engagement. It was based on the motivation to engage in positive interactions and sustain interpersonal relationships.

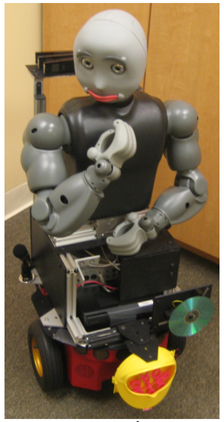
The researchers conclude saying that IROMEC as a programmable system, could provide several stimuli, such as movement or sound, since the responses of the robot could be modified according to the child's interaction. The robot was used as an object of shared attention that can encourage interaction with peers and adults. Moreover, IROMEC increased the complexity of the interaction promoting different learning skills (Ferrari *et al.*, 2009).

The summary of the research described above represents the projects that had been presenting relevant studies, results and encouraging conclusions in the past few years regarding the topic of social robotics for intervention with children with ASD. However, other projects have also been tackling this subject. Table 2.1 summarizes other relevant studies based on the type of the robot used, its capabilities, goals, participants' characterisation, experimental design, and main results. It is possible that some authors of the same project developed other studies on this topic, but only one is presented in the table, based on the reference in the first column.

Table 2.1: Summary of further research using robots to interact with children with ASD.

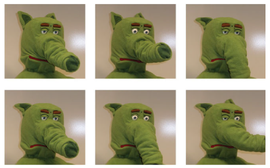
| Robot | Capabilities | Goals | Particip. | Exp. Design | Main Results |
|---|---|---|---|---|---|
|  Auti (Andreae *et al.*, 2014) | furry mobile animal-like robot with sound and motion sensors. | to encourage children with ASD to interact physically and verbally. | 18 children with ASD aged 4 to 8 years old. | 1 session: 2.5 to 3 hours, assessment of the children over a structured play session with a comparison in the interaction between a fully-interactive Auti and an active-only version. | the robot with the interactive behaviour encouraged more positive behaviours, such as gentle speaking and touching, than the active-only version. |
|  CHARLIE (Boccanfuso, 2013) | the robot has a head and two arms, each with two degrees of freedom, and a camera for face and hand detection. | to create a financially accessible robot and to develop a hand detector to enable interactive games in which the robot can engage the child autonomously. | 8 children with ASD aged 3 to 6 years old. | 12 sessions: 30 minutes, the child performed different activities focusing on joint attention, imitation and turn-taking. | there were significant improvements in speech and social skills of children when interacting with CHARLIE. Generalisation from the child to the experimenter was observed. |

| Robot | Capabilities | Goals | Particip. | Exp. Design | Main Results |
|---|---|---|---|---|---|
|  NAO (Wikitherapist) (Huskens *et al.*, 2013) | humanoid robot with a full moving body, having an accelerometer, a gyrometer, ultrasonic sensors, and force-sensing resistors. It has 2 high-definition cameras and 4 microphones. | to compare an applied behaviour analysis intervention conducted by a robot and by a human trainer, encouraging self-initiated questions by children with ASD. | 6 children with ASD aged 8 to 12 years old. | 4 sessions: 10 minutes, all children received two interventions: one conducted by the robot and one conducted by the human trainer, counter balancing the two experimental groups. Combined crossover multiple baseline design across participants was used to collect data. | the number of self-initiated questions for both experimental groups increased and the high number of self-initiated questions during follow-up indicates that both groups maintained this skill. |
|  NAO (Anzalone *et al.*, 2014) | | to compare how children with ASD and typically developing children interact with a humanoid robot exploring their 4 dimensions (spatial 3D and time) during a task which elicits joint attention. | 16 children with ASD and 16 typically developing (TD) children, with age mean of 9.3 (SD = 1.9) and 8.1 (SD = 2.5), respectively. | 1 session: variable duration, the robot/therapist pointed to an image of a dog or a cat in opposite sides of a room, either using only a head movement, a head movement combined with a pointing gesture, or a head movement combined with a pointing gesture and speech. | the activity with the therapist revealed the same performance for both groups of children. With the robot both groups had lower joint attention scores, and children with ASD had significantly lower scores than the TD children. |

| Robot | Capabilities | Goals | Particip. | Exp. Design | Main Results |
|---|---|---|---|---|---|
|  Tito (Duquette *et al.*, 2008) | robot with a humanoid appearance using wheels to move, with a simple mouth and a camera device in one of the eyes. | to verify if the robot could be useful to elicit reciprocal communication in children with ASD. | 4 children with ASD aged 5 years old. | 4 sessions: 10 minutes, interaction in a group with the robot or a human as a mediator. The two mediators executed the same imitation plays involving facial expressions, body movements, and other actions (e.g. to point or to wave hello). | imitation of body movements and of familiar actions were higher with the two children paired with the human. The two children paired with the robot demonstrated more frequent shared attention, reduced repetitive play, and more imitation of facial expression of joy (smiling). |
|  Bandit (Feil-Seifer & Mataric, 2011) | upper-torso humanoid robot on a mobile base with two 6 DoF arms, a pan-tilt neck, and an expressive face. | to automatically distinguish between positive and negative reactions from children with ASD to a robot and to use those reactions in real-time changing the robot's behaviour. | 8 children with ASD aged 5 to 10 years old. | 3 sessions: 5 minutes, two with a robot and one with a non-mobile toy, in a free-play scenario to enable social interaction as natural as possible. The children received specific instructions on what to do in the interaction. | the approach achieved a 91.4% accuracy rate in classifying different behaviours and demonstrated that these classes were sufficient for distinguishing between positive and negative reactions. |

| Robot | Capabilities | Goals | Particip. | Exp. Design | Main Results |
|---|---|---|---|---|---|
|  Troy (Goodrich *et al.*, 2012) | humanoid robot with a fixed upper-body. Its head is a computer screen displaying a happy, sad, or neutral face. | to identify the role of a robot in children's therapy. | 2 children with ASD aged 3 and 8 years old. | 16 sessions: 40 minutes without the robot and 10 minutes with the robot, the clinician encouraged turn-taking activities in dyadic and triadic interactions. The clinician, the child, and the robot participated in reciprocal activities, such as waving, pushing toys to each other, and singing songs with actions. | observations showed that children were interested in interacting with the robot. There were behaviours after-treatment that were not observed before, including greeting clinicians by waving and symbolic pretend play with toys. |
|  GIPY-1 (Pradel *et al.*, 2010) | cylindrical mobile robot. The cladding of the robot is a simple face composed by two round eyes, a triangular nose, and an elliptical mouth. | analysis of the robot-child interactions during predictable play. | 4 children with ASD aged 7 to 9 years old. | 1 session: 5 minutes, the intervention is based on free play between a child with ASD, a mobile robot and a therapist. Video sequences were analysed, in order to evaluate quantitatively the robot-child interaction. | the authors proposed a model based in Thom's catastrophe theory to represent the changes in the child behaviour. However, the authors verified that this model, which is based on a particular catastrophe type, cannot be applied to all cases. |

| Robot | Capabilities | Goals | Particip. | Exp. Design | Main Results |
|---|---|---|---|---|---|
|   AIBO ERS-210 (Stanton *et al.*, 2008) | animal-like robot, similar to a dog. AIBO has a plastic appearance and sensors that can detect distance, acceleration, vibration, sound, and pressure. | to investigate if a robotic dog could help the social development of children with ASD. | 11 children with ASD aged 5 to 8 years old. | 1 session: 30 minutes, the children played with AIBO and Kasha (a simple mechanical toy dog with no ability to detect or respond to its physical environment). | results showed that, in comparison to Kasha, the children spoke more words to AIBO, and more often engaged in social behaviour with AIBO. |
|  ISOBOT (Srinivasan & Bhat, 2013) | 7-inch humanoid robot, controlled remotely. | to evaluate the changes in social attention and verbalisation skills using a imitation protocol within a robot-adult-child context. | 2 children with ASD aged 7 and 8 years old. | 8 sessions: 30 minutes, training sessions alternated between karate and dance themes. Sessions were coded for attention patterns and the duration of verbalisation of the children. | the context of robot-child interactions encouraged social attention and spontaneous verbalisation in both children with ASD. |

| Robot | Capabilities | Goals | Particip. | Exp. Design | Main Results |
|---|---|---|---|---|---|
|  LEGO Mindstorms (Costa *et al.*, 2010) | modular and low cost robot using sonar, sound and touch sensors. | to evaluate the reaction of adolescents with ASD to the introduction of a toy-like robot in their daily routine. | 2 adolescents with ASD aged 17 and 19 years old. | 5 sessions: 10 minutes. The sessions involved two tasks: the activation of the robot's movements using the touch or the sound sensors. | results showed that the adolescents behaved differently concerning their interest in manipulating and interacting with the robot. In the last session, they were able to play with each other a collaborative game. |
|  Probo (Vanderborght *et al.*, 2012) | animal-like robot and able of performing basic facial expressions. | to study the role of the social robot Probo in providing assistance to a therapist for robot assisted therapy with children with ASD. | 4 children with ASD aged 4 and 9 years old. | 30 sessions: 20 minutes maximum, the robot tells social stories to teach ASD children how to react in social situations. | results indicated the effectiveness of robot-assisted therapy in enhancing the social interaction, motivation and communication skills of children with ASD. |

### 2.3.2 Robots used for affective touch-based interactions

Touch is fundamental to the development of the physical, emotional, and psycho-social areas. When deprived of human touch early in life, children may suffer from severe consequences such as emotional isolation or lack of trust (Korkman, 2001; Montagu, 1971; Ratey & Hagerman, 2008). Touch can convey affectionate feelings or express pain or discomfort and typically developing children learn early on to understand and to identify different types of physical contact.

Force-sensing resistors (FSR) are low-cost and robust sensors which can measure force or pressure by changing their resistance. The detected contact is used to produce concordant robotic behaviours, which stimulates the interaction between the user and the robot. Robots within the current tactile human-robot interaction literature can have different shapes (Argall & Billard, 2010).

The baby seal Paro (Marti *et al.*, 2005), the teddy bear Huggable (Stiehl *et al.*, 2005), the robotic cat NeCoRo (Libin & Libin, 2004), and the child-sized robot KASPAR (Amirabdollahian *et al.*, 2011) are some examples of different artificial pets and humanoid robots designed to engage persons based upon tactile interactions which might help to promote social relationships. This kind of affective interaction is a growing area of research, especially concerning the target group of individuals with special needs.

Paro (Fig. 2.6) is used in assistive therapy, using sensors incorporated in it (Marti *et al.*, 2005).

FIGURE 2.6: Paro, the baby seal-shaped robot used in elderly homes (Marti *et al.*, 2005)

Human touch is classified and used to adaptively change the robot's behaviour. Tactile data contributes to the determination of Paro's internal state, driving the choice and

implementation of a limited number of hand-coded behaviours, similar to those of a real seal (Wada & Shibata, 2006). The results of the study with elderly residents in a care home, during which the robot was daily available for over nine hours indicated that the interaction with the seal robot increased their social interaction. Furthermore, the physiological tests of the subjects' vital organs when reacting to stress improved after the introduction of the robot in their daily routine (Wada & Shibata, 2007).
Huggable, a robotic teddy bear (Fig. 2.7), is capable of affective touch-based interactions with a human partner. It features a high number of sensors such as electric field, temperature, and force, over the entire surface of the robot, underneath a soft silicone skin and fur fabric covering.

FIGURE 2.7: Huggable, a robotic teddy bear used for affective touch-based interactions (Stiehl *et al.*, 2005)

The robot is able to orient itself towards the human touch through motion in its neck and shoulders, using twelve touch sensors. For example, if two side zones are activated, it can be inferred that the human partner is picking up the bear. The authors affirmed that the combination of temperature, electric field, and force sensors provided a wide classification of detected social affective content of touch (Stiehl *et al.*, 2005).
The robotic cat NeCoRo (Fig. 2.8) is used to analyse human-robot communication, responding to human voice, movements, and touch. Its multiple sensors, together with artificial intelligence technology produce a real-life-looking robotic cat capable of playful and natural communication with humans.

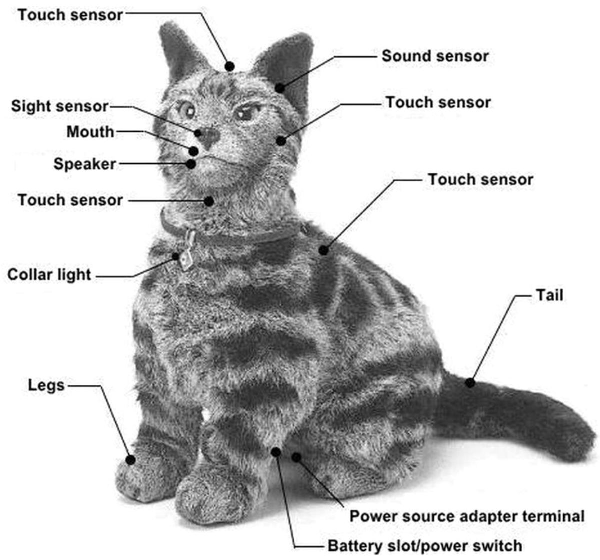



FIGURE 2.8: NeCoRo, the cat-shaped robot used in studies of human-robot communication (Libin & Libin, 2004)

In a study with NeCoRo, results from cross-cultural analyses of human-robot communication revealed a preference by older participants to interact with the robotic cat. It was considered a more desirable companion for them than for the younger participants. This study took into account findings on the robot's use by children, young and older adults, and elderly persons with dementia. Persons with severe levels of cognitive impairment were engaged with the robotic cat for a shorter duration than those with higher levels of cognitive functioning. In addition, the interactions with the robotic pet triggered positive emotions such as pleasure and interest, and the level of agitation decreased during the treatment phase (Libin & Libin, 2004).

KASPAR, already presented in the section 2.3.1, was used in the ROBOSKIN project (Fig. 2.9). A robotic skin was developed to provide tactile feedback and it was added to KASPAR with the goal of improving human-robot interaction capabilities in the application domain of robot-assisted play (Robins *et al.*, 2010). Recent work in this project developed tactile play scenarios (Robins & Dautenhahn, 2010) and included also a taxonomical classification of tactile interactions. The experiments allowed to observe the tactile interaction and record the location and type of these interactions. The results showed significant differences across touch type intensities (Robins *et al.*, 2013).

FIGURE 2.9: The figure on the left shows the 'undressed' version of KASPAR (on the right of the figure), with tactile skin patches (Amirabdollahian *et al.*, 2011)

### 2.3.3 Facial expressions displayed by robots

This section presents projects involving the use of robots to display emotional facial expressions. FACE and Probo were the robots from this list already employed in studies with children with ASD.

The humanoid robot FACE (Mazzei *et al.*, 2011) was built to allow children with ASD to deal with expressive and emotional information. The expressions and movements of FACE were modelled to be harmonized with the feelings of the user. HEFES (Hybrid Engine for Facial Expressions Synthesis) is a system created by the same authors to generate and control facial expressions both on physical androids and 3D avatars (Mazzei *et al.*, 2012). The system used in FACE was tested on a panel of 5 children with ASD and 15 typically developing children interacting with the robot individually under therapist supervision. The evaluated facial expressions were happiness, anger, sadness, disgust, fear, and surprise, defined as the basic emotions by Ekman (Ekman & Rosenberg, 1998). These emotions are going to be referred from now on as basic emotions or basic facial expressions. The participants labelled each expression and this labelling was scored by the therapist as correct or incorrect. Their results showed that both children with ASD and typically developing children were able to label happiness, anger and sadness performed by FACE with good accuracy. However fear, disgust, and surprise had not been labelled correctly, especially by participants with ASD. The results for FACE's recognition rates with children with ASD were the following: anger - 100%, disgust - 20%, fear - 0%, happiness - 100%, sadness - 100%, surprise - 40%, and the average of all emotions was 60%. The results for FACE's recognition rates with typically developing children were anger: 93.3%, disgust: 20%, fear: 46.7%, happiness: 93.3%, sadness 86.7%, surprise: 40%, and the average of all emotions was 61.1%. The authors justify these results claiming that fear, disgust, and surprise are emotions which rely greatly on gestures to convey its expression, and facial expressions on their own were not enough for an efficient recognition.

Probo (Saldien *et al.*, 2010) is an animal-like robot, designed to act as a social interface. The authors used Probo as a platform to study human-robot interaction and it was capable of performing facial expressions. These were represented as a vector in the two-dimensional emotional space, valence and arousal, based on the Russell's circumplex model of affect (Russell, 1980). The recognition of the robot's facial expressions were evaluated by 23 typically developing children, giving an identification rate of 96% for anger, 87% for disgust, 65% for fear, 100% for happiness, 87% for sadness, 70% for surprise, and the average of all emotions of 84%. In their opinion, a better recognition of the robot's facial expressions contributes to the general social acceptance. In addition, the recognition of the facial expressions is important for an effective non-verbal communication between a human and a robot.

Kismet (Breazeal, 2000) was designed with the possibility to process a variety of social cues from visual and auditory channels, and delivered social signals to humans with whom it interacted. Kismet's facial expressions were generated using an interpolation-based technique over a three-dimensional, multicomponent affect space: arousal, valence, and stance (Breazeal, 2004). In this model, valence and arousal were used to construct an emotional space, based as well on the circumplex model of affect defined by Russell (Russell, 1980), which has as well been implemented in the robot EDDIE (Sosnowski *et al.*, 2006). EDDIE similarly to Kismet is a robotic head, and they were evaluated by 8 typically developing children between the ages of 5 to 8 and 16 adults between the ages of 25 to 48. The study consisted of a total of 32 questions. Participants had to choose their best guess for a displayed emotion. The results for Kismet's recognition rates were: anger: 76%, disgust: 71%, fear: 47%, happiness: 82%, sadness 82%, surprise: 82%, and the average of all emotions was 73%. For EDDIE, the recognition rates were: anger: 54%, disgust: 58%, fear: 42%, happiness: 58%, sadness 58%, surprise: 75%, and the average of all emotions was 57%.

The humanoid robot WE-4RII was designed to communicate naturally with a human partner by expressing human-like emotions (Itoh *et al.*, 2004). The authors measured the recognition rate of the emotional expressions performed by the robot, including facial expressions and gestures. Eighteen adult participants watched films of the six basic emotional expressions exhibited by WE-4RII, and chose an emotion corresponding to the expression. The recognition rates were: 100% for anger, 100% for disgust, 66.7% for fear, 94.4% for happiness, 100% for sadness, 100% for surprise, and the average of all emotions was 93.5%.

SAYA (Hashimoto *et al.*, 2011) is a tele-operated android robot, that can display human-like facial expressions. SAYA's face includes actuators distributed on its surface in order to improve the structure of the facial muscle-like movement. The facial expressions were designed based on control points of the face, and the directions of movement of those control points were designed empirically or from the anatomical knowledge of the facial muscle morphology on the facial skin. To evaluate whether the designed facial expressions could be recognized, 20 adults observed videos of SAYA performing each facial expression and chose one of six options corresponding to the basic emotions. The authors found a high recognition rate for all the six basic emotions: anger: 92%, disgust: 92%, fear: 100%, happiness: 100%, sadness 100%, surprise: 100%, and the average of all emotions is 97.3%.

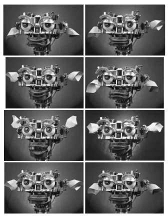
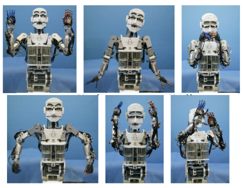
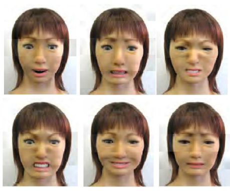
From the projects mentioned above only the facial expressions of the humanoid robot FACE were evaluated by children with ASD. Overall, the average recognition rate of the studies presented in this section is 70% for typically developing children and 80.2% for adults. The evaluation of the expressions performed by Kismet and EDDIE were included in the group of adults since detailed information was not provided by the authors, and the group was mostly composed by adults.

Table 2.2 compares the facial expressions' recognition rates of all the projects presented above, where A = Anger; D = Disgust; F = Fear; H = Happiness; Sa = Sadness; Su = Surprise; Avg = Average.

## 2.4 Summary and Conclusions

The above sections explore the robot-assisted research for intervention with children with ASD. There is a gap in the literature especially concerning these interventions comparing to traditional ones. Furthermore, Researchers have been focusing on skills such as turn-taking, joint attention and imitation, but few projects deal with specific emotional information and the difficulty of recognizing it by children with ASD. In addition, the understanding of how the robot can facilitate the ability to acquire knowledge about human body parts is seldom explored. Based on the literature and this gap, the

TABLE 2.2: Summary of the facial expressions' recognition rates of the presented projects.

| Robot | A | D | F | H | Sa | Su | Avg |
|---|---|---|---|---|---|---|---|
|  FACE (Mazzei *et al.*, 2012) | | | | | | | |
| Children with ASD | 100 | 20 | 0 | 100 | 100 | 40 | 60 |
| Typically Developing Children | 93.3 | 20 | 46.7 | 93.3 | 86.7 | 0 | 61.1 |
|  Probo (Saldien *et al.*, 2010) | 96 | 87 | 65 | 100 | 87 | 70 | 84 |
|  Kismet (Breazeal, 2000) | 76 | 71 | 47 | 82 | 82 | 82 | 73 |
|  EDDIE (Sosnowski *et al.*, 2006) | 54 | 58 | 42 | 58 | 58 | 75 | 57 |
|  WE-4RII (Itoh *et al.*, 2004) | 100 | 100 | 66.7 | 94.4 | 100 | 100 | 93.5 |
|  SAYA (Hashimoto *et al.*, 2011) | 92 | 92 | 100 | 100 | 100 | 100 | 97.3 |

goals in section 1.2.1 were specified. The research presented in this thesis differs from the research presented in the previous sections in the following points:

- In the study presented in Chapter 3, a humanoid robot was equipped with touch sensors which data provided an automatic way to identify harsh from gentle touch performed by the children during the interaction. The feedback from this data was used to identify when the tactile interaction was not appropriate. The original aspect of this study was the use of a humanoid robot to help teaching the identification and labelling of body parts to children with ASD;
- In the studies presented in Chapter 4, professionals were consulted to build different games scenarios to tackle the difficulty in emotion recognition showed by children with ASD. A questionnaire and focus groups allowed the design of three different game scenarios focusing on emotion recognition skills, with a humanoid robot as the main actor. The robot differs greatly from most of the equipments used until now, due to its special skin covering its face, which allows the display of facial expressions representing emotions. A perceptual study with 103 participants between typically developing children and adults was performed to evaluate the recognition rate of the designed facial expressions. The results showed that the facial expressions created based on the Action Units defined by Ekman were acceptable to be used as representations of the five basic human emotions: happiness, sadness, surprise, anger, and fear. The main differences between the literature and the study presented in this document rely on the process to refine the facial expressions and the influence of added gestures;
- In most of the cases of robot-assisted intervention for children with ASD the Wizard-of-Oz control is used. The software produced in this thesis allowed the robot to autonomously identify the answers of the child during the experimental procedure. This automatic identification helped the fluidity of the game and freed the experimenter to participate in triadic interactions with the child;
- In Chapter 5 and with the information from the exploratory studies presented in Chapter 4, two experimental studies were presented. Sixteen and forty five children with high-functioning ASD, aged five to ten years old were selected to participate in these two studies. The children performed the game scenarios (designed and tested in Chapter 4) with the robot or without the robot. The main differences between the literature is the size of the sample and using three

game scenarios to compare the influence of the robot in the intervention of children with ASD;

- In the study performed with 45 children, an extra control group was formed. Comparing to the literature, this research compared an experimental group who interacted with the robot to two control groups. One group performed the tasks without the robot and the last one performed one task common to all the groups in a pre- and a post-test;
- The evaluation performed in the studies presented in Chapter 5 took in attention not only the performance in the activity (number of successful, unsuccessful answers, and unanswered prompts), but also behaviours based on the literature which indicate social engagement. Examples of these behaviours are verbal communication, non-verbal communication, and joint attention time;
- In the study presented in section 5.1, the results with respect to non-verbal behaviours, and an analysis of simultaneous non-verbal behaviours is presented;
- The study presented in section 5.2 showed significant results regarding the use of an expressive humanoid robot to encourage children with ASD to identify and label emotional facial expressions, to imitate facial expressions, and to infer the affective state in others.

Typically developed individuals are able to experience, recognize, and use emotions to socially interact with others, as described in section 2.1. However, a growing percentage of individuals is unable to show or use facial expressions defined as innate to all, jeopardising one the most basic human needs: social interaction. This is the case of children diagnosed with ASD (defined in section 2.2) showing repetitive patterns of behaviour, restricted activities or interests, and impairments in social communication. One of the most visible characteristics of children with ASD, even when not familiarised with the condition, is the lack of eye contact, essential to joint attention and the promotion of social interaction (section 2.2.1). Furthermore, an impairment in imitation skills prevents children with ASD to develop cognitive and social communication behaviours, such as language and play (section 2.2.2). In addition, the difficulty in emotion recognition (section 2.2.3) complicates the understanding of mental states necessary to predict behavioural outcomes.

With an increasing awareness about ASD and an in advance diagnosis by professionals, children with ASD are forwarded early on to professionals for specialised help (section

2.2.4). Social robots have been shown to be a helpful tool to be used with children with ASD attracting their attention and keeping their focus to train different skills (section 2.3), such as social interaction (section 2.3.1), appropriate tactile interaction (section 2.3.2), and emotion recognition (section 2.3.3).

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# Chapter 3

# Eliciting Body Awareness and Appropriate Physical Interaction in Children With ASD

The content of this chapter is part of the following publications:

- Costa, Sandra, *et al.* (2013), "Where is Your Nose? - Developing Body Awareness Skills Among Children With Autism Using a Humanoid Robot", ACHI 2013, The Sixth International Conference on Advances in Computer-Human Interactions.
- Costa, Sandra, *et al.* (2014), Using a Humanoid Robot to Elicit Body Awareness and Appropriate Physical Interaction in Children with Autism. International Journal of Social Robotics, 1-14, DOI: 10.1007/s12369-014-0250-2.

## 3.1 Introduction

Human touch is processed in the brain by the somatosensory cortex and mediated by the skin (Merzenich, 1984). The stimulation of the skin caused by mechanical, thermal, chemical, or electrical events provokes different sensations, and the mechanical and physiological characteristics of the skin define its sensitivity to the stimuli (Heller & Schiff, 2013).

Touch can be divided into cutaneous, kinaesthetic, and haptic systems. The cutaneous system is comprised of mechanoreceptors sets, and this system processes the stimulation on the skin. The kinaesthetic system is comprised of receptors situated in the muscles, tendons, and joints, and it allows humans to identify positions and movements of the body, and muscle tension. The haptic sensory system concerns both cutaneous and kinaesthetic receptors, however it is associated to an active procedure, such as the process of recognizing objects through touch (Klatzky & Lederman, 2003).

The skin is responsible for the discovery of the social environment and the surrounding world. Touch is crucial for the development and welfare of the human being, and there are three critical factors for the healthy physical and psychological child's development: touch, movement and interaction with other humans (Montagu, 1971). Touch is one of the earliest senses developed in human embryos and the most developed sense at birth (Montagu, 1971). Thus, touch plays a key role in the physical, emotional, and psycho-social development. Touch deprivation early in life leads to severe consequences, such as complete emotional isolation or lack of trust in others (Korkman, 2001; Montagu, 1971; Ratey & Hagerman, 2008). On one hand, touch can convey affectionate feelings, on the other, it can express pain or discomfort. Children learn early on to understand and to identify different types of physical contact. This comprehension is made in order to communicate with other children and adults, building trust relationships, based on the exchange of support and mutual confidence, developing their social relationships. According to Piaget, infants develop object permanence through touching and handling objects (Bremner, 1994). Object permanence is the understanding that objects continue to exist even when they cannot be seen, heard, or touched (Moore & Meltzoff, 1999). Caregivers typically offer organized environments where children can explore, touch and manipulate different materials and where they are able to ask questions, use their creativity and learn new concepts. Children have to build their own learning experience, with the focus on the reasoning processes, where they form conclusions, judgements, or inferences from facts or premises (Smith *et al.*, 2003).

In the study presented in this chapter, the robot was used to verify if it could help children with ASD to learn appropriate physical social engagement. In addition to this, the study's goal was to understand if and how the robot could promote interactions between a child with ASD and another person, and whether it could facilitate the ability to acquire knowledge about human body parts. Thus, the robot was used as a social mediator between the child and the experimenter as well as a teaching tool. The artefact used in this study was the humanoid robot KASPAR, a minimally expressive child-sized robot (Dautenhahn *et al.* (2009) for technical details). KASPAR is able to move its torso, arms, and head and to use different facial expressions in order to simulate gestures in social interaction. KASPAR possesses simplified and minimalistic human-like features. The robot's behavioural repertoire includes expressive postures. It can approximate the appearance and movements of a human without trying to create an ultra-realistic appearance. KASPAR is equipped with tactile sensors which allow the automatic response to gentle or harsh touches from the child. The body parts teaching game was included in the scenario presented in this study since body awareness is part of the primary school curriculum. The aim of the game is to help children to develop an understanding of their body in relationship to the environment. The activities were designed to encourage tactile interaction in the children during the sessions using their own body, and without any additional special setup.

### 3.1.1 Research Questions

With this study, the following research questions were addressed:

**(a)** Can the robot elicit increased interaction levels between the child and the other person in the experiment?

**(b)** Can the robot elicit the ability to acquire knowledge about human body parts?

**(c)** Can the robot help teaching children with ASD appropriate physical (tactile) social engagement?

In order to answer (a), the time children spent looking at KASPAR, the experimenter or elsewhere was compared and it was expected that children were more focused on KASPAR rather than on the experimenter registered in eye gazing patterns and tactile interaction behaviours. However, it was desirable that the children increased their eye

gaze towards the experimenter along the sessions.
Moreover, learning the name of different body parts (b) was to be expected at the end of the experiments, and this learning was measured using a specific task, as it is described in the next section.
Concerning (c), it would be interesting to see if the encouraged interaction would be appropriate and in accordance with social norms (e.g. it is wrong to poke others' eyes). It was expected to see a decrease in harsh touches and an increase in gentle touches. This was measured counting the times the child touches KASPAR or the experimenter, either gently or harshly.
One of the goals of this study was to test whether a robot equipped with tactile sensors is able to help in teaching children with ASD appropriate physical social interaction. Since the main problem for these children is the modulation of the force they use in touching others, the robot provides a safe environment to playfully test their skills. The fact that the robot is equipped with tactile sensors that allow the measurement of the strength of touch used enables a direct "social" feedback to be given to the children in form of verbalisations like "ouch, that hurts" or "that is nice". This is a safe way for them to learn without hurting anyone. The absence of frustration or physically hurtful feedback by the robot provides a pleasant experience for the children and encourages them to engage in such interactions with others.
The role of the experimenter was to introduce the robot, or to intervene during the experiment in case of problems. The experimenter was also involved in the activity providing guidance, ensuring that the children would not become agitated or bored during the activity, and being available as an interaction partner for the children.

## 3.2 Methods

The following sections present all the topics regarding this study: ethical concerns, source of participants, undertaken procedures, characteristics of the robot, setup employed, and evaluation tools.

### 3.2.1 Ethics Statement

This study was performed in the United Kingdom and the procedures were approved by the Ethics Committee of the University of Hertfordshire. In addition, the experimenter involved in the sessions with the children was certified with an Enhanced Criminal Record Certificate by the Criminal Record Bureau before any trial took place. Parents of the children signed an informed consent in which they were briefed about the goals and applied methods of the research (Appendix A.1). The children's teachers were consulted and informed about the activities to be performed and gave suggestions intended to improve them.

### 3.2.2 Participants

The study was conducted in a primary school for children with special needs in Hertfordshire, United Kingdom. Eight boys diagnosed with ASD, aged six to nine years old (M = 7.4; SD = 0.9), from three different classrooms participated in the study. The eight children were divided into two groups with four children each and according to their diagnose: High Functioning ASD (Group A) and Low Functioning ASD (Group B).

Although not being possible to obtain the children's individual diagnoses for ASD, it was received confirmation from their head teacher that each child had previously been diagnosed with ASD by a medical professional. The experimenter did not know any of the children prior to the experiments. Since the participants in this study were all boys, everything related to the participants will use the masculine form.

### 3.2.3 The Robot

The robot KASPAR (Fig. 3.1 a) has been used in several studies with children with ASD (Robins *et al.*, 2005, 2008, 2009; Wainer *et al.*, 2010), and it has also been employed in other studies with typically developing children (Kose-Bagci *et al.*, 2009, 2010; Wood *et al.*, 2013).

KASPAR is a child-sized, humanoid robot with a minimally expressive face and arms able to produce gestures. The robot has a total of seventeen degrees of freedom (DoF), eight of them on the robot's head and neck and the remaining along the arms, hands, and torso (Dautenhahn *et al.*, 2009). The robot has simplified but realistic human features and body parts, which made it very suitable for the present study. In Fig. 3.1 b), circles represent the location of the joints of the robot and squares represent the location of the sensors on the robot.

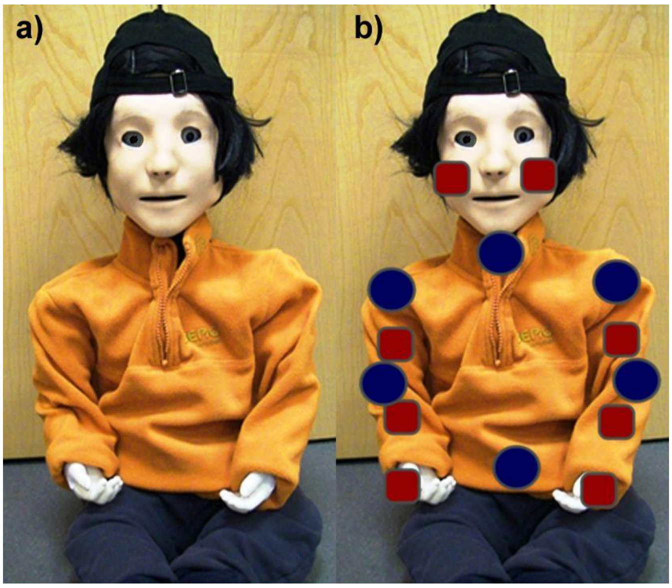



FIGURE 3.1: The robot KASPAR. The diagram on the right shows the joints (circles) and the location of the FSR sensors (squares).

In this study, the robot was controlled via Wizard-of-Oz (Kelley, 1984), using a Java based Graphical User Interface (GUI), which allows customisation. For the developed activities with the robot in this study, several poses were designed to indicate which body parts should be pointed out by the children, as well as the sequences of those poses. A key pressed on a wireless numeric keyboard activated a determined sequence, requesting the child to perform the activity. This keyboard was small enough to be close to the experimenter, on the chair, but far away enough from the child, so he would not be distracted by it. The sentences were generated from a text-to-speech synthesis software, and included in the produced sequences.
Although the robot was controlled by the experimenter, an autonomous behaviour was introduced. The robot was equipped with eight force-sensing resistors (FSR) sensors positioned on the right and left side of the head, shoulder, wrist, hand, and foot of the robot. These FSR sensors only distinguished a gentle from a harsh touch. If the child touched the robot, activating the sensor below the threshold limit, it answered a sentence such as "You are so gentle. Thank you.". If the child touched the robot and activated the sensor above the threshold limit, it answered with a sentence such as "Ouch, you are hurting me.". The threshold limit was defined during experimental pre-tests. The goal of this feedback was to automatically produce a response to the children's tactile interaction, teaching appropriate physical social engagement, reinforcing suitable behaviours when using touch to interact with another agent. The algorithm associated to the tactile interaction is presented in Appendix A.2.

### 3.2.4 Experimental Setup

The robot was connected to a laptop and placed on a table in the centre of the room. The position of the child, the experimenter and the robot is represented in the Fig. 3.2 a).

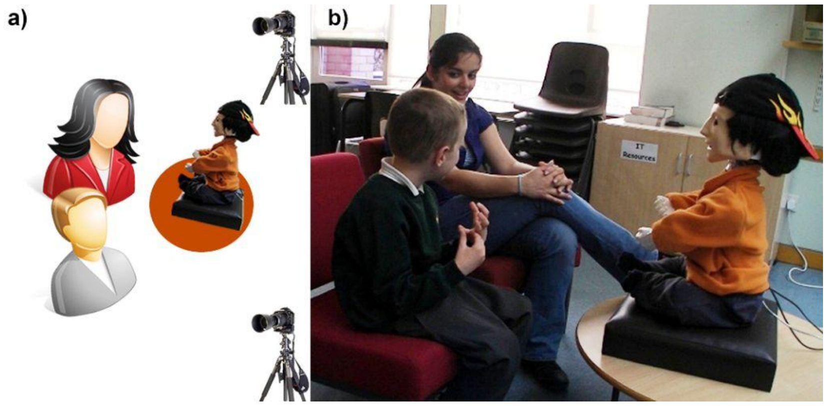



FIGURE 3.2: Room used for the experiments a) Room setup schematic, b) Positioning of the participants in the room.

The experiment took place in a familiar room in the school often used by the children for their activities (Fig. 3.2 b). The arrangement of the actors involved in the session (robot, child, and experimenter) had into consideration a cooperative position (Pease & Pease, 2008). In this arrangement of the room, two persons work together on the same task, which provides an opportunity for eye contact and mirroring. The experimenter is able to move without the child feeling as if his territory has been invaded. Most importantly, this arrangement in a triangle allows the experimenter to encourage the child to engage in the interaction, without threaten his space and forcing eye contact. All the sessions were recorded on video for further analysis and the two cameras were placed in such a way that one recorded the face of the child and the other camera recorded the experimenter during the experiments.

### 3.2.5 Procedures

The designed methodology for this study includes four different phases: familiarisation, pre-test, practice, and post-test (Fig. 3.3).

**Familiarisation Phase:** Individuals with ASD have problems with changes to their daily routine. Therefore, they have difficulties to accept changes to their environment


FIGURE 3.3: The four different phases of the study. All phases had one session each, with exception to the practice phase, which had seven sessions.

(Koegel *et al.*, 1980). For this reason, the familiarisation phase was included to reduce the effect of a new person in their environment. Before starting the experiments with the robot, the experimenter attended one day of classes with the children. The goal of this phase was to get acquainted with the children and to integrate the experimenter in the school environment.

**Pre-Test & Post-Test Phases:** One of the goals of this study was to evaluate the ability of the child to acquire knowledge about human body parts while participating in the activities with the robot, following consultation with children's teachers. To verify if this goal was achieved, a performance task was created, which was done before and after the activities with the robot - the practice phase. The pre-test served as a baseline to be compared to the results of the identical post-test, evaluating the acquired knowledge. This task was performed without the robot.
In the performance task, the children were asked to choose the right location for the different body parts, and place them on a drawing of a little human figure printed on a cardboard (Fig. 3.4). The performance task applied in the pre- and post-test used the TEACCH program (Mesibov *et al.*, 2004) already used in the classroom by the teachers and presented in section 2.2.4.

**Practice Phase:** Each session with the robot was introduced with a Picture Exchange Communication System (PECS) card, which children usually use in their daily routine to start new activities. When the experimenter went to the classroom to pick up the child, the card was given to the child. The child took the card to the room in which the study took place. After the experiment the child took the card back to the classroom, where he gave the card back to the experimenter. Three different activities were created based on the ASD severity level of each child. The complexity of the activities was different, so whenever the children managed to accomplish the

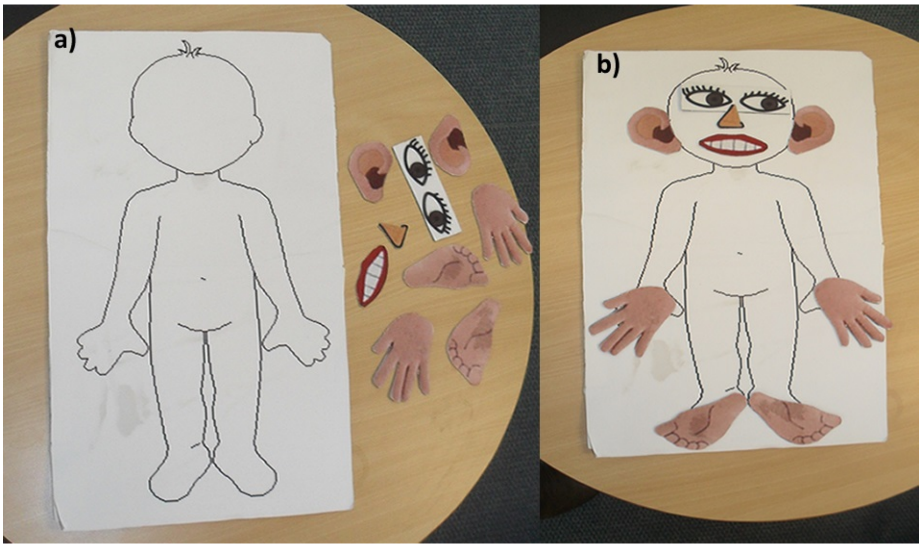



FIGURE 3.4: Performance task in the pre- and post-test (a) Beginning of the Task, (b) Task Accomplished.

activity, in the next session they performed a more complex activity. If a child did not manage to progress, more sessions were done with the basic activity. The evaluation of the right transition moment to the next level for each child was done by the experimenter based on the opinion of the teachers, acquired informally between sessions. The robot's responses were triggered remotely by the experimenter. Seven sessions of approximately ten minutes each were performed and recorded on video, with the three following activities:

- Activity A: The robot identified one part of its body saying: "This is my head". Then, it asked: "Can you please show me your head?". If the answer of the child was correct, the robot responded with a positive reinforcement like "That's right!" or "Well Done!". If the answer was not correct, the robot encouraged the child to try again, e. g. "Almost. Try again!". The human body parts to be identified were: head, tummy, nose, ears, eyes, hands, toes, and mouth.

- Activity B: The robot identified a sequence of human body parts on its own body. For example: head and tummy. Next, it asked the child to point at the same body parts and in the same sequence on his own body. Then, the following step was to use three body parts (e.g., head, tummy and toes). The same type of reinforcement as in Activity A was used.

- Activity C: The robot asked the child to sing together a song, called "Parts of me" about human body parts (Do2Learn, 2012), and the experimenter encouraged the child to do the same choreography, this meaning doing the gestures that accompanied the song. If the child did not use verbal communication, he was asked to imitate the same gestures of the experimenter (moving their body parts according to the song). The song was chosen based on simplicity and the practical learning approach is normally used in the school to teach other contents. When the song finish the robot said "Touch my hands if you want to sing again".

The algorithm associated to the performance of these activities is presented in Appendix A.2.

### 3.2.6 Evaluation Tools

The tools used to evaluate the interaction of the children with the robot and the experimenter are divided into qualitative and quantitative measures. As qualitative measures, a structured interview and observational grids were used. Questionnaires, a behavioural analysis coded from the videos, and the comparison between the pre- and post-test were used as quantitative measures.

#### Structured Interview

The structured interview was done with one of the teachers, showing her extracts of the videos of each child, when the experiments were over. Excerpts of the first and the last sessions were collected for this purpose. In this interview, it was interesting to verify the perspective of the teacher on the children's behaviours. Mainly, this structured interview was used to know how the teacher would describe the reactions of the children towards the robot and what usual or unusual behaviours the children showed in the video. Additionally, the children's social behaviour seen in the video was compared to the behaviour of the children towards teachers and other children in the classroom (tactile interaction, eye gaze, playing, among others). After discussing this, the main differences in the children's behaviour in the two videos (one from the first sessions and one from the last ones) were discussed, as well as whether the robot could have had an influence on the specific behaviours performed by the children. The interviewed teacher knew only four of the eight children very well and thus only commented on these. Despite this fact, her comments were considered very relevant and included in this chapter. This tool can be found in the Appendix A.3.

### Observational Grid

As a qualitative method of collecting data for this study, an observational grid was used, supporting the information obtained by the video analysis. This grid was filled in by the experimenter after each play session, in order to keep records of all the important events, helping the process of identification of play patterns. This grid was also helpful to investigate reinforcing behaviours and which ones may support changes in the children's skills. This tool can be found in the Appendix A.4.

### Questionnaires

The questionnaires aimed to measure the development of children assessing their skills regarding tactile interaction. The questionnaires were delivered to the teachers at two different points during the trials. First, before the trials with the children to establish a data baseline for each child. Then, the last evaluation was done at the end of the study with the same questions, to evaluate the changes in the behaviours of the children. The items were rated with a 5 point Likert-scale. Three teachers, one for each classroom to which the children belong to, completed the questionnaires for the children. For each question, space was available for comments, providing information not covered by the response categories. The questions were mainly related to tactile interaction and the knowledge about body parts, such as, "Does the child use his/her hands to explore novel/unknown objects?" or "Can the child point or identify parts of his/her body in any way?". This tool can be found in the Appendix A.5.

### Behavioural Analysis

The videos produced during the sessions were analysed using The Observer XT 11 program by Noldus (1991). Table 3.1 shows the coding scheme used.

To ensure inter-rater reliability 10% of the videos were re-coded by a second independent coder providing a Cohen's kappa k = 0.63 in an inter-rater reliability test. This is acceptable, as having a Cohen's kappa value higher than 0.60 suggests a good agreement between the raters (Bakeman & Gottman, 1997). For each coded behaviour (except looking), the coders needed to mark whether the child showed the behaviour spontaneously or whether the behaviour was prompted by the experimenter. If the child was for example touching KASPAR for no specific reason, the behaviour should

TABLE 3.1: Overview of coding scheme

| Behaviour | Description |
| --- | --- |
| Looking at KASPAR/at the experimenter | Head orientation of the child pointing towards the robot/the experimenter (preferably eye gaze as marker) |
| Touching KASPAR/the experimenter | Child touching the robot (from the moment the child touches the robot). Types: spontaneous, prompted, harsh, and gentle. Spontaneous and prompted behaviours are mutually exclusive, as well as the harsh and gentle behaviours |
| Touching Child | Touching between the experimenter and the child (from the moment the experimenter touches the child). Reasons for the experimenter touching the child were: child touching robot harshly (and verbal prompts were not enough to stop this behaviour) and to help perform the choreography in Activity C |
| Touching KASPAR - Activity C | Child touches robot's hands after KASPAR says "Touch my hands if you want to sing again" |
| Following | The child follows with head movement (eye gaze if possible) a pointing gesture (with index finger or hand) of the experimenter |
| Pointing | The child points at something with index finger to catch the attention of the experimenter |
| Imitation | Coded when the child repeats movements, imitates vocalisations or gestures of KASPAR/experimenter. Repetition is not coded if the child was performed that particular action previously |
| Prompts | KASPAR requests the child to show one body part: ears, eyes, hands, head, mouth, nose, toes, or tummy. The experimenter can also ask the child to show one of the experimenter's body parts. In activity B: KASPAR asks for a sequence of 2 or 3 body parts and in activity C, this behaviour should start when KASPAR starts singing and ends when it finishes |

| Behaviour | Description |
|---|---|
| Identifying body parts | The child identifies verbally or non verbally the different body parts<br>Prompted by the experimenter: The experimenter has encouraged the child to show the behaviour<br>Prompted by KASPAR: The robot has encouraged the child to show the behaviour<br>Successful: The child shows the correct body part<br>Unsuccessful: The child fails to show the correct body part<br>Self: The child identifies the body part on his own body<br>Robot: The child identifies the body part on the robot<br>Experimenter: The child identifies the body part on the experimenter<br>Prompted by the experimenter or by KASPAR behaviours are mutually exclusive, as well as the successful and unsuccessful behaviours and self, robot and experimenter behaviours<br>When a behaviour is unsuccessful, it does not matter if it is on himself, on the robot or on the experimenter |
| Activity C | Two state behaviours that identify when the child sings at the same time as KASPAR or the experimenter, and if he performs the choreography of the song together with KASPAR or the experimenter |

be classified as spontaneous. If the child touched KASPAR after the experimenter say "Where is KASPAR's nose?", the behaviour should be classified as prompted. A behaviour ended if the child stopped exhibiting that behaviour or showed another directly related behaviour (for example, looking at KASPAR/looking at the experimenter). When the child exhibited behaviours that were not specified on the list, they were not coded. For eye contact, turning away ended the behaviour. Turning back immediately and making eye contact again counted as a new behaviour.

### Comparison between pre- and post-test

The time and efficiency for each child was measured putting nine body parts (eyes, nose, mouth, two ears, two hands, and two feet) in the right place on a drawing of a human (Fig. 3.4). Additionally, an evaluation was made regarding the child's need of help from the experimenter. The evaluation of this task consisted in giving one point to every body part correctly put on the cardboard. If the child did not need any help from the experimenter, he got an extra point. The total amount of points was 18. For no answer or wrong placement of the body part, the child got 0 points.

## 3.3 Results

The collected data from the questionnaires, the behavioural analysis, and the comparison between pre- and post-test were statistically analysed and are presented below. In addition, a descriptive evaluation was made based on the structured interview and on the observational grids.

### 3.3.1 Structured Interview

The interviewed teacher had prior knowledge about the robot's functionalities. During the interview, the teacher classified the following behaviours as improvements:

- "When *Child 1* is happy and playing, he uses an American accent. This is usually when playing with small action figures, alone. Occasionally he will let another (child) join him in this, but only if happy. During the whole session he used his "play" accent. He was smiling and interested, this is very unusual, though not unique. When he slapped KASPAR, he said sorry spontaneously. This is very unusual, I have tried in the past to get him to say sorry, and not succeeded. I have not seen *Child 1* show he caused pain and say sorry before. His expression is more usual in the first video, distasteful and unhappy. However, he is co-operative, which he would not be if not happy. (He was) looking at the experimenter for support, so KASPAR is facilitating co-operation with another. KASPAR said lets sing, he did! Then smiled. *Child 1* held attention for longer than would if I was doing task;
- This may not seem like it, but I feel this is one of the greatest successes I have seen in this collection of videos. *Child 3* is looking at KASPAR, which often is the most you can get from him, and he only does when engaged. When KASPAR said "where are your hands?", *Child 3* slapped his legs with his hands, showing he was listening. Wow! Engaged, looking, making eye contact, and touching KASPAR's body parts, especially face. Was that a kiss? Touched his tummy!

This level of engagement and interaction from *Child 3* is unusual. Also, he is happy, not being held down to take part and voluntarily sitting down while not doing a puzzle, all of these are unusual. When he stood up to go, I think he needed to the toilet. When he pulled the experimenter down, this was amazing! This is a proven example of KASPAR acting as a mediator and facilitating social interaction and communication. *Child 3* wanted more KASPAR, and he knew he needed the experimenter for this. By pulling her to the seat he was requesting something from her, something he does not do much at all. At end he was trying to do what KASPAR wanted, he looked disengaged, but was actually still very much listening and trying to touch the body parts, he just could not get them right. (...) He spent a whole afternoon pulling people to the KASPAR's room, and running away to there. This is very unusual behaviour for *Child 3*, to request an activity which is not a puzzle, especially one which involves interaction;

- "Not a real one". Very interesting that he wanted to make it clear that "KASPAR is not a boy, he is a robot". *Child 5* was VERY compliant, joining in, concentrating, looking and paying attention. Very good work from him, and not usual to have this much compliance. *Child 5* often breaks things, and is very rough with them, though we think that this is mainly because he wants to see how they work, not that he wants to cause damage. It is interesting that when *Child 5* was squeezing KASPAR's hand, he looked at KASPAR's face. (...) KASPAR's 'ouch' is not a clear sound of distress, and I think it needs to be. *Child 5* did not react to KASPAR's 'pain' at all, was just interested, and he does understand people feel pain, and can respond appropriately. He really wanted to tell KASPAR about his hurt finger, an interaction I have not seen him do with a child, but he does with adults. After 'hurting' KASPAR, he patted gently. He was interacting with the experimenter, and responding to her, so KASPAR was facilitating the interaction with her. It might seem like *Child 5* is not interested, but the fact that he lets KASPAR sing, and even touched his hands to get him sing is remarkable, he does NOT like singing. I think he even joined in the 'part of me' (final moment of the song), though I could not hear well. *Child 5* has very occasionally joined in with songs, though usually he will become very disruptive if music is played;

- *Child 6* was looking at the experimenter for clarification when KASPAR speaks, so this is evidence of him acting as a social mediator. When KASPAR said 'ouch, you are hurting me', *Child 6* did not show any sign of recognition, stress, say "sorry" or react in any way. This is very interesting. It either shows that *Child 6* does not see KASPAR as a person, and so has no feelings, or else the 'Ouch' was not clear enough. When *Child 6* hurts someone, if they show clear distress or pain he will spontaneously apologize and show stress, he did not do this. When the experimenter said "you make him happy, give him the hat back", *Child 6* said "hat back". I think this was just repeating the sounds, not comprehension, though I cannot be sure. (...) *Child 6* takes a long time to process things, so the pause when he does not touch his hands is not unwilling, he is just thinking. *Child 6* likes singing, though when he holds his head, you can see his showing stress as does not know what will come next. He is looking at the experimenter for cues, not KASPAR, and is more interested in the experimenter's skin and posture than he is in KASPAR.

### 3.3.2 Observational Grid

As a qualitative tool, the observation grids were used to adapt the experimenter's behaviour towards the child, not invalidating the established experimental procedure. These adaptations were mostly due to specific differences between the children, based on their communication abilities and attention span. The observational grids were also used to validate when to change the activities the children performed in each session, crossed with information given informally by their teachers.

### 3.3.3 Questionnaires

To determine how the responses of the teachers on the written questionnaires matched for the same questions before and after the procedure, the numerical differences between the responses of the two sets of questionnaires were examined, using a Wilcoxon test.

There were significant differences between the two sets of data regarding the exploration of unknown objects by the children using their hands ($p = .046$), and the verbal identification of at least one part of the child's body ($p = .039$). In addition, there were significant differences between the first and the second questionnaire, for pointing to at least one part of their body when asked to do so ($p = .026$), and when identifying body parts in any way ($p = .034$). In all these results, an increased of the average rating by the teachers was observed. As comments, teachers added that one child has changed and that he is now able to listen and understand body parts. Another child changed to being more focused compared to his previous state and he was enjoying the body part activities.

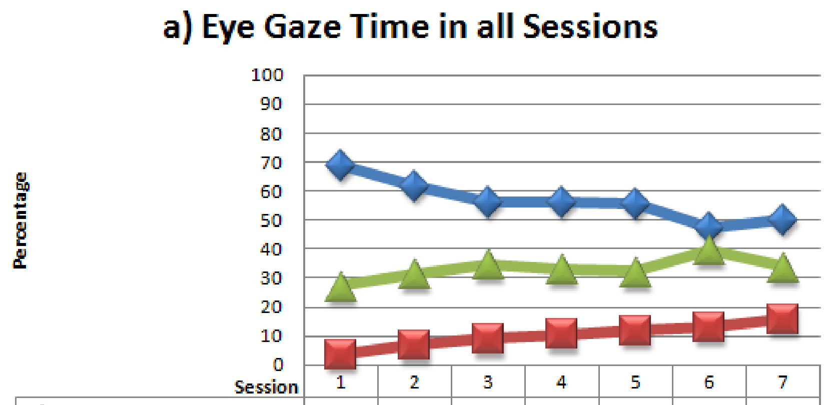
### 3.3.4 Behavioural Analysis

The behavioural analysis is divided in two parts: an analysis of the children's progress and a comparison between the first and the last session to verify if there are significant differences. The seven sessions of the practice phase were used for this analysis.

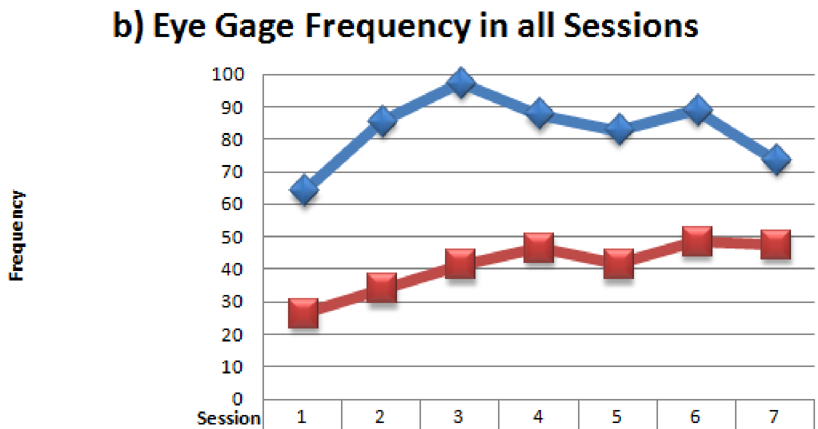
#### Analysis of progress

Eye gaze direction can give a clue where the children were focusing their attention. In Fig. 3.5 a slight decrease in eye gaze towards KASPAR is illustrated, however it always stayed above 47.30% of the total session time.
Looking to other directions besides the robot or the experimenter varied between 27.3% and 39.7%. A Friedman test revealed significant differences between the time spent by the children gazing at KASPAR, the experimenter or elsewhere, $p = .002$, and between the number of times the events looking at KASPAR and at the experimenter occurred, $p = .001$. Comparing the first to the last session, eye gazing towards the experimenter increased fivefold with significance ($p = .012$).

Figure 3.6 shows how tactile interactions with the robot and the experimenter evolved during the sessions.
There was no typical pattern in this data, but there were significant differences regarding the gentle and harsh touches on KASPAR and on the experimenter ($p = .008$ for both cases, using a Chi-Square test). On average, the sum of gentle touches was 8.5 times greater than harsh touches on KASPAR and 23.6 times on the experimenter (Figure 3.6 a). Regarding touches from the experimenter on the child, either to help in the activities or to prevent the child from applying too much force on the robot, there was an increase up to the fourth session (Figure 3.6 a). Concerning the spontaneity of the performed tactile interaction, on average, the sum of spontaneous touches was 10.3 times greater than prompted touches on KASPAR and 6.7 times on the experimenter (Figure 3.6 b).




| Session | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Mean %Looking KASPAR | 68,8 | 61,6 | 56,0 | 56,2 | 55,8 | 47,3 | 50,3 |
| Mean %Looking Exp. | 3,9 | 6,8 | 9,0 | 10,7 | 12,1 | 13,0 | 15,8 |
| Mean %Looking Elsewhere | 27,3 | 31,5 | 34,9 | 33,1 | 32,2 | 39,7 | 33,9 |

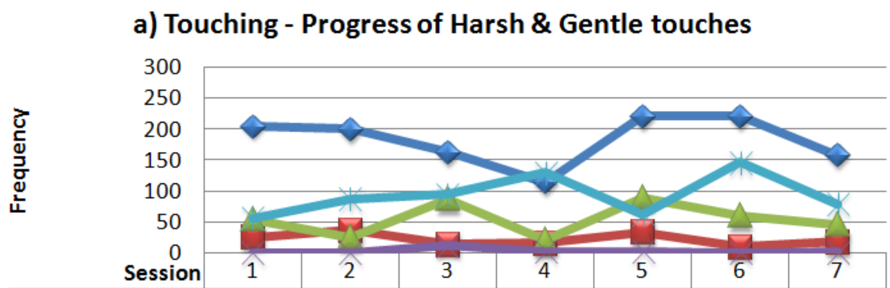



| Session | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Mean #Times KASPAR | 64 | 86 | 97 | 88 | 83 | 89 | 74 |
| Mean #Times Exp. | 26 | 34 | 41 | 47 | 42 | 49 | 48 |

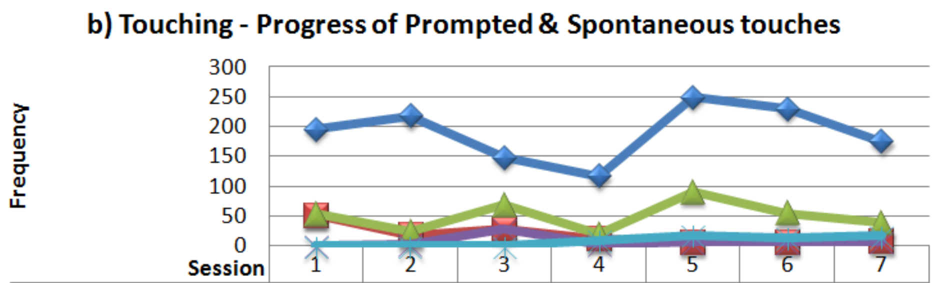
FIGURE 3.5: Children's mean eye gaze during practice phase. a) Eye gaze towards KASPAR decreased but had the highest values, and eye gaze towards the experimenter increased during the sessions. b) On average the children looked at KASPAR between 64 and 97 times, and they looked at the experimenter between 26 to 48 times.

Following the pointing of the experimenter and pointing behaviour (with the index finger) by the children was most pronounced during the first sessions. Regarding imitation, the occurrences of this behaviour decreased over time, having again a higher value until the fourth session. As a remark, it should be stressed that with the introduction of Activity C from the fourth session onwards, performing the choreography (i.e. imitating KASPAR's choreography) was not considered in the imitation behaviour, but in the specific behaviour choreography.

Figures 3.7 to 3.9 show children's success while performing activities A, B, and C and Chi-Square tests were used to compare the results. Regarding Activity A, successful responses overtook significantly unsuccessful ones ($p = .018$) varying the successful




| Session | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Sum # K Gentle | 205 | 200 | 163 | 114 | 221 | 221 | 158 |
| Sum # K Harsh | 25 | 36 | 14 | 15 | 33 | 10 | 17 |
| Sum # E Gentle | 53 | 24 | 86 | 21 | 89 | 60 | 45 |
| Sum # E Harsh | 0 | 0 | 11 | 2 | 2 | 0 | 1 |
| Experimenter | 56 | 87 | 94 | 130 | 62 | 146 | 79 |

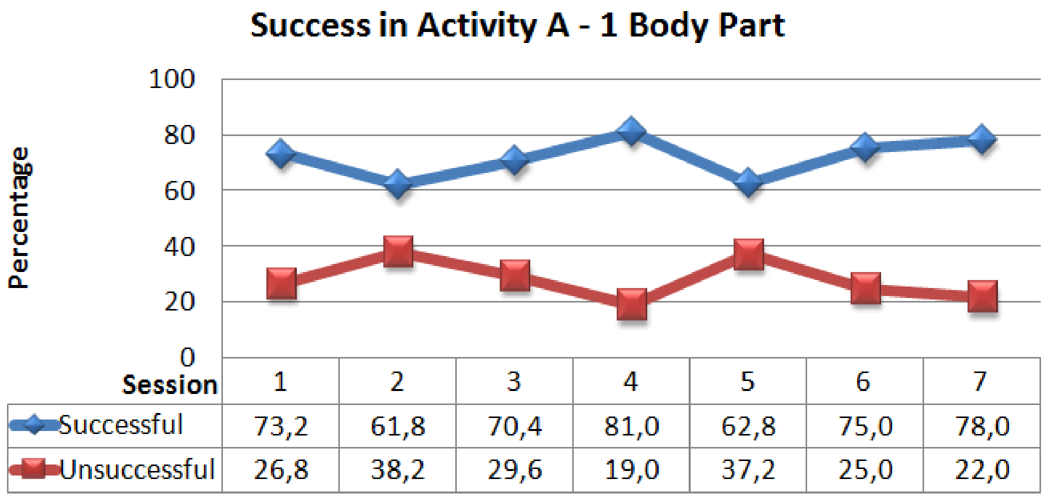



| Session | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Sum # K Spontaneous | 195 | 218 | 149 | 117 | 249 | 230 | 175 |
| Sum # K Prompted | 51 | 18 | 28 | 12 | 6 | 6 | 8 |
| Sum # E Spontaneous | 53 | 23 | 69 | 20 | 90 | 55 | 38 |
| Sum # E Prompted | 0 | 2 | 28 | 3 | 6 | 6 | 7 |
| KPrompted - ActivityC | 0 | 0 | 0 | 10 | 18 | 14 | 17 |

FIGURE 3.6: Touching performance comparison regarding a) harsh and gentle touches; b) prompted and spontaneous touches. Gentle overtook harsh touches and there are more prompted touches in the first session, because the experimenter (E) encouraged that behaviour, but after the first session, children touched KASPAR (K) spontaneously.

answers from 61.8% to 81.0% and with an average of 71.7% for successful answers and of 28.3% for unsuccessful ones (Fig. 3.7).

Concerning Activity B - 2 body parts, successful responses also exceeded unsuccessful ones significantly ($p = .028$), varying the successful answers from 72.9% to 95.2% and with an average of 70.5% for successful answers and of 15.2% for unsuccessful ones (Fig. 3.8 a). Identifying successfully sequences of 3 body parts in Activity B varied between 54.8% and 73.7% and with an average of 54.8% for successful answers and of 30.9% for unsuccessful ones. These values are significantly different ($p = .028$). Activity B was not performed in the first session (Fig. 3.8 b).
Fig. 3.9 shows the percentage of time children performed the same gestures with KASPAR and the experimenter while singing the song and also the percentage of time




| Session | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Successful | 73,2 | 61,8 | 70,4 | 81,0 | 62,8 | 75,0 | 78,0 |
| Unsuccessful | 26,8 | 38,2 | 29,6 | 19,0 | 37,2 | 25,0 | 22,0 |

FIGURE 3.7: Percentages of correct and incorrect responses in Activity A. Successful responses overtook unsuccessful ones.

children sang along. There is only data from the fourth session since Activity C was only performed from this session onwards. There is a general increase in these two behaviours reaching the highest values in the last session.

Fig. 3.10 illustrates the number of times children switched their eye gaze between the other two elements in the room, KASPAR and the experimenter.

A two-seconds time limit between switching from one element to the other was established. This limit was used so events when 1) the child looked at KASPAR, 2) looked elsewhere for a longer period, and then 3) looked at the experimenter for some reason not related to what made him look at KASPAR earlier were not considered. In addition, the total amount of time children shifted their eye gaze from the experimenter to KASPAR, and back to the experimenter (and vice versa) in less than two seconds was also counted. These values potentially indicate if children were effectively engaged in the activity, alternating their focus between the robot (object of common attention) and the experimenter as a social interaction partner. The value of two seconds was chosen considering that the tolerance window in the reliability analysis is one second. These two measures show that there was an increase between the first and the last session. The total number of times children changed their eye gaze from KASPAR to the experimenter, and from the experimenter to KASPAR (Total E-K & K-E) varied from 368 to 502. Total E-K-E & K-E-K shows the total amount of times children looked at the experimenter, to KASPAR, and to the experimenter again in less than two seconds, and vice-versa and it varied from 151 to 242.

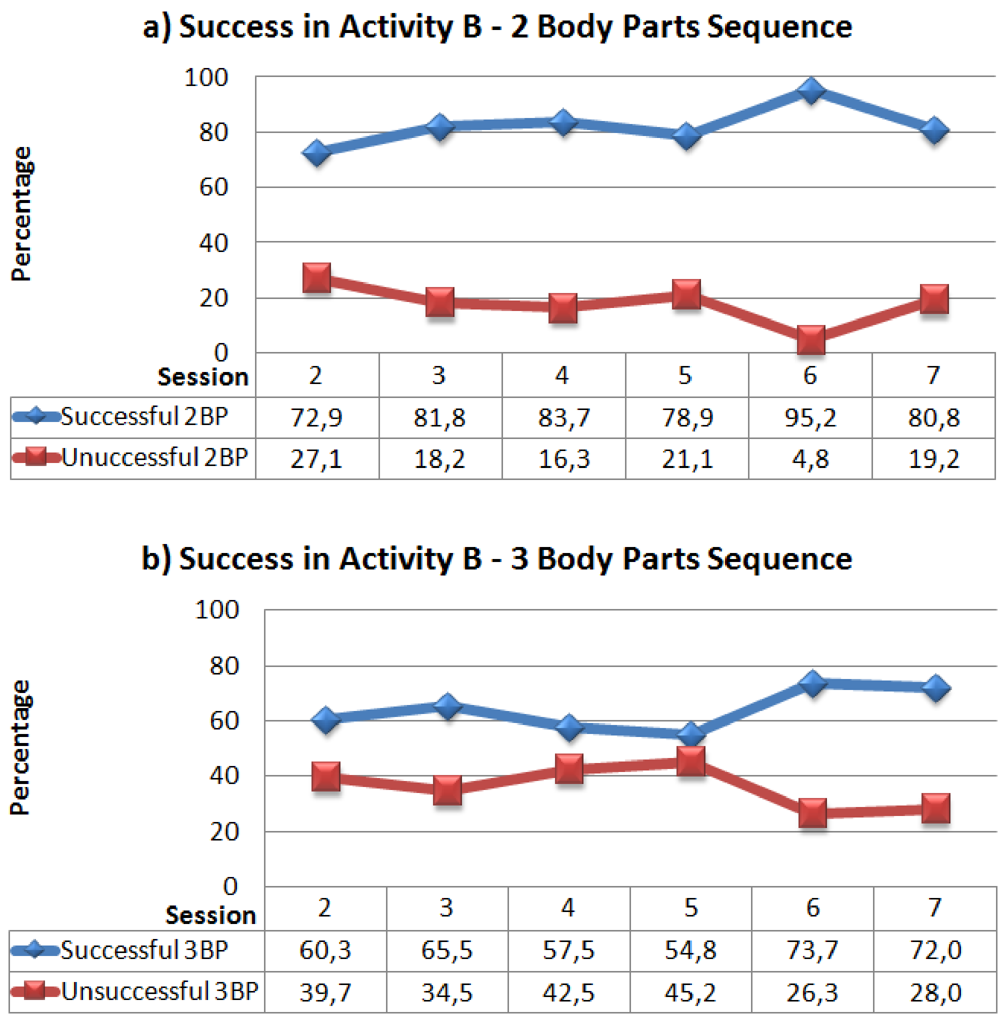



FIGURE 3.8: Percentages of correct and incorrect response in Activity B: a) 2 body parts; b) 3 body parts. Successful responses overtook unsuccessful ones in both cases.

Figure 3.11 refer to locations where children's eye gaze was directed during the activities. During activities A and B, the percentage of time dedicated to KASPAR exceeded 70.0%. Only 8.0% of the eye gaze was directed to the experimenter (Fig. 3.11 a). Analysing each session, a decrease in eye gaze towards KASPAR and an increase towards the experimenter was observed.

During activity C the children gazed with their eyes 70.0% of the time towards KASPAR, and 14.0% of the time they looked at the experimenter. When KASPAR was singing in activity C (Fig. 3.11 b), most of the time children looked at KASPAR. An exception occurred during the sixth session, during which the behaviour looking elsewhere exceeded looking at KASPAR or to the experimenter. As mentioned before, activity C was only performed from the fourth session onwards.

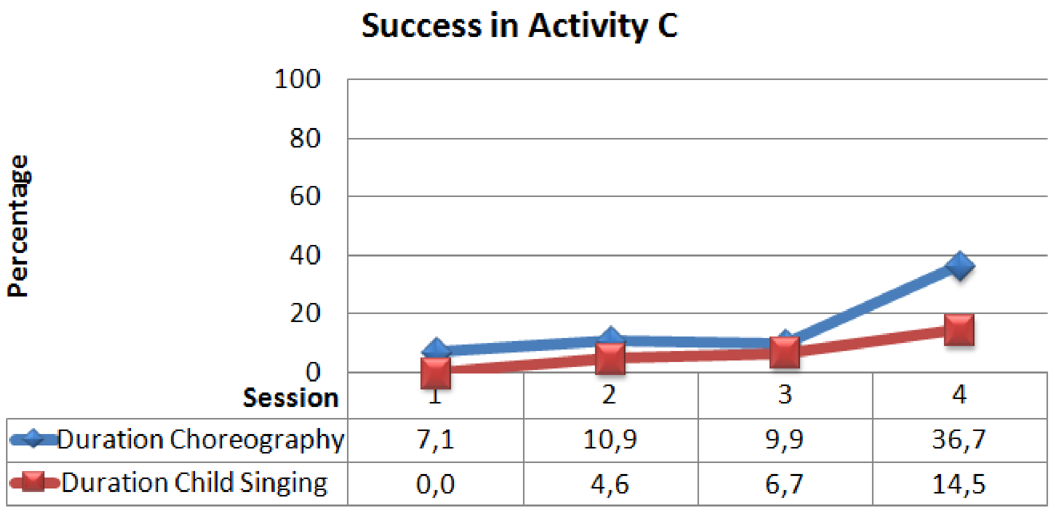



FIGURE 3.9: Percentages of time the children imitated KASPAR's choreography and sang along with KASPAR in Activity C. Some child with verbal communication were able to sing along with KASPAR, and also to imitate KASPAR performing the song's choreography.

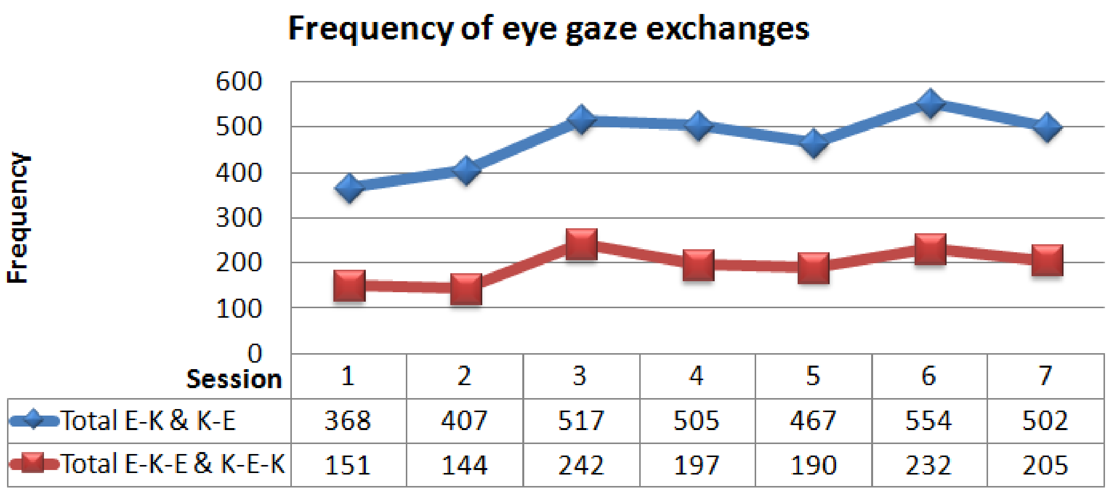



FIGURE 3.10: Frequency of eye gaze exchanges between KASPAR and the experimenter in less than two seconds. On average 40.0% of the total exchanges were of KASPAR-Experimenter-KASPAR and Experimenter-KASPAR-Experimenter type.

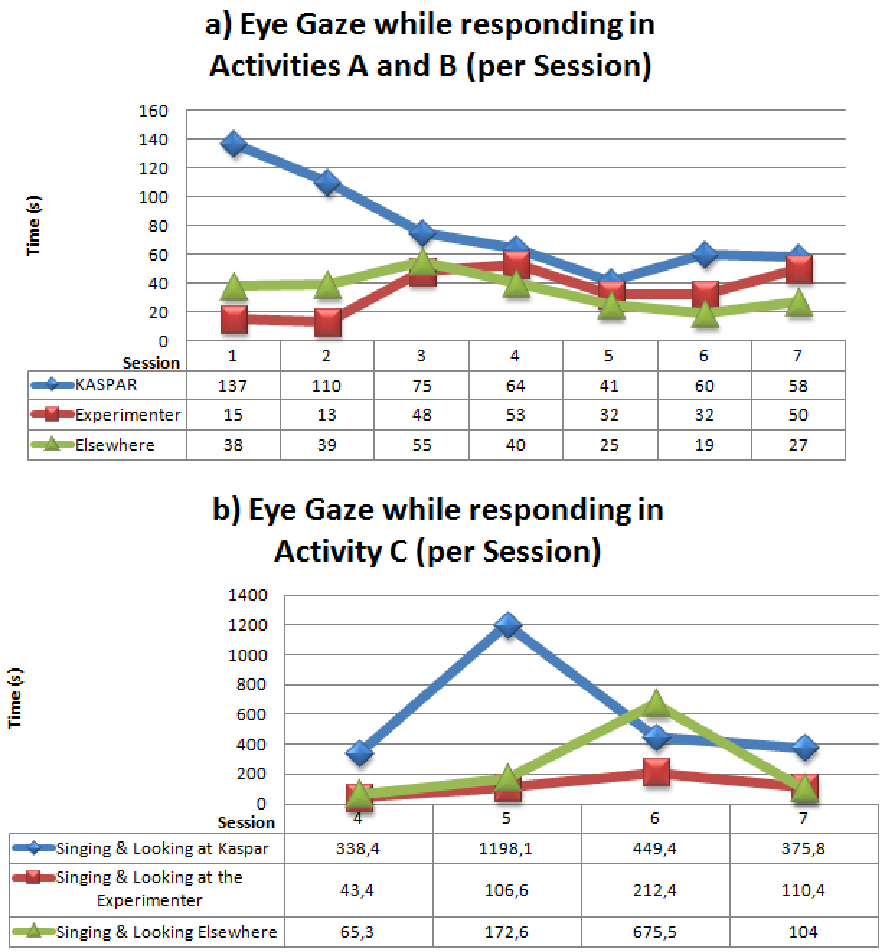



FIGURE 3.11: Eye Gaze Time per session a) during Activities A and B; b) during Activities C. Eye gaze towards KASPAR decreased and towards the experimenter increased. In activity C a slight increase was verified followed by a drastic decrease in the last session.

Besides the number of times children looked at KASPAR and the experimenter, how the duration in these two behaviours evolved was analysed. On average, time intervals while looking at KASPAR decreased, except for the last session, and in general time intervals while looking at the experimenter increased. These values varied between 25.5 and 57.2 seconds and between 3.4 and 12.6 seconds, respectively.

On average, children took between 5.7 and 8.7 seconds to respond to KASPAR prompts in activity A. The lowest value occurred in the first session, in the second session there was a slightly increase, but it decreased in the following sessions. Regarding activity B, response times were longer than during activity A, varying from 7.4 to 12.8 seconds.

### Comparison of first and last session

To compare the data from the video analysis of the first and the last session, a Wilcoxon test was used. As mentioned above, one of the coded behaviours was the direction of the eye gaze of the children when they were interacting with the robot. Significant differences were found when comparing the first and the last session, for the children looking at KASPAR ($p = .012$), at the experimenter ($p = .012$), and elsewhere ($p = .012$). The results (Fig. 3.12) show that the average time the children looked at the robot decreased (75.0% - 51.0%), at the experimenter increased (4.3% - 16.0%) and to no particular place also increased (20.7% - 33.0%).

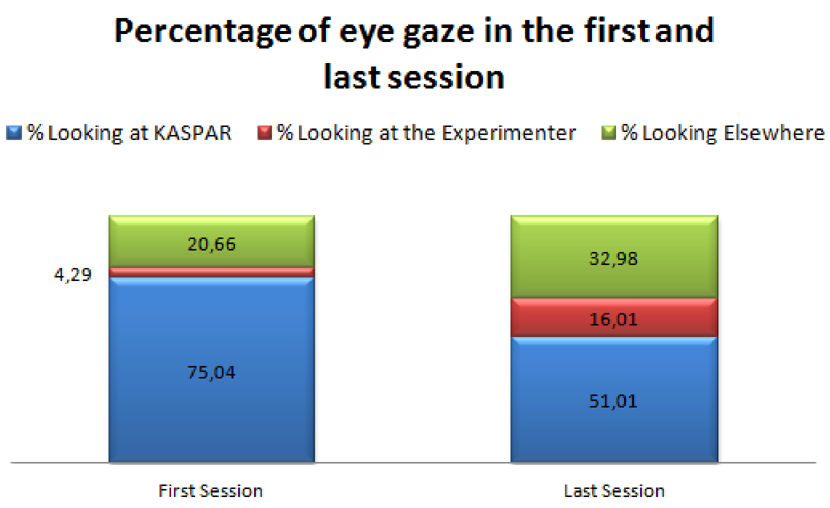



FIGURE 3.12: Percentage of eye gaze in the first and last session of the Practice Phase

Concerning the tactile interaction of the children in the first and last session, there were no significant differences of the number of times the children touched the robot or the experimenter, gently ($p > .05$) or roughly ($p > .05$). Despite having no significant differences when evaluating tactile interaction, more than 90% of the times the children touched the robot gently (Fig. 3.13).

There are no significant differences between the first and the last session in any of the interaction parameters (pointing, following, and imitation). The behaviours that were shown most were imitation and pointing.

Regarding the success of the children while performing the proposed activities, Figure 3.14 shows that the children managed to complete Activity A more than 70.0% of the times in both the first and the last session, but without significant differences.

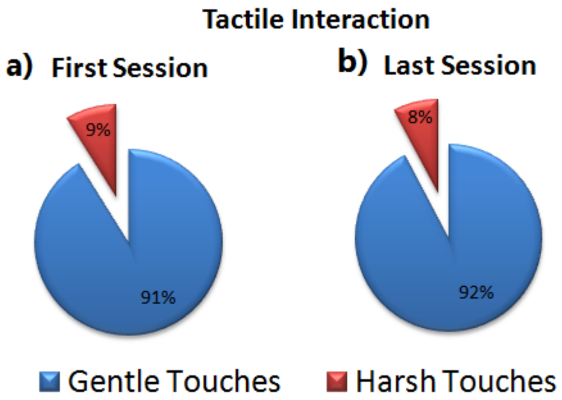



FIGURE 3.13: Percentage of gentle and harsh touches during the interaction with KASPAR in the first and last session of the Practice Phase

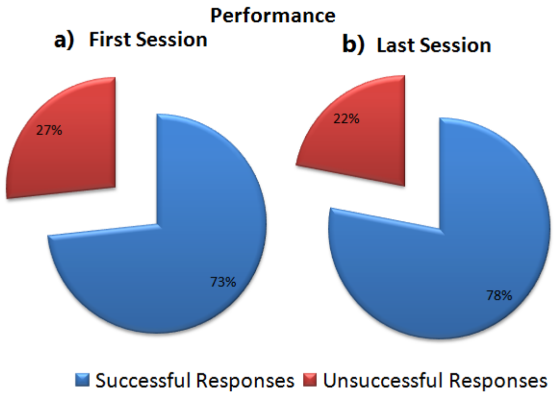



FIGURE 3.14: Percentage of Success of the Activity A in the first and last session of the Practice Phase

### 3.3.5 Comparison between pre- and post-test

When comparing the pre- and post-test using a Wilcoxon test, there were no significant differences in the time children took to complete the performance task ($p > .05$). The average time the children took was 156.0 seconds in the pre-test and 124.0 seconds in post-test. Due to the short sample, the statistical evidence could not support clearly the intended effect, however 75.0% of the children managed to perform the task in less time in the post-test than in the pre-test.

The placement of the body parts on the human figure was scored with zero for not managing, one for managing with help, and two for succeeding without help. On average, children got a score of 15 during the pre-test ($SD = 5.4$), and 17.25 in the post-test ($SD = 1.8$). Significant differences were not found using a Wilcoxon test, comparing these scores in the pre- and post-test ($p > .05$).

## 3.4 Discussion of the Results

The children's attention during the experiments was on the robot (consistent with the expectations concerning research question (a)). During the first sessions this was expected since KASPAR represented a novel object which attracted their attention. However, the interest in the robot was not lost during further sessions, and their interest in the human partner increased.

It was observed that from the first session with KASPAR to the last, children decreasingly directed their eye gaze towards KASPAR. The time they spent looking at the experimenter and at no particular place increased. The latter can be explained with the familiarisation of the children with the situation, but looking five times longer at the experimenter can be interpreted as KASPAR successfully functioning as social mediator.

Pointing to a specific object, and following the index finger of another person are behaviours that indicate social engagement (Woodward, 2005). The children's demonstration of such behaviours may indicate that KASPAR was useful to facilitate interaction behaviours. The first sessions presented the highest frequencies of these two behaviours. It could be argued that this related to the curiosity about KASPAR as a new object.

The data showed that the behaviour concerning imitation decreased over time but since imitating the robot during activity C was coded as its choreography, these values actually increased. Even without analysing quantitatively the number of times that the children performed interaction behaviours (pointing, following, and imitating), it is interesting to notice that imitation is the most pronounced behaviour.

Besides eye gaze towards KASPAR and the experimenter, it was analysed, related to research question (a), if a triadic relationship between the child, the robot and the experimenter would emerge. On average, more than half of the eye gaze exchanges were triadic, which indicates that KASPAR fulfilled the role of social mediator between the child and the experimenter. It can also be argued that joint attention was promoted, shown by the fact that the responses towards KASPAR prompts were made mostly while looking at KASPAR or at the experimenter, corroborating the results from Robins *et al.* (2004).

These results suggest in general that the interaction and games performed with KASPAR were useful for the children's learning. It is reasonable to assume that KASPAR was a tool to promote this learning. The differences between the data in Figs. 3.7 and 3.9 represent the learning achievements of the children based on the type of activity.

For activity A, a comparison of session 1 and 2 shows a decrease of the success rate. This can be explained by the fact that the experimenter in the first session had to demonstrate how the activity worked most of the time, increasing success rate. From session 2 onwards, the children already knew the rules of the activity and the experimenter let the children give their answers spontaneously, this resulted in an increase of success since session 2 to session 4. After session 4 the children wanted to change activity and either to perform activity B or activity C. This can be explained by the lack of interest in one activity they could already perform well, desiring more challenging activities. The success of activities A and B comparing to the success in activity C is measured differently, therefore a direct comparison would not be meaningful. However, it can be said that children being involved in an activity during which they sing along and imitate other agents is a good indicator for social engagement. For them the expectations regarding research question (b) were fulfilled.

According to the data from the interview and the questionnaires some of the children that initially were not able to identify any of the body parts on themselves, showed an improvement on their knowledge. The teachers also indicated that the children transferred some of the knowledge learned during the sessions with KASPAR to the classroom. They gave in general very positive feedback, also described in the transcription of the teacher's interview.

While exploring and getting to know the new object and game partner, children touched KASPAR in different ways. In the first session, the value of prompted touches on KASPAR was higher than in the remaining sessions. The experimenter demonstrated how to touch the robot and then prompted them to tickle KASPAR. During the rest of the sessions, tactile interaction happened naturally. When harsh tactile interaction (e.g. poking KASPAR's eyes or mouth) occurred, it was rebuked by the experimenter by touching the children's arms and by verbal communication. The statistical results show a significant general increase of gentle touches compared to harsh touches (Fig. 3.6) and a significant general increase of spontaneous touches compared to prompted touches. Due to the nature of the experiment, the increase between the sessions is not linear. Sometimes children are less motivated - it can depend on external factors like the weather, for example (rain means no time to play in school yard) - but nevertheless when looking at the data a significant trend emerges. Following the observations from the video recordings, the most common body parts of KASPAR that the children touched were: feet, hands, head, and face. Tactile interaction with the experimenter was done mostly in a context when the experimenter prompted the child to show a body part on the experimenter, after KASPAR's prompt and the response of the child.

For example, the experimenter would say "That is KASPAR's nose, and where is my (the experimenter's) nose?". In those moments, the experimenter would allow the child to touch her, since it was considered a prompted and appropriate touch. Since activity C was introduced in the fourth session, which implied focusing more on the robot while looking at it, all behaviours regarding touching decreased, with the exception of touches performed by the experimenter on the child, and from the child on the robot in order to make it sing again (as mentioned above, the child was encouraged to touch KASPAR's hands to repeat the song). The experimenter touched the children's hands and arms to help them to do the song's choreography. Regarding the learning of appropriate physical social engagement with the robot, the results can be considered consistent with the expectations of research question (c), because tactile interaction with the robot was mostly gentle, which increased over time.

The fact that the difference between the first and the last session regarding the children's tactile interaction with KASPAR was not significant, could have different reasons. One explanation could be that all the children were even in the first session performing gentle touches in more of 90.0% of the tactile interaction. This by itself is interesting, since the teachers reported that this initial gentleness was surprising to them. Based on this descriptive quantitative data it is possible to argue that the exposure of the children to the interactive situation with KASPAR already induced a more careful behaviour.

As mentioned earlier, a key aim of this study was to learn about scenarios, data collection and data analysis when using a robot and children with ASD.

According to the skill to be promoted, and the corresponding tasks, it is advisable to choose different tasks which increase in difficulty on different levels. This will allow the children to improve their abilities and not loose motivation during sessions, which may happen if they have to perform the same task repeatedly. Specifically with this target group, it seems that a cooperative spatial placement of the actors in the room encourages the interaction between the child and the experimenter, since it facilitates the child to easily switch eye gaze between KASPAR and the experimenter.

Regarding the phases designed for this study (Section 3.2.5), the familiarisation phase should be highlighted, since it was quite useful to help the integration of the experimenter in the school environment, facilitating the adaptation of the children to an initial stranger.

On the topic of data collection, the diverse sources of data, such as the feedback from teachers, outcomes of specific tasks, behavioural analysis, among others allowed drawing the conclusions presented in this chapter. An important fact is that since the children are not able to express themselves directly most of the times, the teachers as the persons who work with the children closely should be carefully heard and included in the design of the experiments.

Regarding data analysis a precise definition of the behaviours to identify in the videos was essential. This was important, for example, to deal with instances of occlusion which could alter the final results. All the possible variations, as well as exceptions of a particular behaviour should be clearly expressed in this definition, so that the analysis is consistent.

### 3.4.1 Limitations of the Study

This study presents encouraging results indicating that the use of a robot as a tool to interact with children with ASD, promoting appropriate physical interaction and acquiring knowledge about naming of body parts can be beneficial for these children. However, due to the small size of the sample used in this study, the entire spectrum of the disorder might not be completely represented. Additionally the experimenter had to adapt to the individual differences between the children, mainly constituted by their communication abilities (non-verbal vs. verbal) and differences in attention span, which might have resulted in slight variations of the experimental procedure during the sessions.

### 3.4.2 Summary of Hypotheses and Implications

This study investigated if and how KASPAR could promote interactions between a child with ASD and another person. It specifically addresses the question of whether the robot could facilitate the acquisition of knowledge about human body parts, an issue present in many children on the spectrum. Regarding the research questions presented in the beginning of this chapter, the following implications were found:

**(a) Can the robot elicit increased interaction levels between the child and the other person in the experiment?:** Expectations regarding this research question were supported, with the children showing significantly more gaze directed towards KASPAR over sessions. However, along the sessions this behaviour was transferred to the experimenter;

**(b) Can the robot elicit the ability to acquire knowledge about human body parts?:** Expectations regarding this research question were partially met. The comparison of the scores in the pre- and the post-test allow concluding that the children managed to acquire new knowledge regarding body parts but not significantly. However, the results from the performance during the activities in the practice phase gives a clue that KASPAR contributed to a knowledge acquisition;

**(c) Can the robot help teaching children with ASD appropriate physical (tactile) social engagement?:** There was no typical pattern in the data regarding tactile interaction, however the number of harsh touches toward the robot was always lower than the gentle tactile interaction, which suggests the robot was a useful tool to encourage children with ASD to perform appropriate physical social engagement.

The goals of this research were to understand if and how the robot could promote interactions between a child with ASD and another person, and whether it could facilitate the ability to acquire knowledge about human body parts. The results of this study indicate that KASPAR can be used as an effective tool to elicit new knowledge about body parts, and also as a object of shared attention to improve social interactions with a human partner. Finally, the acquisition of appropriate physical social engagement was observed, using three different play scenarios. These structured play scenarios followed a strict experimental regime, are fully documented and hence represent a first step in the design of reliable behavioural tools for the development of potential future robot interventions.

## 3.5 Summary and Conclusions

This chapter presents a study in which the children were encouraged to learn about human body parts and simultaneously the robot was equipped with tactile sensors to act accordingly to touches from the children. The goal was to verify whether the robot could facilitate the interaction between the child and another person in the experiment using appropriate physical social engagement, and to acquire knowledge about human body parts.

The results show that the children spent more time looking at the robot, and that the

time they looked at the experimenter increased. Additionally, children who initially were not able to identify some of the body parts in the pre-test, showed an improvement of their knowledge, tested in the post-test. Regarding tactile interaction, the robot was a useful tool to promote appropriate tactile interaction since gentle touches on the robot were always lower than harsh touches along the sessions. It is necessary to point out that it is not possible to exclude that any observed improvements could be due to other activities at school or at home.
A triadic relationship was promoted between the child, the robot and the experimenter and the robot represents an alternative tool to already existing interventions with children with ASD, and the scenarios in which it can be used may be adapted to specific needs of a group of children, such as imitation, academic skills, and verbal communication. This study offers empirical support for continuing the research on how to use robots to foster social interaction with children with ASD.

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# Chapter 4

# Building Scenarios for Human-Robot Interaction in Children with ASD

The content of this chapter is part of the following publications:

- Costa, Sandra, *et al.* (2012), Constraints in the design of activities focusing on emotion recognition for children with ASD using robotic tools. 4th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob);
- Costa, Sandra, *et al.* (2013), Facial Expressions and Gestures to Convey Emotions with a Humanoid Robot. ICSR 2013, International Conference on Social Robotics (pp. 542-551). Springer International Publishing;
- Costa, Sandra, *et al.* (2014), Building a Game Scenario to Encourage Children with Autism to Recognize and Label Emotions using a Humanoid Robot, Roman 2014, 23rd IEEE International Symposium on robot and human interactive communication;
- Costa, Sandra, *et al.* (2014), A Pilot Study using Imitation and Storytelling Scenarios as Activities for Labelling Emotions by Children with Autism using a Humanoid Robot, IEEE ICDL-EPIROB 2014, The Fourth Joint IEEE International Conference on Development and Learning and on Epigenetic Robotics.

## 4.1 Introduction

This chapter presents different studies aiming the preparation of the research in Chapter 5. Section 4.2 includes the results of a questionnaire and focus groups performed with professionals who work with children with ASD. The hardware and the common materials used in following studies are presented in section 4.3 and section 4.4 presents the developed software. Section 4.5 presents a perceptual study where facial expressions and gestures performed by a humanoid robot were evaluated by typically developing children and adults. With the information and content of these studies, sections 4.6 and 4.7 present exploratory studies with a reduced sample of children with ASD to test three different game scenarios, aiming the identification and labelling of emotions.

## 4.2 Data Collection from Professionals to Develop Emotion Recognition Skills by Children with ASD

Professionals who work everyday with children with ASD were consulted with the goal of specifying the type of tasks and materials to use during play scenarios where the key element was a humanoid robot. Using the potentialities of a robot to promote emotion recognition skills in children with ASD, the adaptation of existing strategies was intended. This section presents a survey answered by nine professionals such as teachers, therapists, educators or doctors and two focus groups with nine special education carers and therapists.

### 4.2.1 Methods

Having the goal of developing the skill of emotion identification by children with ASD, the first step was to investigate how professionals usually develop this skill with this target group.

#### On-line Survey

Using an on-line survey, several professionals were invited to answer questions regarding their methods to develop these skills, in intervention sessions. Six questions were asked in order to get more information about main activities, main difficulties approaching this subject, and type of employed materials. Nine participants filled in the survey completely. The full survey can be found in Appendix B.1. Fig. 4.1 shows the participants' professional role. Most of the participants were teachers (67.0%) and they have between 3 and 23 years of experience working with children with ASD (M = 9.8 years; SD = 7.4).

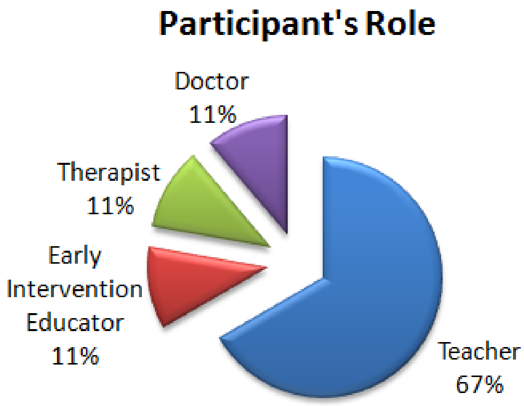


FIGURE 4.1: Professional role of the participants who answer the questionnaire. The majority were teachers working at special units where children with ASD receive individual intervention.

### Focus Groups

The intervention and therapy with children with ASD have specific constraints and in order to keep the children's daily routine, focus groups were organized with the goal of identifying the best procedure to conduct experiments with children with ASD in the session room.

Two focus groups were composed: one of them was formed by five professionals that normally accompany children with ASD as carers, and the other group was formed by four occupational and speech therapists. Focus groups were chosen as the research method for this study because they aimed at a discussion between the participants instead of individual responses to formal questions. It was expected to produce useful qualitative data to establish the protocol of the main experiments of the project. As a technique of qualitative research, the persons who participate in a focus group are asked about their perceptions, opinions, and beliefs. In the interactive group setting, the questions are asked and the participants are free to talk with other group members (Kitzinger, 1994; Stewart, 2007).

One of the goals of this study is to verify what kind of vocabulary should be used by the experimenter and by the robot in the instructions of the game scenarios. In addition, it was necessary to define which is the best position of the participants in the room (experimenter, child, and robot), and the procedure to start and finish sessions. The guidelines of the focus group were based on Krueger (2009), with the facilitator being the person conducting the interview. The structure of the interview with the focus groups was the following:

- Opening:
  - Delivery and signature of the informed consent form;
  - Icebreaker: a sheet of blank paper and a pen were placed in front of each participant. The facilitator requested each participant to draw on his/her sheet of paper, what they thought a robot looked like;
- Presentation of robotics definition: a set of techniques for the operation and use of robots in the execution of multiple tasks instead of man (E.g. washing machine, microwave, unmanned vehicles in the industry, educational robotics, military robots, among others);
  - Brief introduction of Robotica-Autismo Project;
  - Presentation of the research on emotions with humanoid robots;
- Questions:
  - Role-Play: It was requested a volunteer who played a 10-years-old child with ASD. The facilitator played the role of the experimenter during a session. Then, it was asked to the rest of the participants to use the blank sheet of paper to take notes on the following aspects:
    * Vocabulary to use;
    * Distribution of the elements in the session room (experimenter, child, robot);
    * Procedures for starting and ending sessions;
    * Material that can help sessions;
    * Suggestions.
- Scripted Role-Play (from the experimenter's point-of-view):

- Takes the child by the hand and brings him/her into the room;
- Shows a Picture Exchange Communication System (PECS) Card to the child with a picture of the robot (and its name);
- Sits the child on a chair next to the robot and sits in another chair (forming a triangle);
- Introduces the robot;
- Introduces the activity;
- Provides reinforcement, after the child's answer;
- Ends session;
- Takes the child by the hand out of the room.

- Open discussion regarding the methodology to implement;
- Closure:
  - Acknowledgement to participants;
  - Further contact;
  - Report on how the information is going to be used and next steps of the project.

### 4.2.2 Results

The average completion time of the survey was five minutes. As a qualitative source of information, answers from the professionals are transcribed below. The questions, and the corresponding answers were the following:

**Q1: How do you develop emotional recognition? In what ways do you teach feelings: happy, sad, angry, etc.?**
- Imitation of behaviours;
- Social Stories;
- Images;
- In context and supported by visual information;
- Video or alternative communication;
- Symbolic writing;
- Association games with images of facial expressions or events related to emotions;

- Facial mimic;
- The use exaggerated facial expressions.

**Q2: What are the main difficulties while developing emotion skills in children with ASD?**

- To receive an immediate response from the child;
- To attract the child's attention;
- To explain facial expressions nuances;
- The adequacy of the feelings into proper context;
- To put themselves in place of other;
- To associate specific situations to emotions;
- To establish eye contact;
- Incapability to express themselves and convey ideas on what they feel;
- Communication skills;
- To recognize the emotional states of the child;
- To generalize the emotion recognition in pictures or images to real persons and in context.

**Q3: Which kind of materials are used to develop these skills?**

- Images (with or without captions);
- Words associated to emotions and situations;
- Emotions Lotto;
- Stories;
- Sequential image game (Cause-Effect-Emotion);
- Puppets;
- Mirrors;
- Computer Games;
- Clay;
- Films;
- Toys.

**Q4: Is the recognition of emotions a goal of the educational program of the children in your school/association?** Only one participant answered that emotional recognition was not a goal of the educational program in her school/association. The rest of the participants affirmed that this skill was developed in their educational programs.

**Q5: Is this attendance done together with other children or individually?** The professionals' opinions were equally divided between performing these activities in small group or individually (Fig. 4.2).

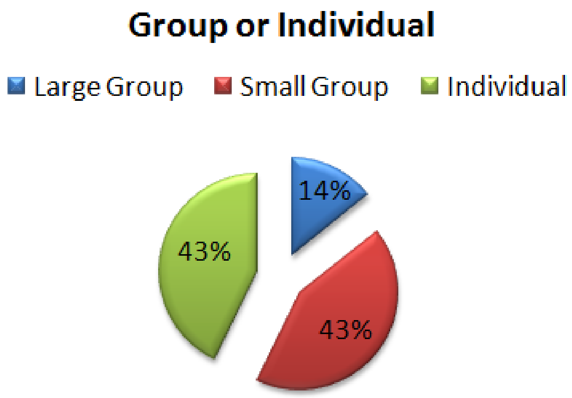


FIGURE 4.2: Children's attendance to sessions. Small groups and individual intervention is used mostly by the participants.

**Q6: If possible, suggest us two or three activities performed by you with children with ASD, to develop emotional recognition.**

- Social Stories;
- Facial expressions imitation;
- Observation of pictures;
- Facial expressions Lotto;
- Peer facial expression reading;
- To build faces in clay;
- Cards game - identify and reproduce;
- To say a word or sentence expressing an emotion.

Regarding the results of the two focus groups made with carers and therapists, the conclusions were divided in four categories: vocabulary to use, distribution of the elements in the session room (experimenter, child, and robot), procedures for starting and ending sessions, and material that can help sessions. In each of the four categories the opinion of all the participants was taken into account, and they are summarized in the following paragraphs:

**Vocabulary to use:**

- Avoid direct questions to the child;
- Use clear instructions and with the same level of vocabulary;
- The speech should be paused and rhythmic.

**Distribution of the elements in the session room:**
- Use a familiar room to perform the sessions;
- Find a position of the elements in which the experimenter does not look directly to the child.

**Procedures for starting and ending sessions:**
- Evaluate if the child tolerates tactile interaction to bring him/her from the classroom;
- Avoid direct physical contact, letting the child start those behaviours;
- Ask one of the carers to take the child and stay in the session room, if necessary;
- Make an introduction about the robot, so the child consider it a safe object to play;
- Use the robot to meet the interest of the child;
- Use PECS if the child normally uses them in their daily routine;
- Let the child explore the new object, giving him/her time to observe the robot's specificities.

**Material that can help sessions:**
- The images the child is going to use to match facial expressions on the robot should be resistant;
- All extra material should be colourful to attract their attention.

### 4.2.3 Discussion of the Results

Having in mind the responses given by these professionals, it was necessary to select the best approaches to be adapted to new game scenarios. These game scenarios would have to include the robot as the central element. Three different game scenarios were chosen:
- Recognize: The child should match the facial expression performed by the robot with a selection of images with facial expressions.
- Imitation: The robot performs a facial expression and the child should imitate it.
- Storytelling: The robot tells a simple story about a situation that happened to it, and the child should match the robot's "feelings" in the end of the story.

All the indications given by the participants in the focus groups were included in the procedure of the exploratory studies presented in the following sections.

### 4.2.4 Summary and Conclusions

The insight and feedback of professionals who interact with children with ASD play a key role in the research design. With this knowledge and with the perspectives based on the literature, game scenarios which aim to develop emotion recognition skills in children with ASD started to be prepared. The definition of these game scenarios was the first step to start modelling the interaction between the experimenter, the robot, and the child, also called a triadic interaction. The following sections are going to take into account this information to establish a flow of events in each game scenario, to increase the children's attention span and interactive behaviours such as verbal and non-verbal communication, or tactile interaction.

## 4.3 Hardware and Common Materials

The adopted materials and general procedures used in this research work are described here. These elements concern the ethical issues, the robot, the room setup, the evaluation tools, and the materials used for the robot to receive the input from the participants. Regarding the two latter, specificities related to the established goals are going to be highlighted in each study.

### 4.3.1 Ethics Statement

A partnership protocol was established between the University of Minho and each of the schools, clinics and associations where the experiments took place. This protocol identified the researcher involved in the experiments and the assigned professionals who supported the research. The experimenter made the commitment to make available the results and conclusions from the research, through scientific reports. The schools, clinics and associations made the commitment to collaborate in the experiments, by the support of their professionals, the use of the intervention rooms and the connection to the children's family.

Parents of the children signed a consent form in which they were notified about the goals and applied methods of the research. This consent also included a document with information about the risks and benefits arising from the research, as their entire freedom to decide on their acceptance to participate and to withdraw their child from the research project at any time. The children's teachers were consulted and informed about the activities to be performed and gave suggestions intended to improve them.

### 4.3.2 The Robot

The robot used in the studies differs greatly from robots used in other designs due to the face being covered with a polymeric material called Frubber, giving it the ability to display varied facial expressions (Fig. 4.3).

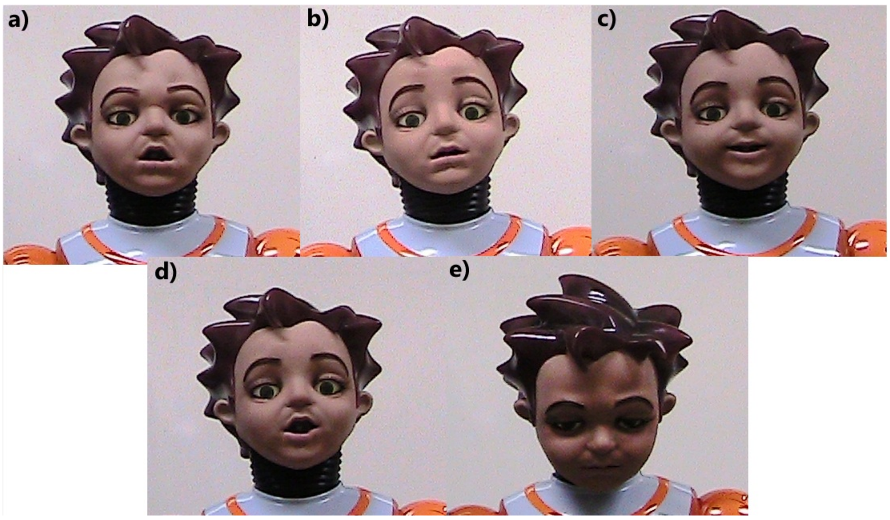


FIGURE 4.3: Facial expressions displayed by ZECA. a) anger, b) fear, c) joy, d) surprise, e) sadness.

This humanoid robot developed by RoboKind (Hanson *et al.*, 2009) possesses a walking body (with 31 degrees of freedom in total) that simulates expressive capabilities of a human-inspired character face and gestural body. The following Degrees of Freedom (DoF) are included:

- 12 DoF for the legs to enable walking, gesture, dancing, and pose. These DoF will use Dynamixel RX-64 servomotors and all associated control electronics;
- 1 DoF for waist turn;
- 10 DoF for arms and hands (5 per arm);
- 3 DoF for neck actions - controlling pitch roll and yaw of the head;
- 1 DoF for Smiling/Frown - zygomaticus major - oblique upward lip corner, and depressor labii (1 motor actuates both sides and both muscle groups);

- 1 DoF for Frontalis/Corrugator/procerus - brow knotting/knitting, brow upwards (1 motor actuates both sides and all these muscle groups);
- 1 DoF for blinking (1 motor controlling all eyelids);
- 1 DoF for jaw action;
- 1 DoF for left eye-turn;
- 1 DoF for right eye-turn;
- 1 DoF for eye up-down action (both eyes together, coupled), also actuating the eye lids up and down.

The robot is 60 cm tall, weights less than 6 kg, is low power, and battery operated (Fig. 4.4).

FIGURE 4.4: Zeno, the humanoid robot produced by Hanson Robotics.

It has two hi-definition (HD) 720p cameras embedded in its eyes with USB-2.0 interfaces and it includes Wi-Fi, USB ports, and all associated power adapters. The RoboKind software performs animation and motion control functions and it includes an Application Programming Interface (API) for rapid integration of other components, distributed computation and shared control. The robot includes the parameters between face expressions and servo-motors. Technical drawings of the robot can be found in the Appendix B.2. Hereafter, the robot is going to be referred as ZECA (Zeno Engaging Children with Autism).

### 4.3.3 The Room Setup

The sessions took place in an individual context, encouraging triadic relationships between the child, the experimenter and the robot (Fig. 4.5).

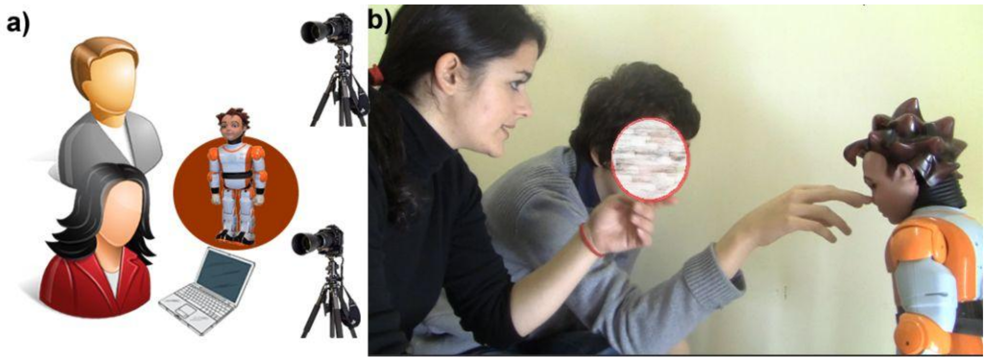


FIGURE 4.5: Room setup which comprises besides the robot, the child, and the therapist, two cameras to record two different angles of the interaction, and one laptop.

The arrangement of the elements in the room (robot, child and experimenter) was organized according to a cooperative position (Pease & Pease, 2008), in accordance to the results from section 4.2. The robot in the centre of the room forms a triangle with the child and the experimenter, promoting a triadic interaction. Two persons work together on the same task, providing an opportunity for eye contact and mirroring. With this arrangement, the child's space is not threaten and there is no forced eye contact, allowing the experimenter to encouraged the child to participate and be engaged in the interaction. With exception to the study presented in section 4.5, all sessions were videotaped, with two cameras put in strategic places to record the interaction of the child with the robot and the experimenter.

### 4.3.4 Behavioural Analysis

Besides formal questionnaires given to teachers, the video analysis of the children's behaviours played an important role and they are the main source of information. The produced videos were analysed using the specialized software The Observer XT from Noldus (Noldus, 1991) to quantify predetermined behaviours performed by children.
The selection of the behaviours was done according to its relevance (regarding engagement, and interactive behaviour), and feasibility to identify them in the recorded data. Regarding non-verbal communication, the literature was consulted to choose

the expected behaviours to be observed in children with ASD (Mundy *et al.*, 1986). In each study, the coded behaviours from the list below will be presented according to the goals of the study. In this list, state events stand for behaviours that take a period of time and therefore have a duration. Point events stand for a behaviour that only takes an instant in time, or whose duration is not important.

- Eye Gazing Behaviour (State Event):
  - Robot: head orientation of the child looking towards the robot;
  - Experimenter: head orientation of the child looking towards the experimenter, except experimenter's eyes;
  - Task's Material: head orientation of the child looking towards the task's material;
  - Eye Contact: head orientation of the child looking towards the experimenter, specifically to her eyes;
- Tactile Interaction (Point Event):
  - Robot's Body: from the moment the child touches the robot on its body;
  - Robot's Head: from the moment the child touches the robot on its head;
  - Experimenter's Body: from the moment the child touches the experimenter on her body;
  - Experimenter's Head: from the moment the child touches the experimenter on her head;

    For all the above behaviours regarding tactile interaction, they were classified into:
    * Spontaneous: the experimenter did not encourage the child to perform the behaviour;
    * Prompted: the experimenter encouraged the child to perform the behaviour;

    Touches were also classified into gentle and harsh;
- Non-Verbal Communication (Point Event & State Event (for imitation, smiling and leaning forwards)):
  - Following: the child follows with head movement (eye gaze if possible) a pointing gesture (with index finger or hand) of the experimenter (even if the pointing gesture is not being performed any more);

  - Pointing: the child points at something with index finger to attract the attention of the experimenter;
  - Robot's Imitation: coded when the child copies movements from the robot;
  - Experimenter's Imitation: coded when the child copies movements from the experimenter;
  - Smiling: upward curving of the corners of the child's mouth;
  - Clapping Hands: the child joining hands together producing sound;
  - Leaning forwards: the child leans forward towards the robot/experimenter or stands up getting closer while either looking at or touching;

- Verbal Communication (State Event):
  - Echolalia: words or sentences repeated after the experimenter or the robot said them;
  - Vocalisations: speech that becomes broken down, cluttered, or unintelligible due to a variety of reasons, and oral sounds made by child without meaning;
  - Speech: words and sentences said by the child;

- Prompts (Point Events):
  - Ins-Happy: prompt made either by the robot or the experimenter to request the answer happy;
  - Ins-Sad: prompt made either by the robot or the experimenter to request the answer sad;
  - Ins-Surprised: prompt made either by the robot or the experimenter to request the answer surprised;
  - Ins-Afraid: prompt made either by the robot or the experimenter to request the answer afraid;
  - Ins-Angry: prompt made either by the robot or the experimenter to request the answer angry;

- Answers (Point Events):
  - Happy, Sad, Surprised, Afraid, Angry: answer given by the child;
  - Successful: Right answer to the previous prompt;

  - Unsuccessful: Wrong answer to the previous prompt;
  - Unanswered Prompt: There is no answer from the child or when the experimenter repeats the previous prompt;

The following list summarises the behaviours coded in the performance task of the pre- and post-test used to assess the knowledge of the child regarding emotion recognition. This task is explained in section 4.6.

- Happy, Sad, Surprised, Afraid, Angry: emotion the child is attempting to match with PECS card;
  - Right Answer: If the child puts the picture of the person in the right place;
  - Wrong Answer: If the child puts the picture of the person in the wrong place.
- Duration: Duration of execution of the performance task

Independent raters were trained to code the behaviours above. Their rating included the following rules:

- When looking at an interaction, the rater should, first, classify the function; second, decide who initiated the function; to establish if the child's behaviour is prompted or spontaneous, if applicable; and third, identify the particular behaviour code;
- If a behaviour is not well-defined, it may not be rateable. It is better not to rate a behaviour than to categorize it without sufficient information;
- Do not code any behaviour that is obscured (e.g., by the experimenter blocking the camera's view of the child);
- When the child exhibits behaviours that were not specified in the list, they are not coded;
- A behaviour ends if the child stops exhibiting that behaviour or shows another behaviour, directly related (for example, looking at ZECA/looking at the experimenter);

- For Eye Gaze, turning away ends the behaviour. Turning back immediately and looking again counts as new behaviour;
- For Tactile Interaction, mark whether the child shows the behaviour spontaneously or whether the behaviour is prompted by the experimenter. If the child touches the robot for no specific reason, the behaviour is classified as spontaneous. If the experimenter gives an indication such as "Do you want to touch him?", the behaviour is considered prompted;
- For Tactile Interaction, if the child hits, pushes, or grabs the robot, the touch is marked as harsh. Poking eyes, nose or mouth is considered harsh touch. If the child taps, tickles or touches the robot, the touch is marked as gentle;
- For Following, the emphasis is on behaviours made after the experimenter directs attention to an object or event, thus establishing a common focus of attention between the child and adult. This behaviour should be coded when the experimenter starts pointing;
- For Pointing, the emphasis is on behaviours used by the child to request the experimenter's attention for any objects or events. This behaviour should be coded when the child starts pointing;
- For Imitation, repetition is not coded if the child is performing that particular action previously. Verbal repetitions are not considered imitation;
- An activity starts after the sentence "Push START to begin", and an activity ends after the robot says "See you soon";

The onset and offset times of behaviours and coding of events were used to record the behavioural sequences.

Recording the onset and offset times was chosen because, for most of the research questions, time information is necessary (Bakeman & Gottman, 1997). In this way, it is possible to report time-budget information and report different kind of behaviours coordinated with time. To facilitate, it is useful that these codes are mutually exclusive because the offset times do not need to be recorded. In such cases, the offset of a code is implied by the onset of another mutually exclusive code. So, with this recording scheme, it is possible to preserve a complete record of how behaviour unfolds in time, recording the onset (and offset, when it is necessary) times for all events that can be coded.

The use of coding events is useful, when there is a concern with the sequence of behaviours rather than their duration. So, coding events will also be a recording scheme to be used when analysing data.

After choosing a recording scheme, it is important to decide which observational data representation will be used. Depending on how data is recorded, different representations from the same data can be extracted for different purposes. For the studies presented in this thesis, the appropriate data representation form is time-event sequences (Bakeman & Gottman, 1997). Once data is represented in this form, it is possible to determine, for instance, how often specific behavioural codes co-occur, or whether certain behavioural codes tend to follow or precede other codes in systematic ways. As mentioned before, event sequences are used to represent observational data from events coded. Event sequences consists simply of codes for the events, ordered as they occurred.

### 4.3.5 Robot's Input and Processing

To allow the automatic identification of the answers to the robot's prompts, the children could select one of five rackets presented in front of them and showing it to the robot (Fig. 4.6).


FIGURE 4.6: Rackets used by the children to answer the prompts of the robot. Each racket features a picture of a face, a label (written in Portuguese), and QR code corresponding to the emotion.

The images displayed on the rackets were chosen considering the opinion from professionals working in special education. Four options were presented: to use PECS images, photographs depicting the emotional state of the experimenter, the robot or an unknown person. The first option was discarded because even though these cards are normally used with these children to develop other types of skills, they present the difficulty of generalizing the labelling of emotions to human beings. Using an image of the experimenter could be an advantage, and the generalisation could be easier, but the fact that the experimenter was also in the room could lead the child to compare the racket to the experimenter and not to the robot. This option was excluded to try to prevent all sources of distractions. The third option was discarded as well not to hinder potential generalisation. Thus, the chosen option was the images with unknown persons, so it could be easier for the children to generalize to another human being.

Each racket featured a picture with a face representing an emotion and its corresponding label. The images representing the facial expressions on each racket were evaluated using an on-line questionnaire with a group of 76 adults (with the age range: M = 28.3; SD = 8.3). The ratings given by the participants showed a good accuracy level. Specifically, the recognition rates were: fear - 100.0%, joy - 100.0%, sadness - 100.0%, surprise - 96.1%, and anger - 98.7%.

Additionally, each racket had a Quick Response (QR) code which was used to automatically identify the emotion. This QR code was then read by one of the HD cameras of the robot.

The experiments started with the robot prompting the child. The child answered, choosing the corresponding racket. When the child answered successfully, the robot gave him/her a reward based on the type of favourite reward identified by the teacher (either movement, verbal, sound or combinations of them). If the answer was incorrect, the robot shook its head and said, for example "Ups. Pay attention. Let's try another one!".

## 4.4 Software Architecture

Fig. 4.7 presents the main procedure of the software produced to include in ZECA. The software is based on parallel programming using threads to execute individual processes at the same time. When the process starts, the robot moves to a default position and greets the experimenter, asking the code of the child who is going to participate in the session.

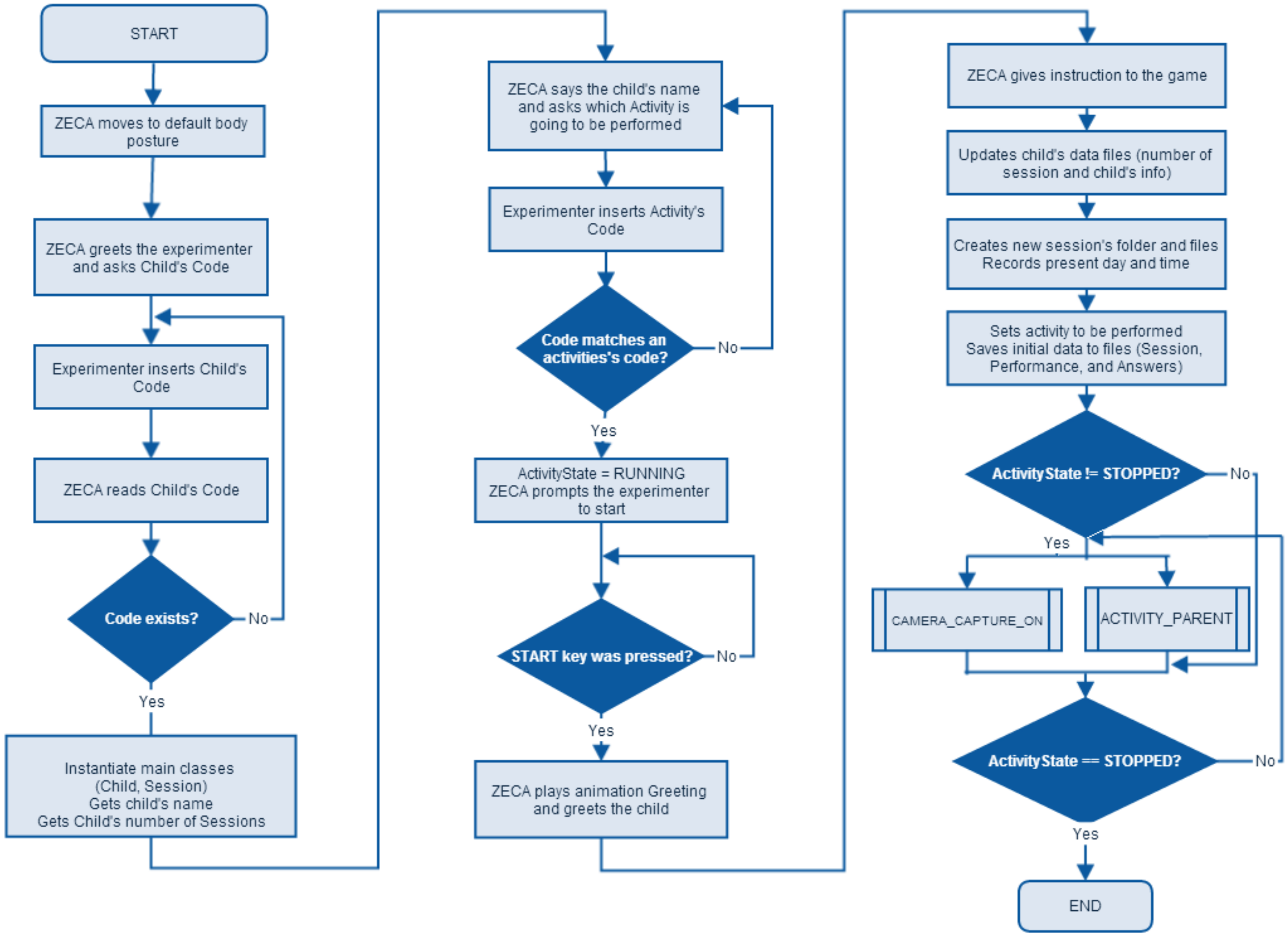


FIGURE 4.7: Flow chart with the main procedure of the software, calling the subroutines CAMERA_CAPTURE_ON and ACTIVITY_PARENT.

After the validation of the child's code, the main classes are instantiated, and the name of the child and the number of the sessions already performed by that child are obtained from the database. The database was previously prepared with the information from the questionnaires filled in by the teachers or therapists: name, date of birth, favourite reinforcement, among others). The experimenter is prompted by the robot to insert the code corresponding to an activity, and this code is verified. After the experimenter pushes the start key, ZECA greets the child and gives the instruction to the chosen game. The child's data is updated and the folder to save the files of the session is created, recording the date, time, performance, and answers in that session.

The ACTIVITY_PARENT subroutine (Fig. 4.8) describes the common procedures to all game scenarios, such as accessing the database and the state management (RUNNING, PAUSED, STOPPED). Once one game scenario is activated, none of the others can be running at the same time. However, after pausing the game scenario, the experimenter can switch from one game to the other, in the same session.

After getting the information from the child and the session, the classes related to the answers, performance, emotions, and time are instantiated. The type of reinforcement to give to the child is obtained and the timer is started. While the activity is running, and not paused, the activity is processed according to its type. When the time is up or the stop key is pressed the activity finish, with the robot's farewell.

Besides the ACTIVITY_PARENT subroutine, CAMERA_CAPTURE_ON is running. The robot is equipped with cameras in its eyes, and one of then is used for image processing (Fig. 4.9). Briefly, after connecting the camera service, the image obtained by the camera is converted from Blue-Green-Red (BGR) to Red-Green-Blue (RGB). Afterwards, the threshold method is used to obtain the region of the image equal to yellow, the colour of the rackets. If the racket is detected, and a valid QR Code is obtained, the string obtained from this reading is saved in a variable.

There are five types of QR codes possible to identify by the system matching the five basic emotions. During the experiments, the experimenter has the access to a wireless numeric keypad. The software was prepared to receive commands from this keypad either to start, pause, stop, change the game scenarios, and to insert the child's answer, if necessary. This was only done, if the children showed impaired motor skills preventing them of holding the racket in front of the robot. There are three reasons why the use of the keypad was avoid, every time possible: in order to help the fluidity of the game scenario; to free the experimenter to interact with the child, and to match the children's expectations, since they can get frustrated and discouraged in case of the robot not being able to receive their answer and evaluate it in a synchronized interaction.

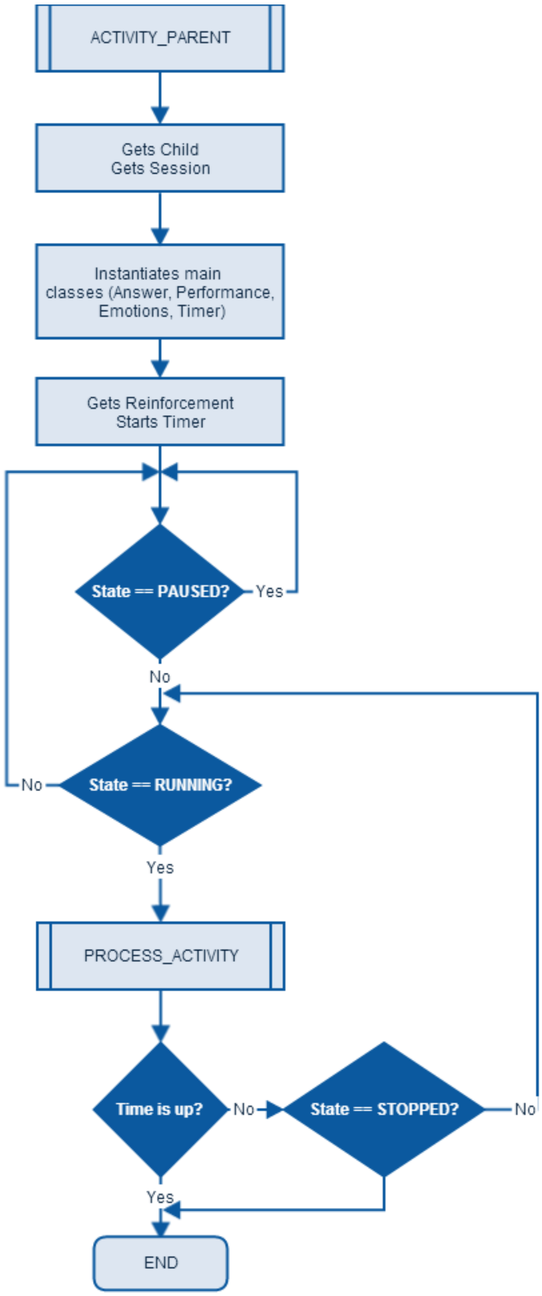


FIGURE 4.8: Subroutine showing the general process for all the game scenarios which start in the ACTIVITY_PARENT subroutine.

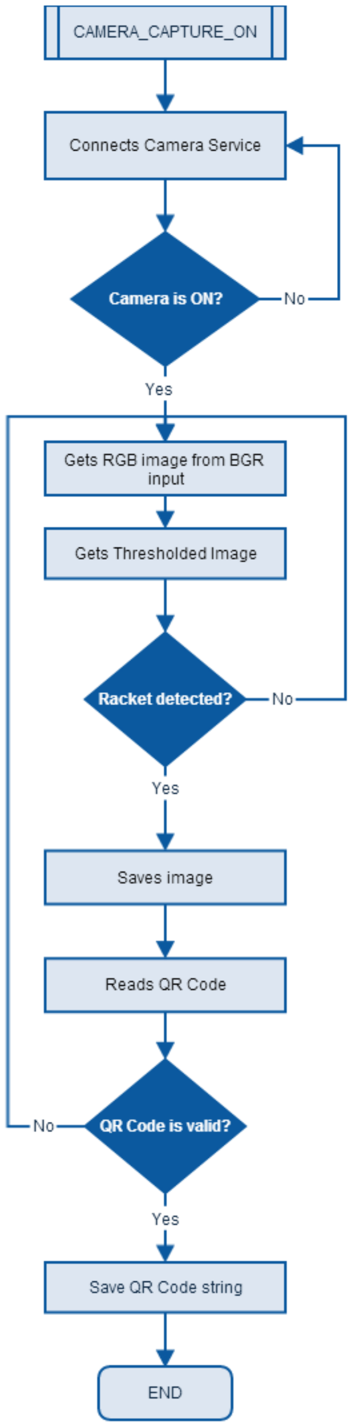


FIGURE 4.9: Subroutine showing the processing done over the image obtained from the robot's camera.

## 4.5 Recognizing Emotions displayed by a Humanoid Robot - a Perceptual Study

This section presents the results of a perceptual study with ZECA, evaluating its ability to display facial expressions representing emotions. The design process and its iterations is presented targeting the final study with children with ASD. Facial expressions and gestures conveying emotions such as sadness, happiness, or surprise are displayed by ZECA. The design of those facial expressions based on action units and the matching gestures is presented.
The group of participants composed by typically developing children and adults answered a questionnaire intended to verify if those expressions with or without gestures were recognized as such in the corresponding video.
With this study, the following research questions were addressed:

**(a)** Can facial expressions displayed by a humanoid robot and showed in video elicit the recognition of the corresponding emotion?

**(b)** Would the addition of gestures increase the emotion recognition rate?

**(c)** Is there a difference in the emotion recognition when the participants belong to different age ranges?

In order to answer (a), a questionnaire based on videos of ZECA showing the different emotions was shown to the participants to be rated accordingly. It was expected that the groups of participants achieved a recognition rate at least of 70.0% for all the presented emotions and between them. This value was found calculating the overall average recognition rate of the studies presented in section 2.3.3.
Concerning (b), and using the same source of information, it was expected that the addition of gestures increased the recognition rate.
Regarding (c), an analysis of the participants' answers was done to verify if their age influenced the results, and it was expected that both children and adults had similar recognition rates.

### 4.5.1 Methods

This section presents the process used to design the facial expressions and gestures displayed by ZECA. Preliminary tests were used to evaluated them and a perceptual study was prepared to assess videos containing the created facial expressions and gestures. The feedback from the preliminary tests is presented in this section and it is used as input for the perceptual study, whose results are presented in the next section.

**Preliminary Test 1** Using a robot to foster emotion recognition skills leads to the question of which emotional classification should be used to represent different facial expressions. Two options arise: emotions as discrete categories or dimensional models of emotion.

On one hand, the Discrete Emotion Theory suggests that every human being is thought to have an innate set of basic emotions that are cross-culturally recognizable. On the other hand, dimensional models of emotion attempt to conceptualize human emotions according to one or more dimensions.

The two-dimensional models that are most well-known are the circumplex model, the vector model, and the Positive Activation-Negative Activation (PANA) model. James Russell defined the circumplex model of affect where the emotions are distributed in a two-dimensional circular space, containing arousal and valence dimensions (Russell, 1980). The vector model of emotion is a two-dimensional model, which assumes that there is always an underlying arousal dimension, and that valence determines the direction in which a particular emotion stays (Bradley *et al.*, 1992). The PANA model of emotion suggests that positive and negative affect are two separate systems. In its graphical representation, the vertical axis represents low to high positive affect and the horizontal axis represents low to high negative affect. The dimensions of valence and arousal lay at a 45-degree rotation over these axis (Watson & Tellegen, 1985). The three-dimensional Plutchik's model arranges emotions in concentric circles where emotional words were plotted based on similarity (Plutchik, 2001). The PAD (Pleasure, Arousal and Dominance) emotional state model describes and measures emotional states using three numerical dimensions to represent all emotions (Mehrabian, 1980). The Lövheim cube of emotion presents a direct relation between specific combinations of substances levels of dopamine, noradrenaline and serotonin and eight basic emotions (Lövheim, 2012).

It is known that children with ASD need facial expressions to be strong and marked so they can perceive them as such (Baron-Cohen, 1991). For this reason, emotions as discrete categories seem to be the more reasonable choice to display facial expressions by ZECA. The leap from one expression to the other is distinct and disconnected to facilitate the differentiation and identification. In addition, there is already an extensive cross-culturally research based on these expressions which indicates that these discrete

emotions are universal. Emotions represented by other models are based on a mixture of dimensions and present a difficulty of being represented on a robot. In summary, the basic emotions defined by Ekman (Ekman & Rosenberg, 1998) were chosen to display on ZECA: happiness, sadness, surprise, fear, anger, and disgust.
Action Units (AU) used by Ekman (Ekman & Rosenberg, 1998) in the Facial Action Coding System (FACS) were studied to reach the desirable expressions better and faster. Ekman defined which AU (fundamental actions of individual muscles or groups of muscles) would be necessary to define the basic emotions, and using this information, the robot joints were defined to get the correct correspondence as it is shown in Table 4.1. The description of all AU can be found in Ekman & Rosenberg (1998) and in Appendix B.3.

TABLE 4.1: Matching of the Action Units defined by Ekman and the Servo Numbers of ZECA

| Emotion | Action Units - Appendix B.3 | Servo Numbers - Figure 4.10 |
|---|---|---|
| Happiness | 6+12 | 9+11 |
| Sadness | 1+4+15 | 3+4+9+11 |
| Surprise | 1+2+5B+26 | 3+4+5+6+9+11 |
| Fear | 1+2+4+5+7+20+26 | 3+4+5+6+9+11 |
| Anger | 4+5+7+23 | 3+5+6+9+11 |
| Disgust | 9+15+16 | 9+11 |

Figure 4.10 represents the mapping presented in Table 4.1.

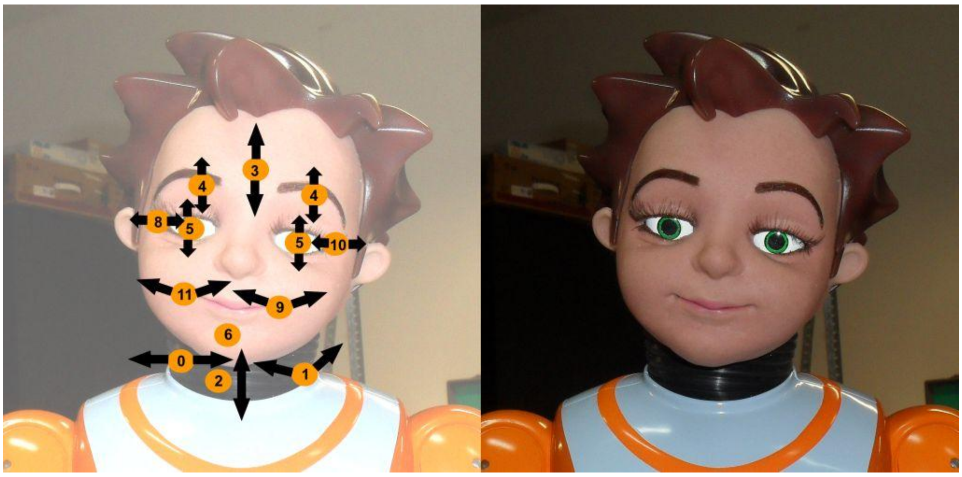


FIGURE 4.10: Mapping of the servos on ZECA's face.

The display of these facial expressions were defined in experimental preliminary tests in laboratory. The preliminary study 1 was done with seven adults who classified the first set of facial expressions. It was requested from these adults to classify each of the facial expressions plus the neutral one, using a forced choice. The participants could also choose the option "I do not know". This experiment was done individually on a computer, and through the observation of seven videos with the robot displaying these emotions. The participants had then to register their answers in a notebook. The results of the preliminary test 1 are represented in Fig. 4.11.

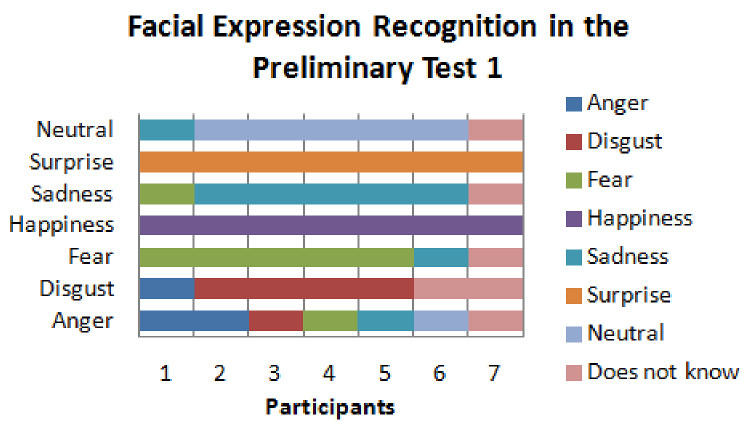


FIGURE 4.11: The result of the recognition of the facial expressions on ZECA in the Preliminary Test 1 with 7 adults.

Despite the good results on the corresponding facial expressions to happiness (100.0%), sadness (71.4%), surprise (100.0%), fear (71.4%), and neutral (71.4%), some more development needed to be done to the disgust (57.1%) and anger (28.6%) facial expressions.

**Preliminary Test 2** Using FaceReader from Noldus (Den Uyl & Van Kuilenburg, 2005), the previous set of facial expressions was evaluated. FaceReader is a software tool for automatic facial expression analysis. This software works in three steps: face finding - an accurate position of the face is found; face modelling - the active appearance model is used to synchronize an artificial face model, which describes the location of 500 key points as well as the texture of the face; and face classification - output is presented as six basic expressions and one neutral state (Den Uyl & Van Kuilenburg, 2005). ZECA has in its head eleven degrees of freedom (DoF): Neck Yaw, Neck Roll, Neck Pitch, Brows Pitch, Eyelids, Eyes Pitch, Eye Left, Eye Right, Jaw, Smile Left, Smile Right. Due to the lack of DoF on the nose and cheeks, it was not possible with the software to identify the disgust facial expression. Therefore, it was decided to exclude this facial expression from the final perceptual study.

Several images were subjected to the FaceReader software analysis. The performance of the robot in the rest of the facial expressions was quite satisfactory and examples can be observed in the following figures. In Fig. 4.12, the robot is displaying the sad face, and a great intensity is obtained from the raising of the inner brow. The Brow Lowered AU was not identified probably because of the distance between the eye and the brow is considerable higher comparing the robot to a human being.

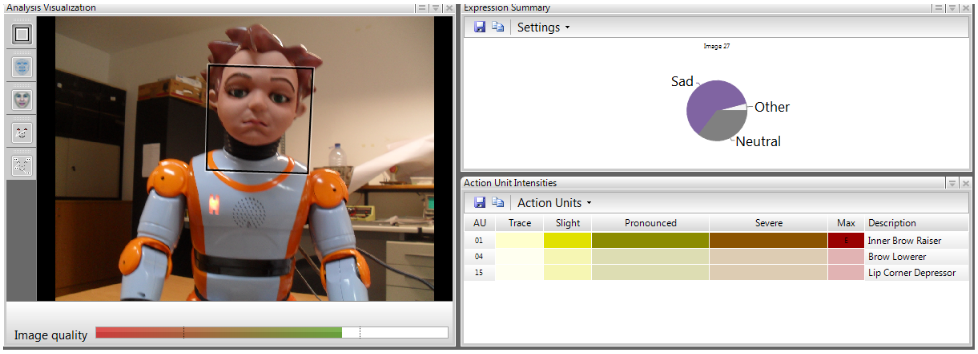


FIGURE 4.12: Results from FaceReader software when analysing the sad facial expression.

Figures 4.13 and 4.14 also show a recognition rate higher than 50% for fear and surprise, respectively. In the first facial expression, the Upper Lid Raiser and Lip Stretcher are activated, while, in the second one the Inner and Outer Brown Raiser, and the Upper Lid Raiser express surprise.

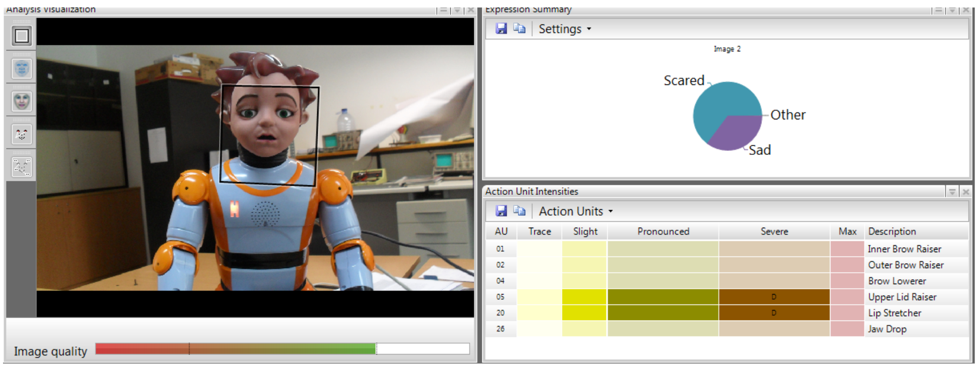


FIGURE 4.13: Results from FaceReader software when analysing the scared facial expression.

Both anger and happiness were hard to be recognized using this software (Figs. 4.15 and 4.16) even that most of the AU necessary to represent these expressions were present. Most probably they were not marked enough for the software to recognized them.

A recognition rate close to 100.0% is presented in Fig. 4.17 for the neutral facial expression.

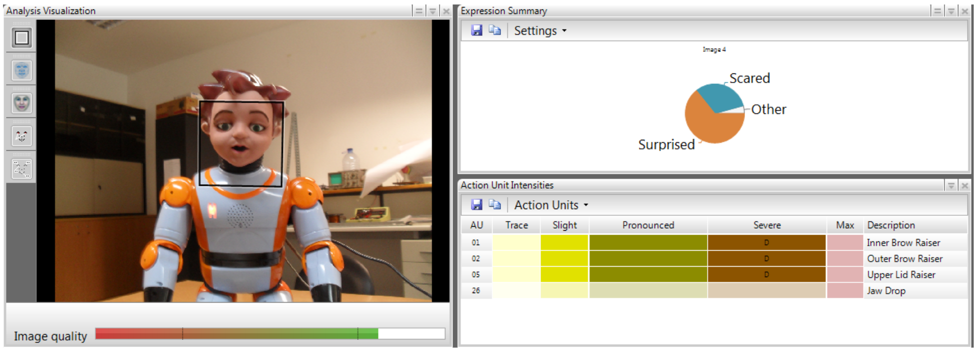


FIGURE 4.14: Results from FaceReader software when analysing the surprised facial expression.

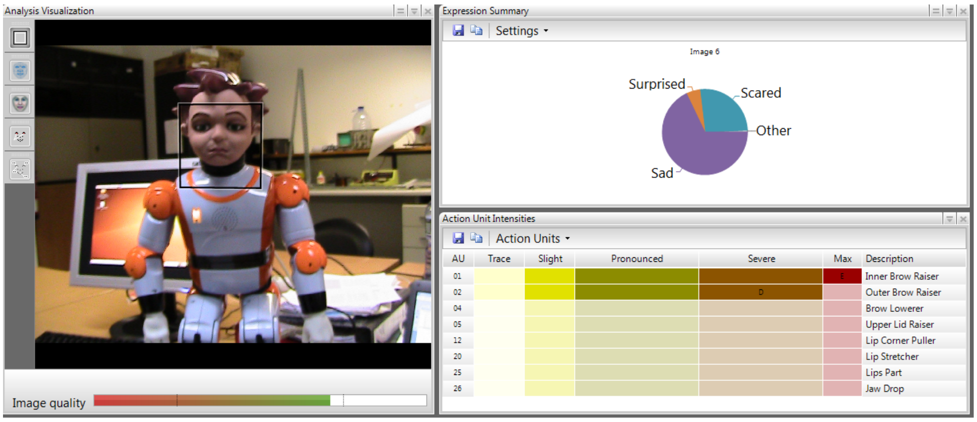


FIGURE 4.15: Results from FaceReader software when analysing the angry facial expression.

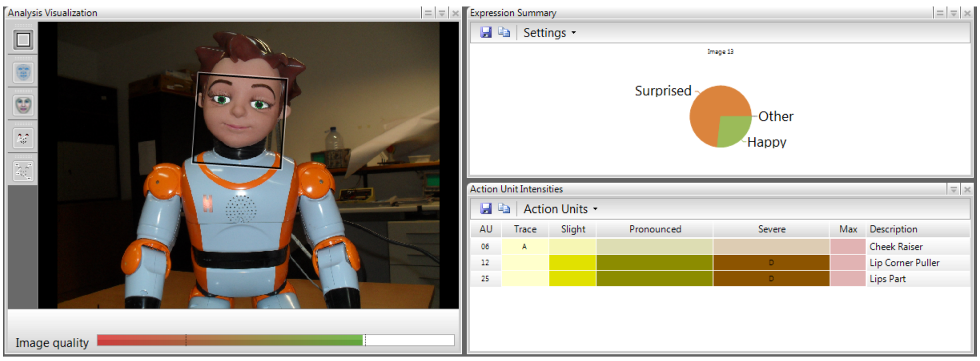


FIGURE 4.16: Results from FaceReader software when analysing the happy facial expression.

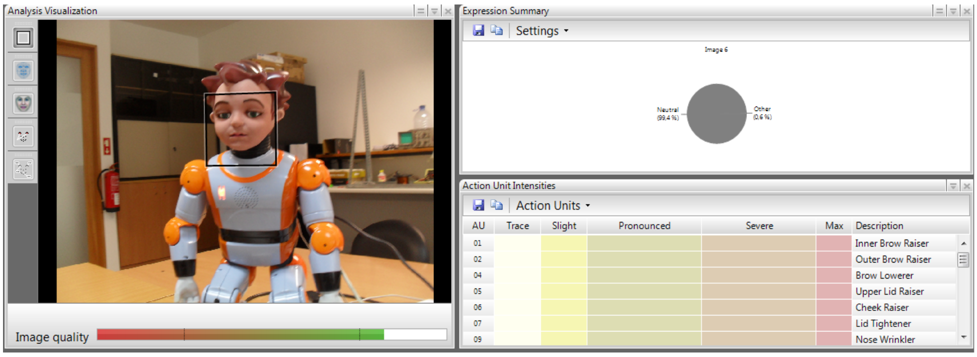


FIGURE 4.17: Results from FaceReader software when analysing the neutral facial expression.

**Perceptual Study** From the previous preliminary tests and post-refinements with the help of a speech therapist, a new set of videos was built, and a perceptual study was designed to verify the reliability of the produced data. An on-line questionnaire was built with the intention of providing a precise representation of the perceptions both from typically developing children and adults. This test was performed with this sample exactly to certify that the produced facial expressions and gestures were suitable to be used as representations of basic emotions and consequently with children with ASD.

The participants watched videos with ZECA displaying only facial expressions and then displaying facial expressions and gestures corresponding to basic emotions. Efron defined emblems as movement patterns that had a precise movement (Efron, 1941). Research based on Efron's work and developed by Ekman & Friesen (1981) and Darwin (1998) was used to design the gestures ZECA performed in this second version of the videos, together with the facial expressions. Descriptions such as "A surprised person often raises his opened hands high above his head, or by bending his arms only to the level of his face. The flat palms are directed towards the person who causes this feeling, and the straightened fingers are separated." or "Fear is often preceded by astonishment, and is so far akin to it, that both lead to the senses of sight and hearing being instantly aroused. In both cases the eyes and mouth are widely opened, and the eyebrows raised. The frightened man at first stands like a statue motionless and breathless, or crouches down as if instinctively to escape observation. The arms may be protruded, as if to avert some dreadful danger, or may be thrown wildly over the head." were used to display the basic emotions on ZECA.

The questionnaire, available on a computer, was divided in three parts. In the first part, the users gave information about their age and gender. The second part consisted in matching the videos showing only different facial expressions and seven options ("I am sad", "I am happy", "I am angry", "I am scared", "I am neutral", "I am surprised", "I do not know"). In the third part of the questionnaire, the same facial expressions were complemented with gestures. It was decided to add gestures, as a component of non-verbal emotion expression, because they are believed to help persons for interpreting the emotional state of another agent (Ekman, 2007). The participants only had to choose the correct option which he/she considered appropriated for each video. Both videos and options were randomized.

**Participants**

Two distinct groups participated in this study. These participants attended the perceptual study through a web page specifically created for this purpose.
Group A was constituted by typically developing children and the sample used in this study had 42 participants between 8 and 10 years old (M = 9.1; SD = 0.7). The test was performed in a primary school, partner in this research project. The experiment with this group was performed in a computer room of the school, with 11 computers with internet connection. Each trial had an approximated duration of 30 minutes. First, the protocol was explained to the children, and then the children performed the experiment, on their own computer. When they finished filling in the questionnaire, another child took his/her place on the same computer. Group B was composed by 61 adults aged between 18 and 59 years old (M = 32.4; SD = 9.7). Both groups were instructed to complete the questionnaire selecting the most appropriate correspondence for each video. The participants of Group B were recruited on-line.

### 4.5.2 Results

The results of the questionnaires performed with Group A and Group B were quite encouraging. Fig. 4.18 and 4.19 show the results of Group A in the second part and third of the questionnaire, respectively. According to the results presented in Fig. 4.18, only two of the facial expressions (fear and anger) had less than 50.0% of the correct recognition rate, but still above chance level. But the other facial expressions yielded more than 75.0% of recognition rate (happiness - 83.3%, neutral - 85.7%, sadness - 97.6%, surprise - 76.2%).
Adding the gesture to the facial expression helped the recognition of the associated emotion (Fig. 4.19). The recognition of fear improved from 45.2% to 73.8% and of

anger from 26.2% to 47.6%.

Similar to Group A, Group B had some difficulties recognizing fear and anger, as it can be seen in Fig. 4.20. However, the recognition rates were considerably better, specially with the associated gestures (Fig. 4.21). The proportions were as follows (without gestures - with gestures): fear: 77.1% - 93.4%, anger: 24.6% - 70.5%, happiness: 91.8% - 98.4%, neutral: 90.7% - 91.8%, sadness: 91.8% - 88.5%, surprise: 86.9% - 83.6%.

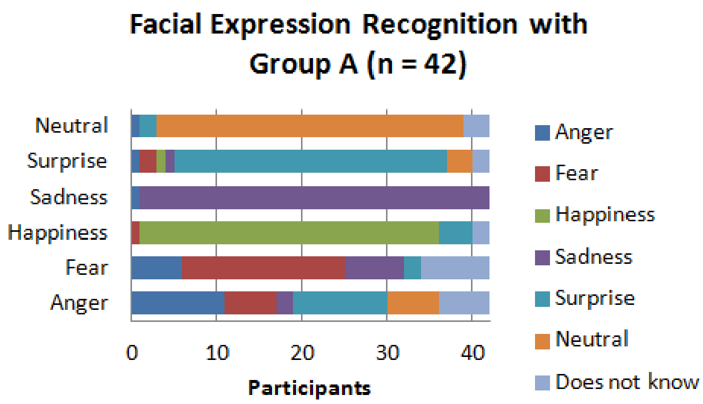


FIGURE 4.18: Results of the recognition rate of the facial expressions on ZECA using a multiple-choice questionnaire with Group A

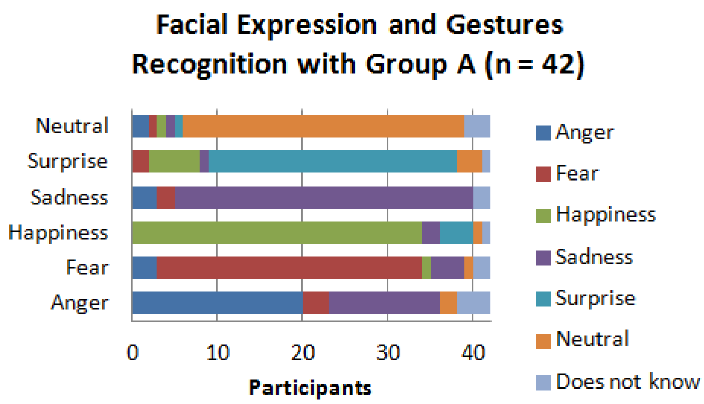


FIGURE 4.19: Results of the recognition rate of the facial expressions and gestures on ZECA using a multiple-choice questionnaire with Group A

Using the data provided above, a Chi-Square test was performed with the goal of verifying if there were differences between the observed and expected frequencies of the choices given by the participants on the perceptual study. The results showed that for Group A ($\chi(5, N = 42) = 23.0, p < .05$) and B ($\chi(5, N = 61) = 27.2, p < .05$), the observed and expected frequencies regarding the videos without gestures were different (the null hypotheses is rejected). The facial expression that most contributed to this

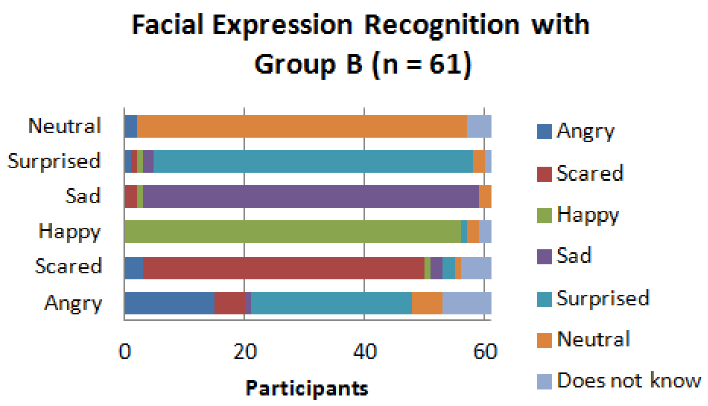


FIGURE 4.20: Results of the recognition rate of the facial expressions on ZECA using a multiple-choice questionnaire with Group B

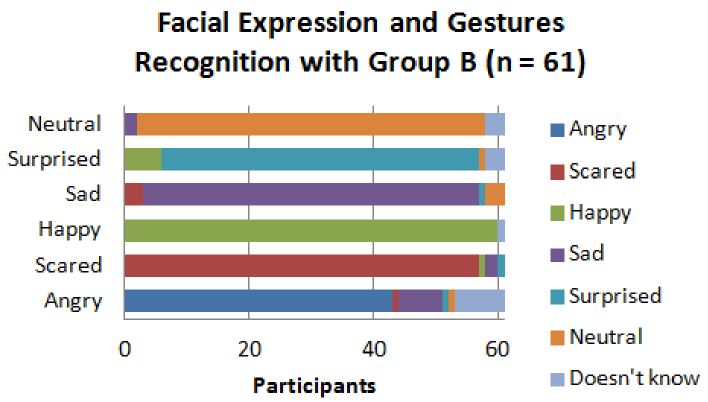


FIGURE 4.21: Results of the recognition rate of the facial expressions and gestures on ZECA using a multiple-choice questionnaire with Group B

result was the angry facial expression, with an average recognition rate of 25.0%. In fact, if the angry facial expression recognition rate was not taken into account, the null hypotheses is not rejected. When the gestures were added to the emotional display, the null hypotheses is not rejected (Group A - $\chi(5, N = 42) = 5.9, p > .05$, Group B - $\chi(5, N = 61) = 6.1, p > .05$), meaning that the observed choices in the recognition of the emotions displayed by the robot were congruent with the expected frequencies. To investigate if there were differences in the answers of the participants according to their age, paired sample t-tests were used. There were no significant differences between the percentage of recognition rate when only facial expressions were displayed by ZECA ($p = .20$), and significant differences were found when comparing the scoring of the groups of participants with adults and with children ($p < .05$) when rating the videos showing facial expressions and gestures.

### 4.5.3 Discussion of the Results

Before testing the facial expressions and gestures with the participants of the perceptual study, the Preliminary Test 1 was fundamental to verify, after the design in laboratory, which improvements had to be done. It was clear that the lack of a few physical characteristics on the robot prevented the explicit design with better quality some of the emotions. However, the final result was considered acceptable for further tests.

The use of the FaceReader software provided more information about which AU should be enhanced, and particularly which AU could give the hint to the correct identification of the emotion displayed by the robot. The results from the perceptual study clearly show that the facial expressions combined with the gestures displayed by ZECA can convey emotions universally displayed by humans, and are also recognized by both children and adults. Having observed an overall improvement of the recognition rate using facial expressions and gestures, following studies using emotional displays of ZECA have these two components.

Having in mind the results above, it might raise some confusion why the disgusted facial expression was discarded in the preliminary test 1, and the angry facial expression was not. This decision was taken together with the psychologist who supports this research. In fact, the first option was not to discard any of the facial expressions, however the low recognition rates, could lead the children to confusion. On the other hand, as anger is an emotion that is more present in children's daily life, both typically developing or with disabilities, it was not discarded.

The summary of hypotheses and its implications are presented in the following points:

**(a) Can facial expressions displayed by a humanoid robot and showed in video elicit the recognition of the corresponding emotion?:** The expectations regarding this research question were partially met. The results showed that on average the participants manage to recognize the corresponding emotions after watching videos only with facial expressions with 72.2% accuracy. However, the angry facial expression yield a recognition rate of only 24.6%.

**(b) Would the addition of gestures increase the emotion recognition rate?:** Overall, the addition of gestures increased the recognition rate of the displayed emotions. The obtained data support this research question. Table 4.2 provides a comparison of the obtained recognition rates with the ones found in the literature.

**(c) Is there a difference in the emotion recognition when the participants belong to different age ranges?:** The expectations of this research question were partially met. For the set of videos with ZECA displaying the emotions only using facial expressions there was no significant differences between the test groups. However, the adults yield a better performance than the group of children with the set of videos showing emotions with facial expressions and gestures.

TABLE 4.2: Comparison of the recognition rate of facial expressions of other robot to the developed system.

| Robot | Participants | Recognition Rate |
|---|---|---|
| FACE (Mazzei *et al.*, 2012) | 5 children with ASD | 60.0 |
| | 15 typically developing children | 61.1 |
| Probo (Saldien *et al.*, 2010) | 23 typically developing children | 84.0 |
| Kismet (Breazeal, 2000) | 8 typically developing children and 16 adults | 73.0 |
| EDDIE (Sosnowski *et al.*, 2006) | 8 typically developing children and 16 adults | 57.0 |
| WE-4RII (Itoh *et al.*, 2004) | 18 adults | 93.5 |
| SAYA (Hashimoto *et al.*, 2011) | 20 adults | 97.3 |
| ZECA (Hanson *et al.*, 2009) | 42 typically developing children | 72.2 |
| | 61 adults | 87.7 |

### 4.5.4 Summary and Conclusions

The goal of this study was to produce recognizable facial expressions and gestures to be displayed on ZECA. These expressions were identified by both adults and typically developing children. Results showed that participants were successfully able to recognize the emotion featured in the corresponding video, and the gestures were a valuable addition to the recognition. The overall recognition rate of the developed system was more than 70.0% for typically developing children and almost 90.0% for adults. These results allow the continuation of further investigation with the main target group of the research presented in this thesis: children with ASD. The produced facial expressions and gestures correspond to happiness, sadness, surprise, fear, and anger and they are going to be used to activate the children's representations of states or situations. The next sections are going to present the construction of game scenarios using data from the sections 4.2 and 4.3.

## 4.6 Recognize Game Scenario

This section presents an exploratory study in which children with ASD interact with ZECA. The study was performed during three sessions with two boys diagnosed with ASD. The results obtained from the analysis of the children's behaviours while interacting with ZECA helped the improvement of several aspects of the game scenario such as the technical specificities of the game and its dynamics, and the experimental setup. The evaluation of the game scenario was the main goal of this pilot study, rather than to quantify and evaluate the performance of the children. The main goal was to test one game scenario with the robot in which the children had to label facial expressions. This identification was done using images representing the emotions the robot displayed.

### 4.6.1 Methods

The software developed allowed the robot to autonomously identify the answers of the child during the session. This automation was considered necessary to help the fluidity of the game and to free the experimenter to interact with the child.
Two different tasks were tested in this pilot study. The first task, called Performance task, was chosen with the help of special education teachers and will be used in the future study to evaluate the skill level of children in labelling emotions. The analysis of the children's progress in this task is not going to be presented for two reasons. On one hand, the goal of this pilot study was not to evaluate the performance of the children, but the task itself and its potential benefits and shortcomings, and on the other hand, based on the professionals' expertise, the programmed number of sessions were not enough to acquire a new skill.
The second task, from now on called Recognize, was presented to the children individually. Each task will be presented in the following sections.

#### Performance Task

This performance task has the final goal of evaluating the skill of children to label emotions and in this study its suitability to be used with children with ASD is tested. This task was performed without the robot and consisted in matching cards on which a man or a woman is showing one of five different emotions (happiness, sadness, anger, surprise, and fear). These cards were matched with cards with PECS (Picture Exchange Communication System) representing the same emotions. The cards showed to the children are presented in Fig. 4.22.

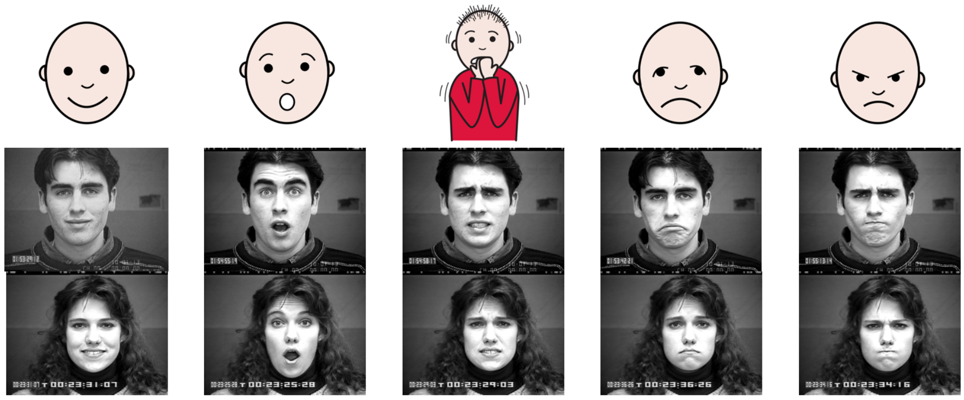

FIGURE 4.22: Images used in the performance task. The top of the figure shows the PECS cards which were matched to the figures with a man shown in the bottom of the figure. These cards represent from left to right the emotions happiness, surprise, fear, sadness, and anger.

The two sets with facial expressions were taken from the database of Kanade *et al.* (2000) and Lucey *et al.* (2010), which was released for the purpose of promoting research into automatically detecting individual facial expressions. The five PECS cards were presented at the same time on a board. Five empty spaces under the PECS cards were available, and the experimenter delivered the cards with the picture of the man or the woman, and prompted the child to match the card he/she had in his/her hand with the ones on the board.

### Game Scenario

The task Recognize consisted in the robot first displaying a facial expression and its associated gestures (as a body posture), representing one of the five basic emotions. The child is then prompted to identify the emotion associated with the facial expression. The child answers by selecting one of five rackets presented in front of him/her and showing it to the robot (the rackets are presented in section 4.3.5). The use case diagrams and sequence diagrams used to build the software of this game scenario are presented in the Appendixes B.4 and B.5, respectively. The evaluation of the children in this game scenario was performed according to the rules presented in section 4.3.4 regarding the following categories: eye gazing (at the robot, at the experimenter or elsewhere), tactile interaction, and response time (calculated from the time of the prompt is shown until the child's answer).

#### Participants

The participants in this pilot study were two boys with ASD aged fourteen and sixteen years old. The participants were high-functioning, according to the diagnosis criteria at the time of the study. The experimenter was in the room to introduce the robot, and to intervene in case of difficulties. She was also involved in the activity as a facilitator of the interaction, providing guidance and ensuring that the children did not become agitated or damage the robot during the activity. A signed consent form was obtained from the parents of each child.

### 4.6.2 Results

This section present the results regarding behaviours performed by the children in the intervention session. Even that the evaluation of the children's progress is not the main goal of this study, the observation of some behaviours performed by them gives a strong indication about the use of this particular robot in the context of emotion labelling skills.
Fig. 4.23 presents the percentage of time the participants looked at the robot and at the experimenter. Participant 1 maintained the percentage of time he looked at the experimenter along the sessions, but the percentage of time he looked at the robot had a slight decrease. Participant 2 increased slightly the time he looked at the experimenter along the sessions, and he looked at the robot for longer in the second session.
Fig. 4.24 shows how tactile interactions with the robot evolved during the sessions. Only gentle touches were observed by the children and the prompts from the experimenter were kept to a minimum. Participant 1 showed a lot of interest in touching the robot, exploring it during the game (Fig. 4.24 a). The robot's body parts touched more often were the face, hands, feet and chest. Participant 2 was more involved in the game and he touched the robot more often in the second session (Fig. 4.24 b).
Tables 4.3 and 4.4 present the children's mean (M) response time, and the standard deviation (SD) of unsuccessful and successful answers given in the corresponding session, respectively. These values were counted from the time the robot gave the prompt to the time the child showed the racket. Both participants took more time answering

to the prompt in Session 3. Participant 1 was usually faster to answer the prompt from the robot than Participant 2. Analysing each participant's data, Participant 1 only improved his performance regarding the display of anger and happiness. Participant 2 improved his performance in labelling fear, happiness, sadness, and surprise.

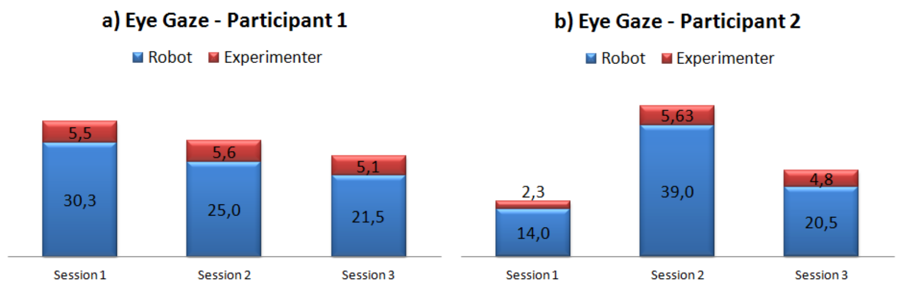


FIGURE 4.23: Eye Gaze Percentage of a) Participant 1 and b) Participant 2 during three sessions. Excluding the time the children spent looking elsewhere or at the task's material, the children gazed more often at the robot.

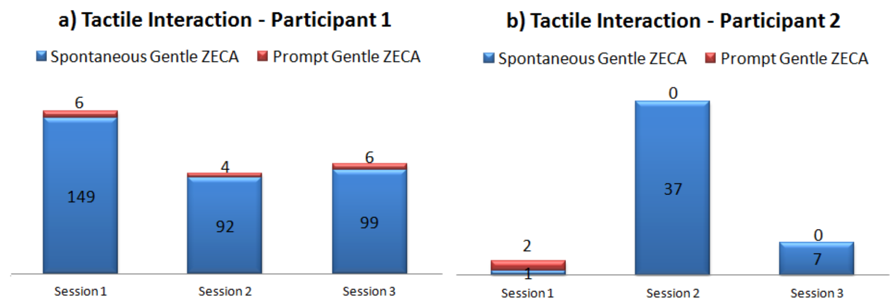


FIGURE 4.24: Number of times the participants touched the robot, either spontaneously or prompted by the experimenter. Mostly, children touched the robot spontaneously but most often the children needed a prompt to touch the robot the first time in a session.

Observing the number of attempts for the child to show the racket, it was verified that even with the correct lighting in the room, sometimes the QR code was not read because the child put the racket too close to the robot preventing the camera to get the entire QR code. This caused the experimenter to interfere in the session to help the child to show the racket.

Regarding the qualitative analysis, in the first reaction of the child to the robot in the first session, both children were specifically interested in the face of the robot, touching it repeatedly and always in a gentle way. Participant 1 also touched the robot on the chest several times. None of the children abandoned the room, or got up of his chair during the sessions indicating that they were interested in the new object.

TABLE 4.3: Children's mean response time in seconds for unsuccessful answers (SD). In general the response time increased in the last session.

| | Session 1 | Session 2 | Session 3 |
|---|---|---|---|
| Participant 1 | 6.5 (7.7) | 9.2 (7.0) | 15.9 (10.0) |
| Participant 2 | 9.1 (10.4) | 30.9 (22.5) | 40.3 (27.8) |

TABLE 4.4: Children's mean response time in seconds for successful answers (SD). In general the response time increased in the last session.

| | Session 1 | Session 2 | Session 3 |
|---|---|---|---|
| Participant 1 | 10.7 (9.8) | 4.9 (1.8) | 25.0 (15.6) |
| Participant 2 | 6.6 (7.0) | 40.0 (17.1) | 50.8 (20.3) |

### 4.6.3 Discussion of the Results

The first version of the performance task had two sets with two persons displaying five different facial expressions. Presenting the two sets at the same time was too confusing and tiring for the children. To simplify the task, but still assessing the ability of the child to match facial expressions and emotions, the children will only use one set at a time. One of the sets will be used as the pre-test and the second one as the post-test. The placement of the figures in the correct places is going to be evaluated, analysing the number of times the children need to find the correct answer. In addition, the time children take to finish the task is going to be compared to infer if there is an improvement of the emotion recognition skill.

When analysing the data regarding the participants' eye gaze during the experiments, the children spent less than half of the time of the session either looking at the robot or at the experimenter. Confronted with this results, the videos were subject to an informal analysis trying to understand this fact, and it was verified that what mostly influenced this result was the fact that the children spent a lot of time gazing at the rackets, while choosing the correct answer. In the initial list of coding behaviours, gazing at the tasks' material was not included. Since it was verified that the children gazed very often at the rackets, this category was inserted, and the list of coding behaviours updated.

The increase of the response time over the sessions might be related to the children thinking and considering all options they have available. Further investigation with a large sample is going to be made regarding the relation between the successful answers

after unsuccessful ones and whether the children manage to answer correctly at the end of the intervention process.
In the first session, the robot's support with a height of 80 cm was put on a table with 75 cm, causing the children to always have to look upward to the robot while seating on a chair, and then to look down to choose the correct racket. In the following sessions, the robot's support was put on a box with 30 cm height. This measure put the robot's head at eye level of the child during the session, facilitating the process of observing the facial expression, and choosing the racket.
In some cases, the QR code's reading failed due to the children's lack of gross motor coordination. To guarantee the session still continues even if the QR code's reading fails, the code was modified to accept commands from a wireless numeric keypad to be used by the experimenter, if necessary, matching numbers to the choice of the child's answer.

### 4.6.4 Summary and Conclusions

Being a pilot, this study had the primary goal to evaluate a performance task and the game scenario Recognize, and several improvements were done. This first contact of this robot and children with ASD allowed the preparation of activities and then to use them efficiently to develop emotion recognition skills.
Overall, this exploratory study demonstrated the possible positive outcomes this child-robot interaction can produce. Issues regarding data collection were highlighted while teaching children about labelling emotions using a humanoid robot embedded in a game scenario. To address such issues, it was developed a research design that could adequately capture the dynamics inherent to the learning process of these children.

## 4.7 Imitate Me and Storytelling Game Scenarios

In this section, a child-robot interaction study is presented, and it focus the recognition and labelling of emotions displayed by ZECA in two different game scenarios, involving imitation and storytelling activities. The goal of these scenarios is to help child with ASD to acquire knowledge about different emotions and to improve their skill in recognizing them. This pilot study's main aim is to test the constraints of the two game scenarios with children with ASD.

In the process of building empathy, the identification of emotions displayed by other persons is essential (Clark *et al.*, 2008), and this skill is fundamental for successful social interactions (Leppanen & Nelson, 2006). As it was presented in Section 2.3, robots have already been used with children with ASD to develop their social and communicative abilities with promising results. In this study, the robot mediates the interaction between the child and the experimenter but it is also a tool for teaching. The experiments consisted of three sessions with three children diagnosed with ASD. The responses given by the children and the time they took to answer the robot's prompt were analysed. Additionally, an analysis of verbal, non-verbal communicative behaviours, and tactile interaction is presented.

### 4.7.1 Methods

Details regarding the constraints of the game scenarios and information about the sample are presented in the this section.

#### Game Scenarios

The game scenarios evaluated in this study concerned two topics: imitation and storytelling, both including an emotional context.
Two different scenarios were tested in this study:

- **Imitate Me**: ZECA performs a facial expression representing one of the previously defined emotions: fear, happiness, sadness, surprise, or anger. The child should display on his/her face the same facial expression.
- **Storytelling**: ZECA tells a social story, where it is the main actor. All the stories end with an sentence that characterizes how ZECA feels. The child should show one racket with an image that identifies how ZECA feels at the end of the story.

The facial expressions used in the Imitate Me game scenario were the same used in the Recognize game scenario presented in the section 4.6 but without the gestures. The gestures were excluded to help the child focus on the imitation of the facial expression. The experiment started with the robot prompting the child to copy it, by saying a sentence such as "Copy my face" or "Imitate my face". The child answered showing the same facial expression with his/her face. The experimenter used a wireless keypad to classify the answer as either successful or unsuccessful, and the robot gave the child a reward based on the type of reinforcement the teacher identified as being his/her favourite (either movement, verbal, sound or a combination of them). For example, as verbal reinforcement, the robot would say "Very good!" and for a reinforcement with movement, the robot would move its arms in the air. If the answer was incorrect, the robot shook its head and said, for example "Ups. Pay attention. Let's try another one!".

In the Storytelling game scenario, social stories were used (section 2.2.1). Social stories were especially created based on the work of Gray & Garand (1993) to provide the children with a context to the emotions felt by a character, in this case ZECA. All the stories in the Storytelling game scenario were accompanied by a visual cue, as the one presented in Fig. 4.25.

FIGURE 4.25: Example of the visual cues shown to the child accompanying the social story.

The background for each story was added based on the advice of professionals who interact with children with ASD. As supported by the literature (Dettmer *et al.*, 2000; Johnson *et al.*, 1983), children with ASD appear to mainly use vision as their main input for information. The list of all the stories and corresponding visual cues are presented in Appendix B.6. An example of the used social stories is: "When I was playing in the playground, I fell on the floor. My arm and my leg were hurting a lot. I had a big scratch, and I could not stop crying". This social story corresponds to the emotion sadness.

A questionnaire was performed to evaluate the emotions conveyed by the stories with 186 participants recruited on-line. The participants were divided into two groups: younger than 18 years old (N = 77), and older than or aged 18 years old (N = 109).

This division was made to verify if this evaluation was transversal to all ages.
For the game scenario Storytelling, the robot started explaining how the game would unfold, told the social story, and prompted the child to choose one of five different rackets, already presented in section 4.3.5. Afterwards, the prompted expression and the answer of the child were matched automatically, and triggered a reinforcement from the robot. The procedure for the reinforcement after the child answered to the prompt was the same as described for the Imitate Me game scenario.
During the first and second sessions, both games were played by the children, but only the game Storytelling was played in the third session. The Imitate Me game scenario was not proposed on the last session since all children obtained a perfect score in this activity in the second session.
Specifically to these two game scenarios, the following behaviours defined in section 4.3.4 were took into consideration: tactile interaction, verbal and non-verbal interaction, and the performance in the game scenarios.

#### Participants

The three participants in this pilot study were two girls and one boy with ASD aged thirteen to fifteen years old (M = 14.0, SD = 1.0). The participants are high-functioning, according to the diagnosis criteria at the time of this study, and they all use verbal communication. None of the participants interacted with the robot before, but it is probable they had access to artefacts such as computers or animated toys during their interventions with speech or occupational therapists. The role of the experimenter in the room was to guide the child if necessary, and to intervene in case of difficulties. The experimenter introduced the robot to the child, giving them the opportunity to touch it if they wanted and ensured that the children did not become agitated or damage the robot during the activity. A signed consent form was obtained from the parents of each child before they participated in the experiments.

### 4.7.2 Results

Table 4.5 shows the results of the questionnaire aiming to evaluate the social stories. On average the participants managed to correctly classify the emotion conveyed by each story with an accuracy of 88.7%, and there are no significant differences between the two groups.

Table 4.5: Analysis of social stories by a total of 186 participants - Mean (SD). There is no significant different between the recognition rate of children and adults.

| | Males | Females | Ages | Rate |
|---|---|---|---|---|
| Younger than 18 | 9 | 68 | 15.5 (2.6) | 88.7% (19.4) |
| 18 or older | 37 | 72 | 25.1 (7.7) | 88.8% (16.5) |

In this exploratory study, if and how the children touched the robot or the experimenter was coded. Table 4.6 shows that only two of three children performed tactile interaction during the sessions. Child 1 was mainly interested in ZECA's head and touched it often and spontaneously, but only in the first session. Child 3 touched both ZECA's head and body also more often in the first session. Differently from Child 1, Child 3 spontaneously touched the experimenter's body, while performing stereotypies, specifically repetitive movements of his hand on the experimenter's arm, hence such a high value for spontaneous touches on the experimenter's body.

Table 4.6: Frequency of tactile interaction during the sessions. Child 2 did not touch the robot or the experimenter. The spontaneous tactile interaction performed on the experimenter's body concerned stereotypical movements of the child's arm on the experimenter's arm.

| Child 1 | Session 1 | Session 2 | Session 3 |
|---|---|---|---|
| Spontaneous ZECA's Head | 22 | 0 | 0 |
| Child 3 | Session 1 | Session 2 | Session 3 |
| Spontaneous ZECA's Body | 16 | 2 | 1 |
| Spontaneous ZECA's Head | 8 | 1 | 0 |
| Spontaneous Experimenter's Body | 49 | 18 | 15 |
| Spontaneous Experimenter's Head | 0 | 2 | 0 |
| Prompted ZECA's Body | 0 | 1 | 0 |

Only Child 1 and Child 2 are verbal, and Child 3 is able to produce vocalisations. However, Child 2 is very shy, talking only when a question is asked to her and only when it is strictly necessary. Table 4.7 presents on average the percentage of time the children used the verbal channel to communicate. Regarding verbal communication, the children mainly used speech or vocalisations.

In Table 4.8, the percentages of time the children imitated either the robot or the experimenter, smiled or leaned forwards are presented. During all three sessions, all children exhibited the coded behaviours. Moreover, the smiling behaviour was observed more frequently than others, and on average, its frequency and duration increased along the sessions. The behaviour leaning forwards was observed more often in each child's first session. Regarding imitation (of movements and body postures and excluding the imitation of facial expressions), the robot was imitated more in the first session, and the experimenter in the last session. In the second session, the time the children spent imitating the robot or the experimenter were similar.

TABLE 4.7: Percentage of time on average the children performed behaviours coded in the verbal communication category (SD). Vocalisations and speech were the most frequent types of verbal communication observed.

| | Session 1 | Session 2 | Session 3 |
|---|---|---|---|
| Echolalia | 0.5 (0.9) | 0.4 (0.6) | 0.3 (0.5) |
| Vocalisations | 5.6 (9.7) | 3.9 (6.6) | 6.6 (11.3) |
| Speech | 6.0 (6.3) | 3.6 (3.1) | 5.4 (4.8) |

TABLE 4.8: Mean of the percentage of time the children performed behaviours coded in the non-verbal communication category (SD). The behaviour shown for longer was smiling but it was also the one who presented higher variability.

| | Session 1 | Session 2 | Session 3 |
|---|---|---|---|
| Robot's Imitation | 0.2 (0.3) | 0.2 (0.4) | 0.0 (0.0) |
| Exp.'s Imitation | 0.0 (0.0) | 0.3 (0.4) | 0.3 (0.5) |
| Smiling | 6.1 (5.3) | 13.6 (13.8) | 23.6 (18.0) |
| Leaning Forwards | 5.7 (5.1) | 0.1 (0.2) | 0.2 (0.3) |

Regarding the time the children took to answer the prompt from the robot, the average response time varied between 3.5 and 3.9 seconds (SD = 0.9) in the Imitate Me game scenario and between 6.4 and 6.9 seconds (SD between 2.0 and 2.7) in the Storytelling game scenario.

Table 4.9 presents the frequency of the behaviours following and pointing, presented previously in the section 4.3.4. Only one child did not point during any of the sessions. On average, the behaviour following was observed more often than the behaviour pointing.

Table 4.10 presents the mean and the corresponding standard deviation (SD) of the answers given by the children during the three sessions. The answers were classified into "successful", "unsuccessful" or "unanswered prompt". The latter was defined when the robot repeated the prompt by decision of the experimenter. In all the sessions, the children responded successfully more often than unsuccesfully or with unanswered prompts given by the robot. During the Imitate Me game scenario, the successful answers varied between 79.3% and 100.0%, and during the Storytelling game scenario between 61.7% and 75.4%.

Table 4.9: Number of times on average the children performed behaviours coded in the non-verbal communication category (SD). It was more frequent the children following the index finger of the experimenter than to point to attract the experimenter's attention.

| | Session 1 | Session 2 | Session 3 |
|---|---|---|---|
| Following | 3.7 (4.6) | 5.3 (9.2) | 3.3 (3.2) |
| Pointing | 3.0 (5.2) | 1.0 (1.0) | 0.7 (1.2) |

Table 4.10: Percentage mean of the children's answers in both game scenarios during the three sessions (SD). The storytelling game scenario provided more difficulties to the children.

| Session Number | Successful Ans. | Unsuccessful Ans. | Unanswered Prompts |
|---|---|---|---|
| Imitate Me 1 | 79.3 (20.0) | 7.0 (6.1) | 13.7 (15.2) |
| Storytelling 1 | 75.4 (29.4) | 9.5 (16.5) | 15.1 (14.4) |
| Imitate Me 2 | 100.0 (0) | 0.0 (0.0) | 0.0 (0.0) |
| Storytelling 2 | 61.7 (37.5) | 19.2 (18.8) | 19.2 (18.8) |
| Storytelling 3 | 70.6 (37.4) | 19.1 (33.0) | 10.3 (9.0) |

### 4.7.3 Discussion of the Results

It is intended to employ the two game scenarios presented previously in a larger study with children with ASD. The results obtained with this pilot study follow the trends identified in the literature (cf. Section 2.3), regarding the use of a robot to mediate interactions between a child with ASD and another person. The scenarios presented were built based on the difficulties of individuals who belong to this spectrum, and the results show positive evidence of their appropriateness, since the children managed to answer to the robot's prompts, improved their performance, and displayed verbal and non-verbal behaviours and tactile interaction indicating positive engagement.
It was notorious the children's curiosity in the first session in touching the robot. Children touched the robot always in a gentle way, and trying to explore its characteristics such as its face and hands. However, tactile interaction performed by Child 3 in the first half of the first session was most of it considered aggressive towards the experimenter. It was not possible to infer if this behaviour was intentional, since the child

was performing stereotypies. This behaviour was only observed in the first session. In the following sessions, Child 3 touched the experimenter's hand to attract her attention.

Regarding verbal communication, only Child 1 effectively spoke to address the experimenter with questions related to ZECA. Child 2 was mainly focused on the tasks, and only answered the questions when questioned by the experimenter. Child 3 was the main responsible for the vocalisations produced in the three sessions. Most of the time of the session was used to observe ZECA or to answer to its prompts, and because of this, the percentage of time used to speak or vocalise is reduced. The behaviours performed by the children were markedly different, but ZECA was the main focus of attention, either as the subject of questions from the children and as object of observation or attention.

In the Imitate Me game scenario it was verified that the children were able already in the second session to produce 100% of successful answers. Regarding the game scenario Storytelling, even with a minor efficacy, the children were able to extract the emotion conveyed by the story told by the main actor.

While exploring and getting to know the new object and game partner, the children followed the index finger of the experimenter when she tried to attract their attention to the robot. This is a good indication of shared attention between the child and the game partner, and it is expected that in a study with more sessions, the child would naturally also point to some detail to attract the experimenter's attention. The analysis of the imitating behaviours displayed by the children during the sessions suggests that the children increasingly transferred the behaviours from the robot to the experimenter. The curiosity about the new object might drive them to get closer to the robot, leaning forwards to observe the details of the robot's face, especially its eyes. On average, the time the children smiled during the sessions increased suggesting they were enjoying the task, and further analysis of the children's eye gaze will be interesting to verify at whom the child was looking when exhibiting this behaviour.

The results presented in the previous section show that the children were able to answer to the robot's prompts and to use all the components of the scenarios, such as the display of the emotion by the robot, the rackets, the automatic QR code identification and the corresponding reinforcement. This supports the idea that these scenarios can be used to test the progress of children learning to label different emotions.

### 4.7.4 Summary and Conclusions

This section presents the evaluation of two game scenarios which are going to be included in the larger experimental study presented in the next chapter. This pilot study presents encouraging results indicating that the use of this robot as a tool to interact with children with ASD can be beneficial for these children. The goal of this study was to verify if the two game scenarios would help the children acquire knowledge about labelling emotions, while at the same time promote child-robot interaction and increasingly child-adult interaction.

The results show that the children accomplish a good performance regarding their answers to the robot's prompts in both scenarios. Regarding the verbal and non-verbal communication, the robot was a useful tool to promote positive behaviours such as speech and vocalisations, and smiling and leaning forwards, respectively. The robot was also used as an object of imitation which was shortly transferred to the experimenter.

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# Chapter 5

# Investigating the use of Affective Robotics for Socio-Emotional Skills Development in Children with ASD

This chapter uses the research presented in the previous chapters to study the behaviour and performance of children with ASD when developing socio-emotional skills. Besides encouraging the children with ASD to learn about recognizing and imitating emotions, special emphasis was given to the ability of the children to infer the affective state of another person.

In 1985 Simon Baron-Cohen *et al.* proposed that children with ASD do not employ the theory of mind. These authors affirmed that children with ASD find tasks that require them to understand another person's beliefs complex (Baron-Cohen *et al.*, 1985), and they have difficulties assigning mental states to others, a skill which typically developing children usually acquire at four years old (Baron-Cohen, 1991).

Other researchers tried to explain the association between ASD and the theory of mind. Leslie (1991) suggested that children with ASD show early deficits in pretend play, impairing their ability to mentally characterize thoughts, beliefs, and desires, if the involved circumstances are real or not.

A distortion in understanding and responding to emotions is proposed by Hobson (1993) as a social-affective justification to the deficit presented by individuals with ASD. He proposed that individuals with ASD are born without a set of capacities that afterwards does not let them understand and act in response to other persons' affective states.

As it was presented in Chapter 2, children with ASD are characterized by showing difficulties in the identification of their own emotions and those displayed by others. Considering this difficulty, and the strategies developed in the exploratory studies presented in Chapter 4, this chapter presents two experimental studies with 16 and 45 children with ASD, respectively. These studies aimed to evaluate the use of a humanoid robot, already described in section 4.3.2, as a tool to mediate triadic interactions and to teach recognition and labelling of emotions. The first study focused on the verbal and non-verbal communication as measures to evaluate the social interaction in a triadic relationship. In the second study the attention was centred on the children's eye gaze and their progress in the emotional skills' development. This goal's achievement was measured using observational data from video analysis regarding pre-established behaviours, data recorded from the robot, and quantitative ratings from a pre- and post-test comparison.

The procedures presented in this chapter were approved by the Ethics Committee of the University of Minho, Portugal and by the Portuguese National Committee for Data Protection. The official documents can be found in the Appendix C.1. All the schools and clinics who participated in these studies agreed on a protocol with the University of Minho. Parents of the children signed an informed consent in which they were acknowledged about the goals and applied methods of the research (Appendix C.2). The children's teachers were consulted and informed about the game scenarios to be performed and gave suggestions intended to improve them.

## 5.1 Analysis of Verbal and Non-Verbal Communication in a Triadic Interaction between a child with ASD, an adult, and a humanoid robot

During a social interaction, verbal and non-verbal behaviours between actors usually occur. In children with ASD, these channels for interacting socially are impaired. As it was specified in section 2.2.1, children with ASD show a qualitative deficit when using multiple non-verbal behaviours, such as body postures and gestures to regulate social interactions. This also applies to verbal communication, which can be very limiting in a social context. The study presented in this section is focused on the verbal and non-verbal communication displayed by children with ASD in a social interaction. Two groups of eight children with high-functioning ASD (G1 and G2) participated in 6 sessions, performing three different tasks. Children from G1 performed the tasks with the robot, and children from G2 without it. The tasks presented in Chapter 4 were used in this study: Recognize, Imitate Me and Storytelling. The goal in this section was to analyse how their verbal and non-verbal behaviours varied along the sessions, comparing the first to the last session of each scenario, and the first to last session between groups.

### 5.1.1 Research Questions

With this study, the following research questions were addressed:

**(a)** Can a humanoid robot elicit verbal behaviours in children with ASD?

**(b)** Does the non-verbal communication of children with ASD change in the interaction with a humanoid robot and another person?

Data regarding verbal and non-verbal communication was used to compare these social behaviours in the two groups. It was expected that children in G1 interacted verbally for longer than children in G2, and it was expected that children in G1 showed non-verbal behaviours which indicate social interaction more often and for longer than children in G2.

### 5.1.2 Methods

The methods used to answer the research questions were presented in Chapter 4, specifically the ethical issues (section 4.3.1), the robot (section 4.3.2), the software (section 4.4), the room setup (section 4.3.3), the evaluation tools (section 4.3.4), and the materials used for the robot to receive the input from the participants (section 4.3.5).
Specifically, only the data regarding verbal and non-verbal interaction categories is presented in this section.

#### Participants

A sample of 16 children was divided in two groups:

- **G1:** 8 children with ASD who perform game scenarios with the robot;
- **G2:** 8 children with ASD who perform game scenarios without the robot.

All children met the following inclusion criteria: aged five to ten years old, diagnosed with high functioning ASD by a professional clinician, and with acceptance of the parents to participate in the study. Children with intellectual problems were excluded from the sample. The experimenter did not have direct access to the children's medical files, but she had access to information provided by teachers or therapists which guaranteed the children's diagnosis. The experimenter did not know any of the children prior to the experiments.

The mean age (M) and corresponding standard deviation (SD) of the children in each group are: G1 - M = 6.8 years old; SD = 1.5; G2 - M = 7.4 years old; SD = 0.9. The percentage of male (M)/female (F) children in each group is: G1 - M = 87.5%, F = 12.5%; G2 - M = 100.0%, F = 0.0%. According to the questionnaires filled in by the professionals who follow the children, the percentage of children who verbalise is 62.5% for both groups. Prior to the studies, all the children from both groups performed activities focusing on emotion's recognition, included in their school curriculum or therapeutic intervention. According to the children's teachers and therapists, the type of reinforcement percentage of the children participating in the study is: G1 - Verbal = 25.0%; Movement = 0.0%; Verbal + Movement = 62.5%; Verbal + Movement + Sound = 12.5%; G2 - Verbal = 50.0%; Movement = 12.5%; Verbal + Movement = 37.5%; Verbal + Movement + Sound = 0.0%.

#### Procedures

The same phases presented in Chapter 3 (section 3.2.5) were used in this study with exception of the pre- and the post-test phases. These tests were not applied since the goal of this study was not to evaluate the learning of a new skill, but to observe the children's behaviours.

The familiarisation phase took place in a familiar room to the children and during a usual day of activities, for at least two hours. In the practice phase, the game scenarios performed by the children were the ones presented in Chapter 4: Recognize - to identify and label facial expressions and gestures matching emotions (section 4.6.1), Imitate Me - to reproduce a facial expression representing an emotion (section 4.7.1), and Storytelling - to evaluate the affective state of a character at the end of a story (section 4.7.1). Each session was introduced with a Picture Exchange Communication System (PECS) card, which children usually use in their daily routine to start new activities.

A total of six sessions were performed with each child. The experimenter interacted with each child twice a week, during three weeks. When any of the children had to miss his/her session, it was re-scheduled. The children missing more than two sessions were excluded from the experiments. The game scenarios were performed as presented in the following list:

- Session 1: Recognize;
- Session 2: Recognize + Imitate Me;
- Session 3: Recognize + Imitate Me;
- Session 4: Imitate Me + Recognize + Storytelling;
- Session 5: Imitate Me + Storytelling;
- Session 6: Storytelling.

The distribution of the game scenarios in such a way took into account the experience taken from Chapters 2, 3, and 4. Each session took between 5 and 15 minutes, according to the number of game scenarios the children had to perform. No more than one minute passed between one scenario and the following one.

To ensure inter-rater reliability 10.0% of the videos were re-coded by a second independent coder (Cohen's kappa $k = 0.73$). This is acceptable, as having a Cohen's kappa value higher than 0.60 suggests a good agreement between the raters (Bakeman & Gottman, 1997).

### 5.1.3 Results

This section presents the results comparing the children's verbal and non-verbal behaviours. Since the obtained data does not follow a normal distribution, non-parametric tests were used to statistically analyse the acquired data. Whenever the data reports to the comparison between the two groups, Mann-Whitney U tests are used to compare independent data from each group (e.g. first session G1 vs. first session G2). The comparison of sessions in the same group represents dependent data since they were performed by the same children (e.g. G1: first session vs. last session) using Wilcoxon tests. From now on, these comparisons will be distinguished presenting them as comparison between groups (Mann-Whitney U tests) and comparison in each group (Wilcoxon tests).

### Verbal communication

When comparing the duration of verbal behaviours between children in G1 and in G2 along the sessions, three behaviours were analysed individually: echolalia, vocalisations, and speech (Fig. 5.1). However, no significant results were found in this comparison. Having in mind that the two groups were balanced for children with and without verbalisation, further analysis was done, where the duration of each behaviour was summed (Fig. 5.2).

Using the sum of verbal behaviours and a Mann-Whitney U test, no significant differences were found between the groups when comparing the corresponding first sessions. The same was verified when comparing the corresponding last sessions of the two groups, in the three game scenarios (Fig. 5.3). When comparing the first to the last session of each group in each game scenario (first session G1 vs. last session G1 in each game scenario), using a Wilcoxon test, no significant differences were found in the duration of verbal behaviours.

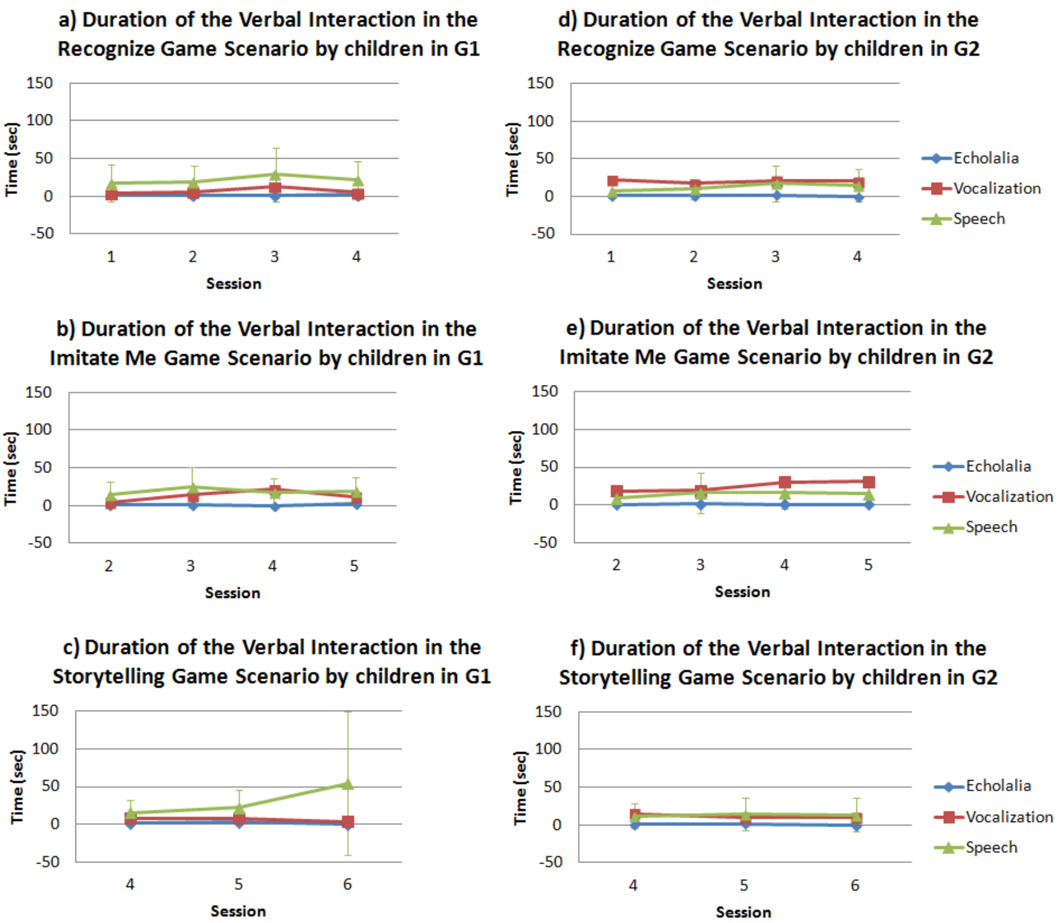



FIGURE 5.1: Verbal behaviours, divided by type of behaviour (echolalia, vocalisation, and speech), performed by children in G1 and G2 a) d) in the Recognize game scenario, b) e) in the Imitate Me game scenario, c) f) and in the Storytelling game scenario. No significant differences were found for this behaviour, comparing the groups or the sessions.

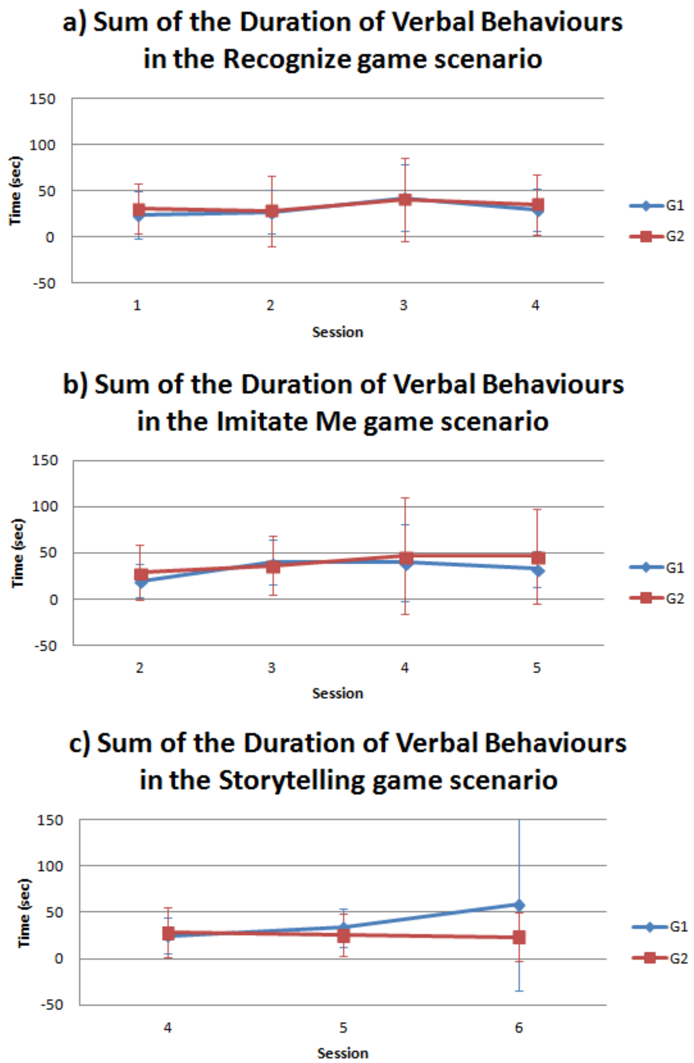



FIGURE 5.2: Sum of the verbal behaviours duration along the sessions a) in the Recognize game scenario, b) in the Imitate Me game scenario, c) and in the Storytelling game scenario. No significant differences were found for this behaviour, comparing the groups or the sessions.

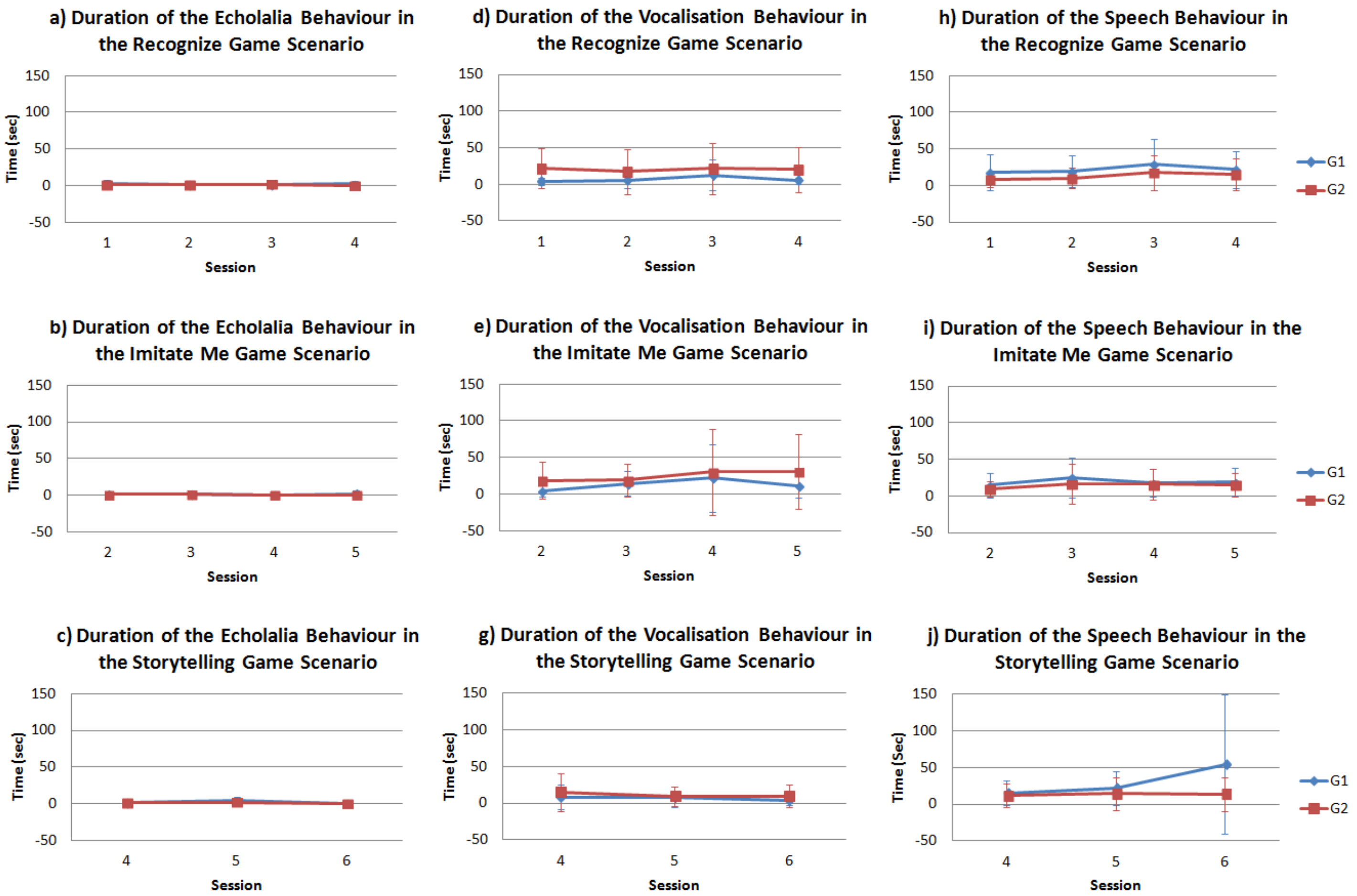



FIGURE 5.3: Verbal behaviours, divided by type of behaviour, comparing G1 to G2 a) d) h) in the Recognize game scenario, b) e) i) in the Imitate Me game scenario, c) g) j) and in the Storytelling game scenario. No significant differences were found for this behaviour, comparing the groups or the sessions.

**Non-Verbal communication**

The results presented below show how often and for how long children in G1 and in G2 performed non-verbal behaviours which indicate social engagement. These behaviours were defined in section 4.3.4. First, these behaviours were analysed individually, comparing the first to the last session in each group (e.g. first session G1 vs. last session G1), and the first and the last session between groups (e.g. first session G1 vs. first session G2).

Fig. 5.4 presents the average frequency children in G1 and in G2 clapped their hands in each of the game scenarios. Even with higher frequencies in all scenarios for the non-verbal behaviours displayed by children in G1, using a Mann-Whitney U test, no significant differences were found between the groups or between the first and the last session in each group using a Wilcoxon test. This was verified for all the game scenarios.

When comparing the average frequency of the leaning forwards behaviour, significant differences were found between the two groups (Fig. 5.5 a), b), and c)). Mann-Whitney U tests showed differences for the Recognize game scenario (between the first sessions: $p = .003$, and between the last sessions: $p = .02$), for the Imitate Me game scenario (between the first sessions: $p = .007$, and between the last sessions: $p = .021$), and for the Storytelling game scenario (between the first sessions: $p = .018$, and between the last sessions: $p = .028$).

The frequency of the leaning forwards behaviour performed by children in G1 and in G2 is presented in Table 5.1. Using a Wilcoxon test, no significant differences were found between the first and the last session of each activity in each group (e.g. Recognize game scenario: first session G1 vs. last session G1).

Similar results were obtained when comparing the duration of the leaning forwards behaviour (Fig. 5.5 d), e), and f)). Significant differences were found between the two groups with Mann-Whitney U tests, for the Recognize game scenario (between first sessions: $p = .003$, and last sessions: $p = .018$), for the Imitate Me game scenario (between first sessions: $p = .012$, and last sessions: $p = .009$), and for the Storytelling game scenario (between first sessions: $p = .014$, and last sessions: $p = .021$). Using a Wilcoxon test, no significant differences were found between the first and the last session of each activity in each group (Table 5.2).

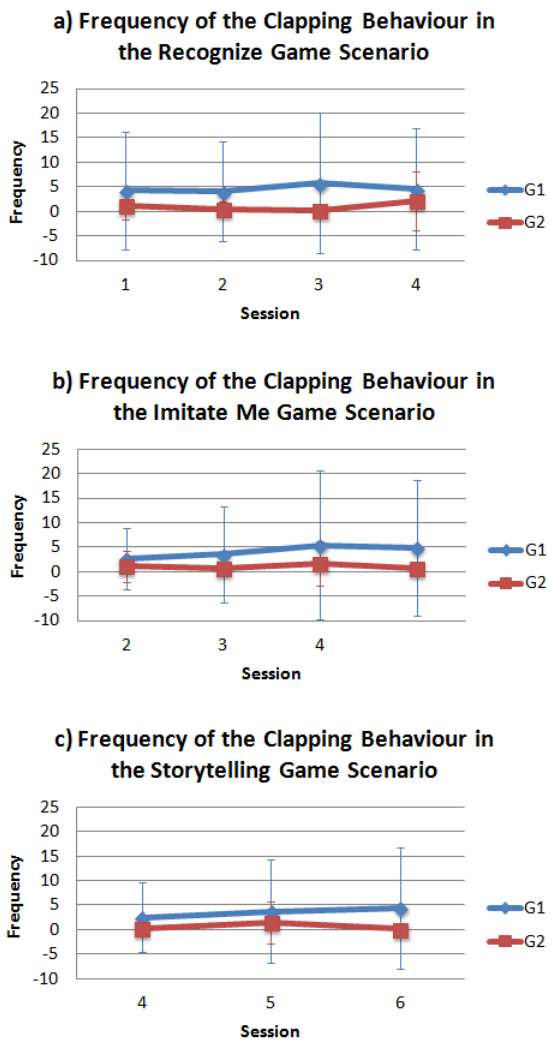



FIGURE 5.4: Frequency of the clapping behaviour along the sessions a) in the Recognize game scenario, b) in the Imitate Me game scenario, c) and in the Storytelling game scenario.

TABLE 5.1: Frequency of the leaning forwards behaviour performed by children in G1 and in G2 (SD).

| Game Scenario | Session | G1 | G2 |
|---|---|---|---|
| Recognize | First | 4.4 (4.0) | 0.3 (0.5) |
| | Last | 3.1 (3.1) | 0.4 (0.7) |
| Imitate Me | First | 7.5 (4.9) | 1.0 (2.5) |
| | Last | 4.4 (3.4) | 1.1 (2.5) |
| Storytelling | First | 4.8 (7.2) | 0.4 (0.7) |
| | Last | 4.8 (6.1) | 1.0 (2.8) |

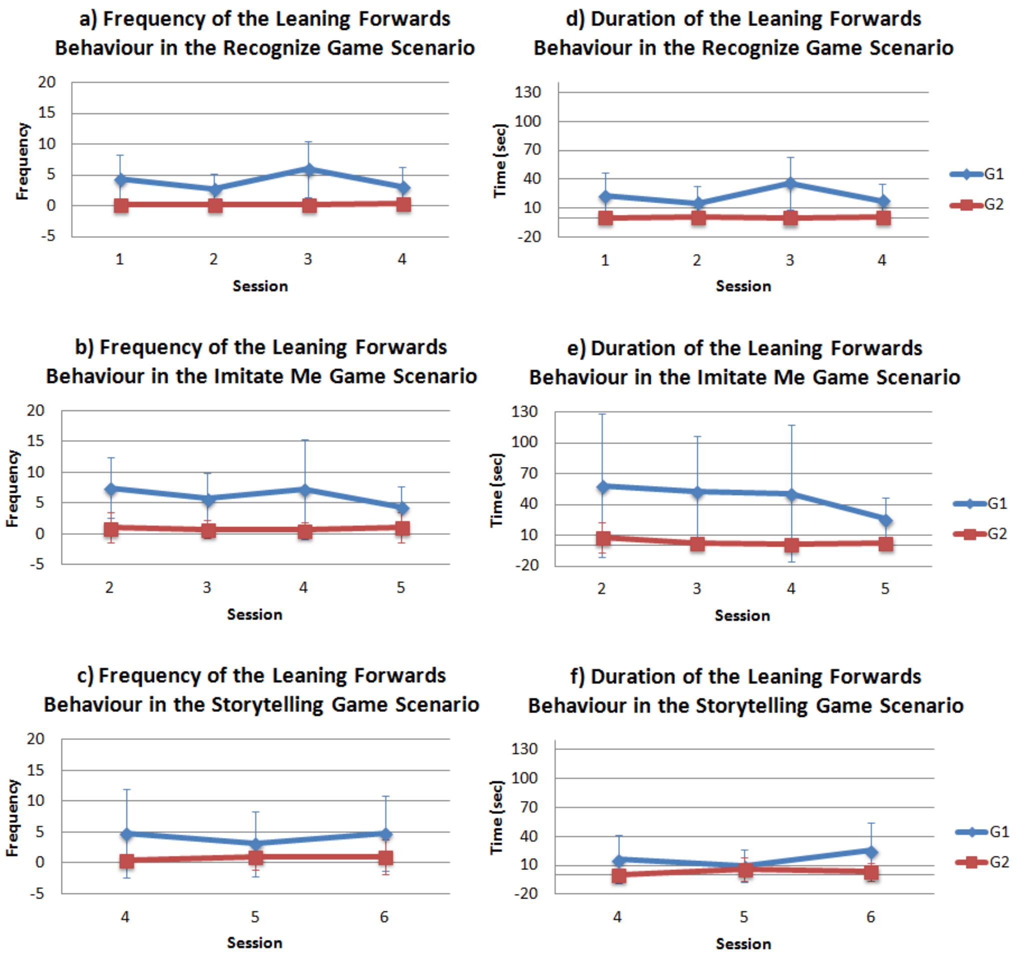



FIGURE 5.5: Frequency and duration of the leaning forwards behaviour along the sessions a) d) in the Recognize game scenario, b) e) in the Imitate Me game scenario, c) f) and in the Storytelling game scenario.

TABLE 5.2: Duration of the leaning forwards behaviour performed by children in G1 and in G2 (SD).

| Game Scenario | Session | G1 | G2 |
|---|---|---|---|
| Recognize | First | 22.7 (24.5) | 0.3 (0.5) |
| | Last | 17.2 (18.5) | 0.6 (1.4) |
| Imitate Me | First | 58.4 (69.6) | 7.7 (14.4) |
| | Last | 26.0 (20.4) | 2.5 (4.8) |
| Storytelling | First | 16.4 (24.9) | 0.8 (1.5) |
| | Last | 25.4 (28.4) | 3.3 (9.4) |

Regarding the frequency of the following behaviour (Fig. 5.6 a), b), and c)), significant differences were only found when comparing the two groups in the Imitate Me game scenario (between first sessions: p = .05, and last sessions: p = .005). Fig. 5.6 d), e), and f) presents the frequency of the pointing behaviour by the children in G1 and in G2 along all the session and game scenarios. No significant differences were found between the first and last sessions of each group or between groups.

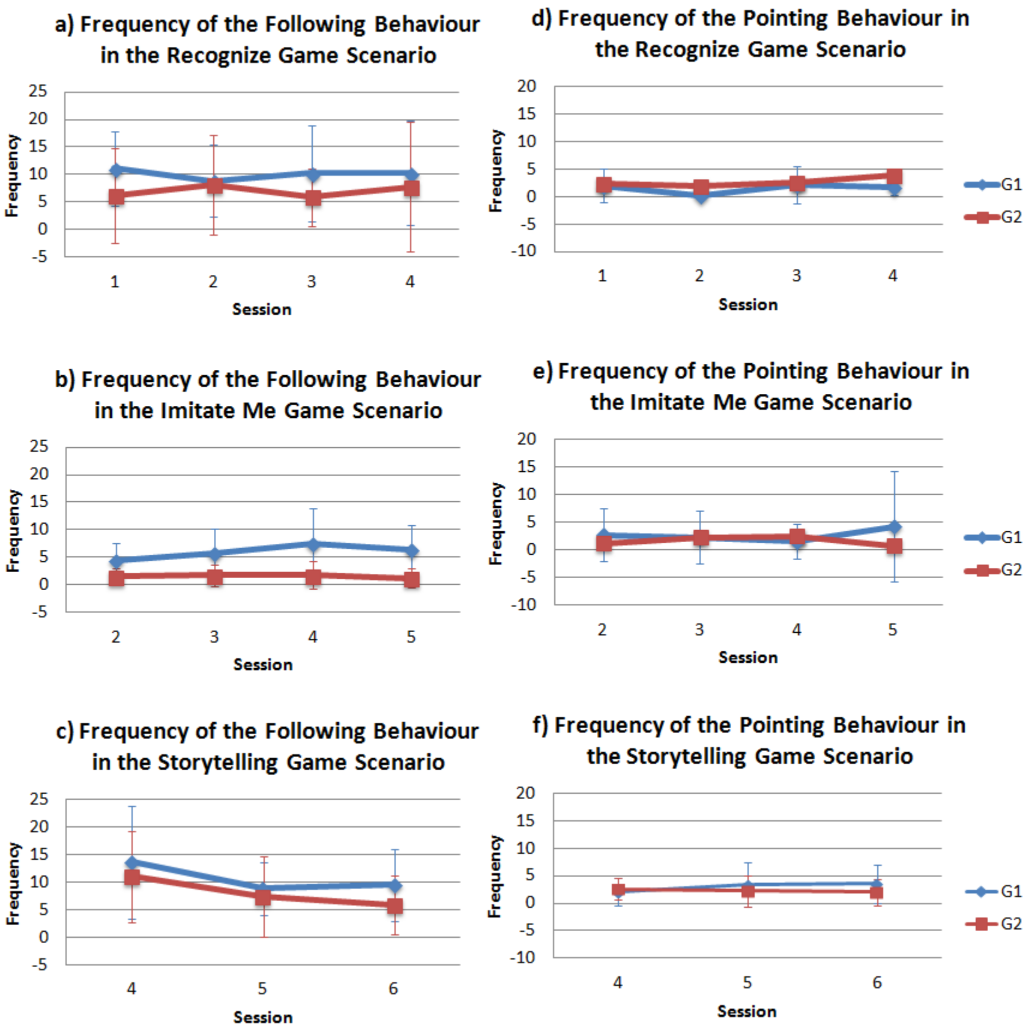



FIGURE 5.6: Frequency of the following and pointing behaviours along the sessions a) d) in the Recognize game scenario, b) e) in the Imitate Me game scenario, c) f) and in the Storytelling game scenario.

The experimenter's imitation behaviour is represented in Fig. 5.7, for the average of its frequency and duration. No significant differences were found between the first and last sessions of each group or between groups.

The children's smiling behaviour is represented in Fig. 5.8, for the average of its frequency and duration. No significant differences were found between the first and last sessions of each group or between groups, both for its frequency and duration.

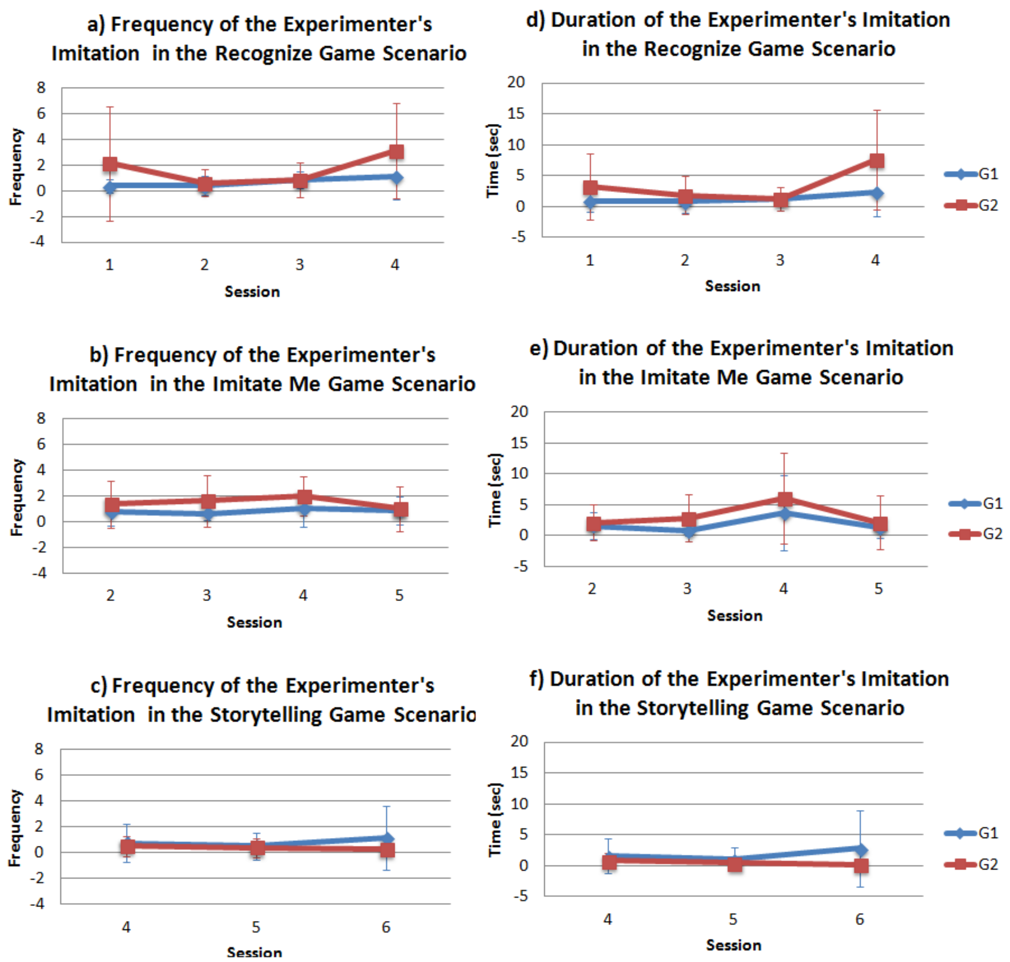



FIGURE 5.7: Frequency and duration of the experimenter's imitation behaviour along the sessions a) d) in the Recognize game scenario, b) e) in the Imitate Me game scenario, c) f) and in the Storytelling game scenario.

On average, the children in G1 performed non-verbal behaviours more often than children in G2 (Table 5.3). Fig. 5.9 a), b), and c) presents the sum of the non-verbal behaviours frequencies including clapping, following, pointing, smiling, imitation of the experimenter, and leaning forwards. The justification of adding these behaviours is discussed in section 5.1.4.

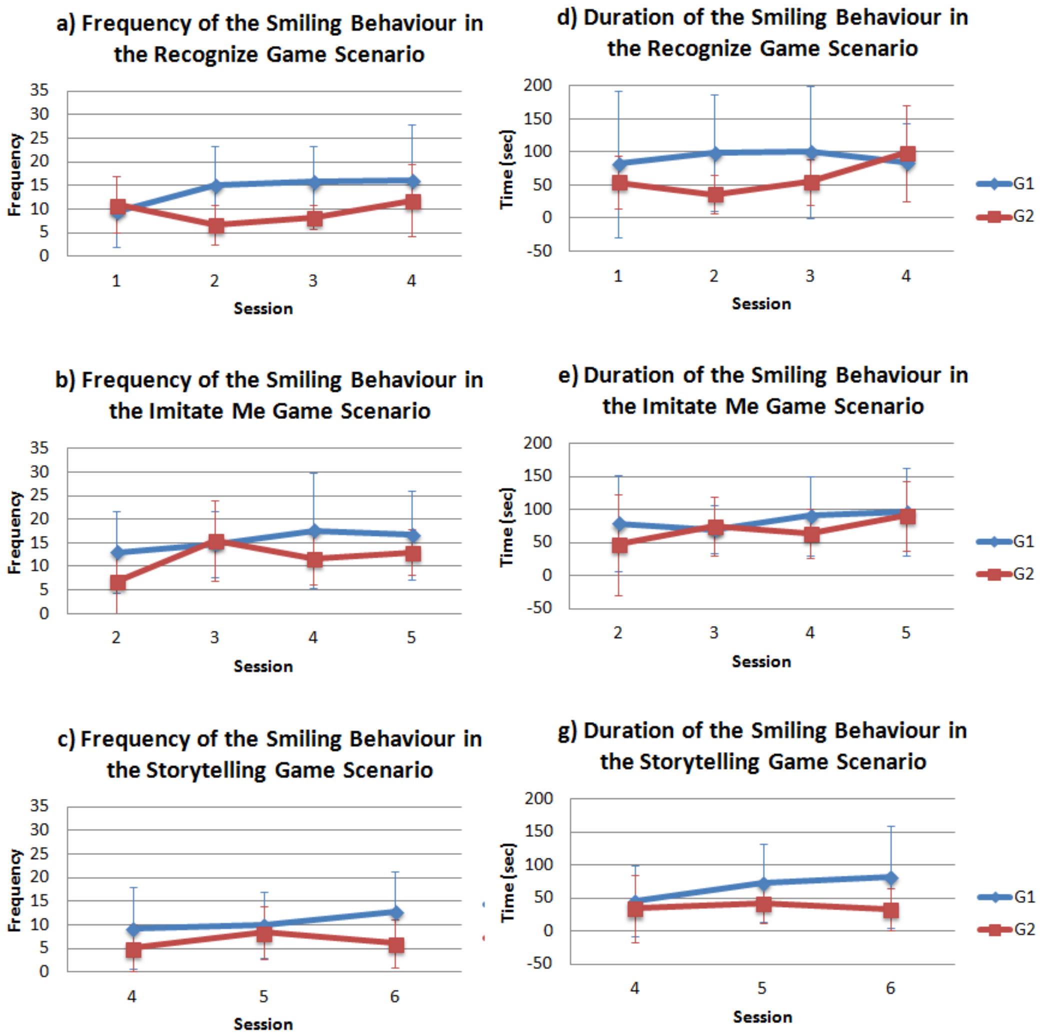



FIGURE 5.8: Frequency and Duration of the smiling behaviour along the sessions a) d) in the Recognize game scenario, b) e) in the Imitate Me game scenario, c) f) and in the Storytelling game scenario.

TABLE 5.3: Sum of the non-verbal behaviours frequencies performed by children in G1 and in G2 (SD).

| Game Scenario | Session | G1 | G2 |
|---|---|---|---|
| Recognize | First | 31.6 (13.7) | 22.9 (20.8) |
| | Last | 36.8 (25.5) | 29.1 (24.4) |
| Imitate Me | First | 31.0 (13.9) | 12.9 (13.8) |
| | Last | 37.4 (18.1) | 17.8 (8.0) |
| Storytelling | First | 33.0 (21.1) | 19.9 (11.0) |
| | Last | 36.1 (17.4) | 15.4 (8.3) |

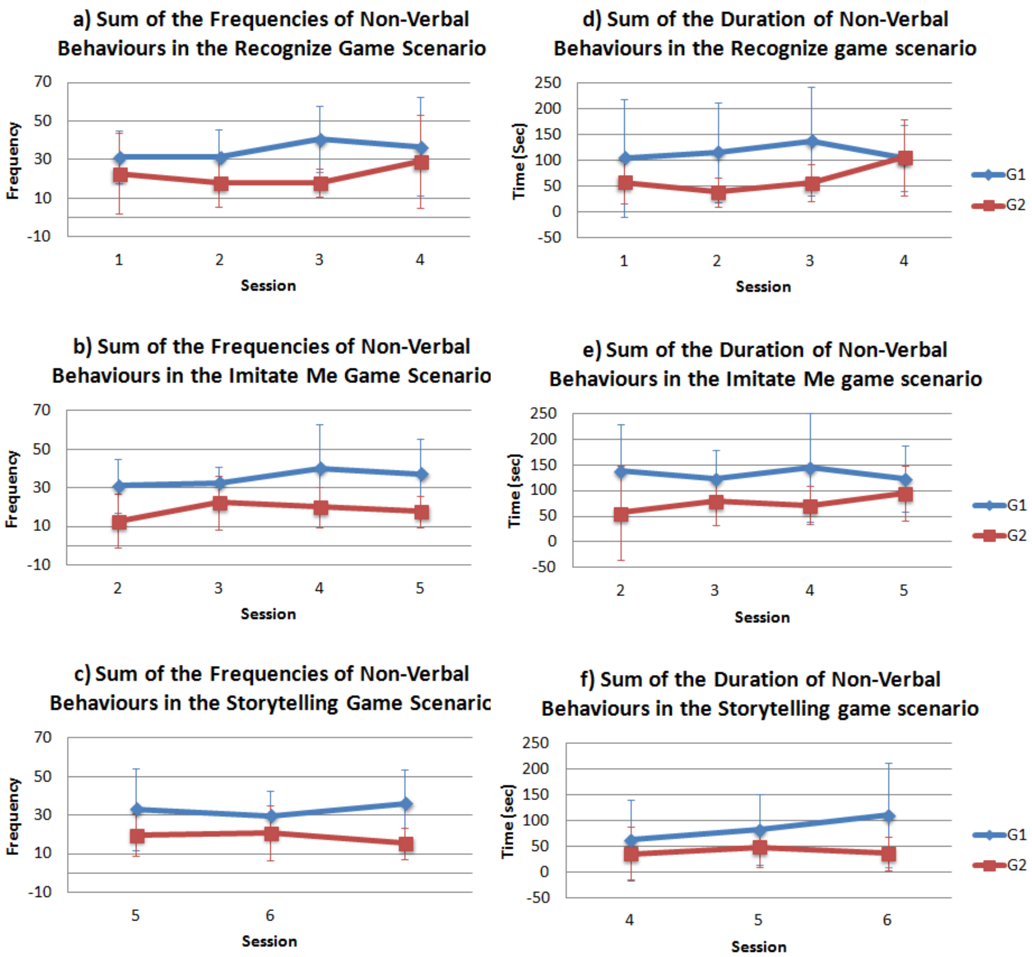



FIGURE 5.9: Sum of the frequencies of the non-verbal behaviours (clapping, following, pointing, smiling, imitation of the experimenter, and leaning forwards) and sum of the duration of the non-verbal behaviours (smiling, imitation of the experimenter, and leaning forwards) along the sessions a) d) in the Recognize game scenario, b) e) in the Imitate Me game scenario, c) f) and in the Storytelling game scenario.

Mann-Whitney U tests did not show differences for the Recognize game scenario between first sessions: p = .141, and last sessions: p = .636 of each group. In the Imitate Me game scenario there were significant differences between first sessions: p = .021, and last sessions: p = .015 of each group. In the Storytelling game scenario, there were significant differences between the last sessions: p = .013 of each group, but not for the first ones: p = .293.

Regarding the comparison between the first and the last session in each group, a Wilcoxon test revealed significant results only for the comparison between the first and the last session of the Storytelling Game Scenario for G2 (p = .03).

The sum of the average duration of the leaning forwards, imitation of the experimenter, smiling behaviours is presented in Fig. 5.9 d), e), and f).

No significant results were found using Mann-Whitney U tests to compare the first and the last session between groups (Table 5.4). Comparing the first and the last session in each group, significant differences were only found in G1 for the Storytelling game scenario ($p = .004$) and for the Recognize game scenario performed by G2 ($p = .013$).

Table 5.4: Sum of the non-verbal behaviours duration performed by children in G1 and in G2 (SD).

| Game Scenario | Session | G1 | G2 |
|---|---|---|---|
| Recognize | First | 105.6 (114.1) | 57.9 (40.6) |
| | Last | 104.4 (64.3) | 106.7 (74.0) |
| Imitate Me | First | 139.0 (89.2) | 56.8 (91.3) |
| | Last | 123.5 (64.3) | 95.1 (53.3) |
| Storytelling | First | 62.9 (77.1) | 35.4 (52.0) |
| | Last | 110.3 (101.4) | 35.9 (32.8) |

Fig. 5.10 presents the average percentage of the simultaneous non-verbal behaviours along the sessions. These durations were obtained, for example, when the child leaned towards the robot and smiled. When comparing the average duration of the simultaneous non-verbal behaviours between G1 and G2, along all sessions significant differences were found in all the game scenarios. In the Recognize game scenario ($p = .021$) children in G1 showed simultaneous non-verbal behaviours in an average of 90.7 seconds and children in G2 22.6 seconds. In the Imitate Me game scenario ($p = .021$), simultaneous non-verbal behaviours occurred during an average of 129.7 seconds for children in G1, while children in G2 performed them only 33.2 seconds. Finally, in the Storytelling game scenario ($p = .005$), children in G1 display more than one non-verbal behaviour on average for 105.6 seconds, and children in G2 for 18.5 seconds.

### 5.1.4 Discussion of the Results

As stated in section 5.1.2, children in groups G1 and in G2 were balanced for verbalisation. The results regarding the children's verbalisation are inconsistent with the expectations concerning the research question (a), since there was no difference between children in G1 and G2 regarding verbal behaviours. Several issues may influenced these results. The game scenarios used in this study may not have encouraged the child to verbalise more. The goal was to verify if spontaneous verbalisation would occur but most likely an initial prompt should have been needed to encourage the children to interact verbally. In addition, the fact that only five of the eight children

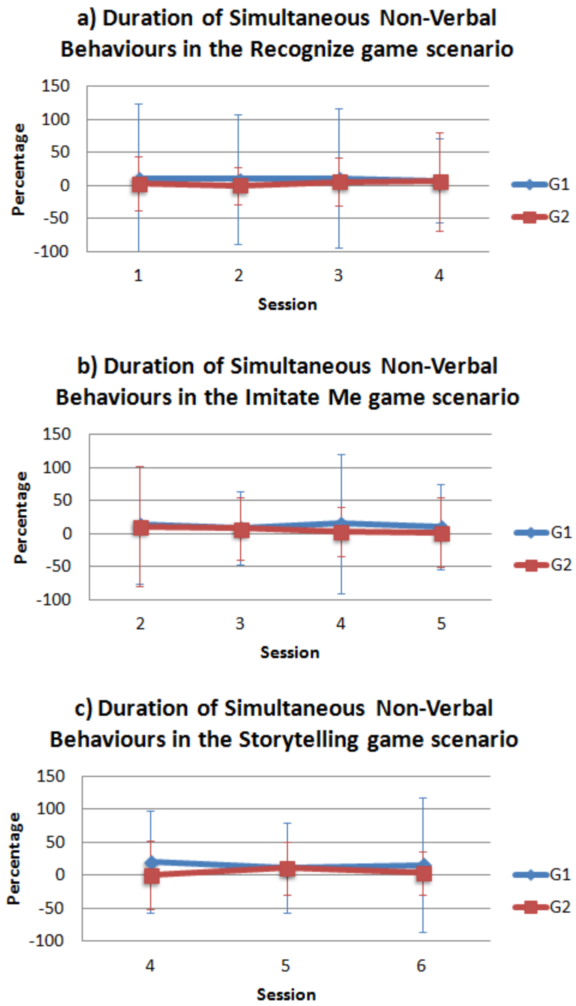



FIGURE 5.10: Duration of the simultaneous non-verbal behaviours along the sessions a) in the Recognize game scenario, b) in the Imitate Me game scenario, c) and in the Storytelling game scenario.

were verbal may had affect the results making it harder to find significant differences. Tables 5.5 and 5.6 present the summary of the results in section 5.1.3 when comparing the behaviours performed by children in G1 and in G2. The results may be due to the size of the sample, but also because the children displayed a preferred way to show their engagement either clapping, smiling, or other. Since they normally used the same way to show their interest, the other behaviours were often reduced to the minimum, influencing the group average. This happened for both groups. This was the reason why the sums of the frequencies and the duration of the non-verbal behaviours were also presented in section 5.1.3.

One behaviour showed significant differences both in frequency and in duration, comparing the two groups. Concerning the frequency of occurrence, the children in G1 leaned forwards 17.5 times more often in the Recognize game scenario, 8.3 times more often in the Imitate Me game scenario, and 7.5 times more often in the Storytelling game scenario than children in G2. Likewise, concerning the duration of this behaviour, the children in G1 leaned forwards 85.5 times longer in the Recognize game scenario, 27.2 times longer in the Imitate Me game scenario, and 7.5 times longer in the Storytelling game scenario than children in G2. In the triadic interaction performed in the intervention with children in G1, there was an extra object when comparing to the dyadic interaction performed with children in G2. The fact was that the object, in this case the robot, was interesting enough for the children to lean forwards, attracting their attention.

Furthermore, when analysing the sum of the frequency and the duration of the non-verbal behaviours, more significant differences were discovered (Tables 5.7 and 5.8). Regarding the frequency of non-verbal behaviours, the Imitate Me game scenario presented interesting results with more than the double of behaviours frequency for children in G1 comparing to children in G2. This might be related to the focus on the robot's face which may lead the children to get closer to observe its facial expression, but also to attract the experimenter's attention to some detail in the robot's face by pointing at it. It should be noted that the imitation of the facial expression itself was not coded as a non-verbal behaviour. These results partially meet the expectations concerning research question (b).

When comparing the children's behaviour with respect to game scenarios, generally less behaviours were shown during the Storytelling game scenario. In fact, the game scenario did not provide many opportunities to express verbal or non-verbal behaviours. Most of the time, the children were focused on the visual cue corresponding to the story being told and listening to the storyteller.

The display of simultaneous non-verbal communication is also revealing on the children's interest while performing the game scenarios. Table 5.9 summarizes the results presented before, and in fact, children in G1 performed significantly more simultaneous non-verbal behaviours in all the game scenarios. Performing simultaneous non-verbal behaviours is more common during the Imitate Me game scenario for both groups, since the children focus their attention on the specific movements of the robot's face. It was usual for the children to get closer to the robot and pointing at particular characteristic of the face.

Table 5.5: Statistical comparison of the non-verbal behaviours frequency. The comparison is made between the first sessions of both groups, the last sessions of both groups, and the first and last session of each group. Scenarios: R = Recognize; I = Imitate Me; S = Storytelling.

| Behaviour | Group(s) | Sessions | Scenarios | p |
|---|---|---|---|---|
| Clapping Hands | G1 vs. G2 | first vs. first<br>last vs. last | All | >.05 |
| | G1 | first vs. last | | |
| | G2 | first vs. last | | |
| Leaning Forwards | G1 vs. G2 | first vs. first | R<br>I<br>S | = .003<br>= .007<br>= .018 |
| | | last vs. last | R<br>I<br>S | = .024<br>= .021<br>= .028 |
| | G1 | first vs. last | All | >.050 |
| | G2 | first vs. last | | |
| Following | G1 vs. G2 | first vs. first | R<br>I<br>S | >.050<br>= .050<br>>.005 |
| | | last vs. last | R<br>I<br>S | >.050<br>= .050<br>>.050 |
| | G1 | first vs. last | All | >.050 |
| | G2 | first vs. last | | |
| Pointing | G1 vs. G2 | first vs. first<br>last vs. last | All | >.050 |
| | G1 | first vs. last | | |
| | G2 | first vs. last | | |
| Experimenter's Imitation | G1 vs. G2 | first vs. first<br>last vs. last | All | >.050 |
| | G1 | first vs. last | | |
| | G2 | first vs. last | | |
| Smiling | G1 vs. G2 | first vs. first<br>last vs. last | All | >.050 |
| | G1 | first vs. last | | |
| | G2 | first vs. last | | |

TABLE 5.6: Statistical comparison of the non-verbal behaviours duration. The comparison is made between the first sessions of both groups, the last sessions of both groups, and the first and last session of each group. Scenarios: R = Recognize; I = Imitate Me; S = Storytelling.

| Behaviour | Group(s) | Sessions | Scenarios | p |
|---|---|---|---|---|
| Leaning Forwards | G1 vs. G2 | first vs. first | R | = .003 |
| | | | I | = .012 |
| | | | S | = .014 |
| | | last vs. last | R | = .018 |
| | | | I | = .009 |
| | | | S | = .021 |
| | G1 | first vs. last | All | >.050 |
| | G2 | first vs. last | | |
| Experimenter's Imitation | G1 vs. G2 | first vs. first<br>last vs. last | All | >.050 |
| | G1 | first vs. last | | |
| | G2 | first vs. last | | |
| Smiling | G1 vs. G2 | first vs. first<br>last vs. last | All | >.050 |
| | G1 | first vs. last | | |
| | G2 | first vs. last | | |

TABLE 5.7: Statistical comparison of the sum of non-verbal behaviours frequency. The comparison is made between the first sessions of both groups, the last sessions of both groups, and the first and last session of each group. Scenarios: R = Recognize; I = Imitate Me; S = Storytelling.

| Behaviour | Group(s) | Sessions | Scenarios | p |
|---|---|---|---|---|
| Non-verbal behaviours frequency sum | G1 vs. G2 | first vs. first | R | >.050 |
| | | | I | = .021 |
| | | | S | >.050 |
| | | last vs. last | R | >.050 |
| | | | I | = .015 |
| | | | S | = .013 |
| | G1 | first vs. last | All | >.05 |
| | G2 | first vs. last | R | >.050 |
| | | | I | >.050 |
| | | | S | = .030 |

TABLE 5.8: Statistical comparison of the sum of non-verbal behaviours duration. The comparison is made between the first sessions of both groups, the last sessions of both groups, and the first and last session of each group. Scenarios: R = Recognize; I = Imitate Me; S = Storytelling.

| Behaviour | Group(s) | Sessions | Scenarios | p |
|---|---|---|---|---|
| Non-verbal behaviours duration sum | G1 vs. G2 | first vs. first<br>last vs. last | All | >.050 |
| | G1 | first vs. last | R<br>I<br>S | >.050<br>>.050<br>= .004 |
| | G2 | first vs. last | R<br>I<br>S | = .013<br>>.050<br>>.050 |

TABLE 5.9: Statistical comparison of the simultaneous non-verbal behaviours duration. Scenarios: R = Recognize; I = Imitate Me; S = Storytelling.

| Behaviour | Group(s) | Sessions | Scenarios | p | Difference (sec) |
|---|---|---|---|---|---|
| Simultaneous non-verbal behaviours | G1 vs. G2 | Overall | R | = .021 | G1: 90.7<br>G2: 22.6 |
| | | | I | = .021 | G1: 129.7<br>G2: 33.2 |
| | | | S | = .005 | G1: 105.6<br>G2: 18.5 |
| | G1<br>G2 | Overall<br>Overall | All<br>All | >.050<br>>.050 | |

#### Summary of Hypotheses and Implications

This study looked into the changes in verbal and non-verbal behaviours performed by children with ASD during a social interaction where a robot was used as a mediator. Three different scenarios which encouraged the child to identify emotions either by recognizing them, imitating them or inferring the affective state of a character in a story were used to induce reactions from the child. Regarding the research questions presented in the beginning of this section, the following implications were found:

(a) **Can a humanoid robot elicit more verbal behaviours from children with ASD?:** Expectations regarding this research question were not supported, since no differences were found between the groups. It should be pointed out that only five out of the eight children in each group were verbal. A further study could consider prompting the child to speak, to verify if this behaviour occurs spontaneously along the rest of the session;

(b) **Does the non-verbal communication of children with ASD change in an interaction with a humanoid robot and another person?:** Results from observational data showed that in fact there was some behavioural differences in the non-verbal category which indicate an increased social engagement of the children. This was verified when comparing the simultaneous demonstrations of non-verbal behaviours. The only different element in the procedure between the two groups was the use of a robot as a tool to promote the interaction, leading to the belief that the robot had an influence in this change. When comparing the individual behaviours, significant differences were not found since each child have a particular way to show their interest regarding non-verbal communication, affecting the average of the group. The sum of the non-verbal behaviours frequency and duration pointed out some significant differences, but not common to all game scenarios. However, a reinforced behaviour was observed in the children interacting with the robot performing more simultaneous non-verbal behaviours indicating a stronger engagement (Johnson *et al.*, 2007).

## 5.2 Analysis of Eye Gaze and Game Performance

The study presented in this section aimed to investigate the use of a robot to develop socio-emotional skills in children with ASD. A comparative study with 45 children, divided in three groups, was conducted testing the robot as the main actor in the development of emotion recognition skills. These scenarios tackled three main impairments in children with ASD related to emotion recognition: visual identification of emotions, imitation of facial expressions conveying emotions, and inference of the affective state of another person, principle of the Theory of Mind.

Besides the performance of the children in the tasks, special attention was also given to where the children focused their attention during the intervention session, using this behaviour as a measure to calculate the joint attention time, which has a direct relationship with engagement.

### 5.2.1 Research Questions

In this study, the following research questions were addressed:

**(a)** Can a humanoid robot contribute to develop visual emotion recognition in children with ASD?

**(b)** Can a humanoid robot with the capability of displaying facial expressions elicit facial expressions' imitation skills in children with ASD?

**(c)** Can a humanoid robot help children with ASD to attribute mental states and to identify others' affective state?

**(d)** How does the use of a humanoid robot influence eye gaze and joint attention time in children with ASD in an interaction with another person?

In order to answer (a), the performance of children with ASD in an emotion recognition game scenario was evaluated. The number of successful, unsuccessful answers and unanswered prompts was recorded and compared between groups who performed the game scenario with and without the robot. It was desirable to verify an improvement when comparing the first to the last session of intervention in number of successful answers. In addition, data from a common task performed by the groups in a pre- and a post-test were analysed, comparing not only how long children took to perform the task, but also the number of attempts to a correct correspondence. In a comparative study between G1, G2, and G3, it was expected the acquisition of the emotion recognition skill faster using a humanoid robot (G1) comparing to a traditional strategy (G2) or without intervention (G3).

Concerning (b), the number of successful, unsuccessful answers and unanswered prompts in an imitation game scenario was compared. An analysis between G1 and G2 was made, and it was expected that children in G1 had a better performance imitating facial expressions than children in G2, increasing this skill from the first to the last session.

Regarding (c), children in G1 and G2 identified the main character's affective state at the end of social stories. It was expected that children in G1 were able to identify the state of mind of the character more often than the children in G2. Additionally, a higher improvement was to be expected between the first and the last session in children in G1.

With respect to (d), data collected from video analysis was used to compare the time children looked at the experimenter (either looking at one part of the experimenter's body or making eye contact) with the time they looked at the robot (in case of G1), the task's material, or elsewhere. Joint attention is defined as the capability children have to share attention with others about an object or an event, gazing alternatively at the object and at the peer (Johnson *et al.*, 2007). In this study, the term joint attention time (JAT) was measured by the eye gaze time at the experimenter, together with the time the children looked at the task's material and the robot (in case of G1). The children's JAT was compared to the time the children looked elsewhere, and it was expected that the JAT increased more in G1, than in G2 along the sessions.

### 5.2.2 Methods

This section presents the methods used to investigate the use of a humanoid robot to promote socio-emotional skills in children with ASD. The materials used in this study were presented in Chapter 4. Specifically, the section 4.3 presents the ethical issues, the robot, the software, the room setup, the evaluation tools, and the materials used for the robot to receive the answer from the participants.

#### Participants

The sample of 45 children was divided in three groups:

- **G1:** 15 children with ASD who perform game scenarios **with** the robot, the pre-, and the post-test;
- **G2:** 15 children with ASD who perform game scenarios **without** the robot, the pre-, and the post-test;
- **G3:** 15 children with ASD who only perform the pre- and the post-test (without intervention).

This study was carried out in eight primary schools and two clinics which conduct therapies to children with ASD. All children met the following inclusion criteria: aged five to ten years old, diagnosed with high functioning ASD by a professional clinician, and with authorisation of the parents. Children with intellectual problems were excluded from the sample. The direct access to the children's medical files was not granted to the experimenter, but the questionnaires filled in by the teachers or therapists guaranteed the children's diagnosis. The experimenter did not know any of the children prior to the experiments. All children receive weekly therapy from speech, occupational therapists and some of them by psychologists. During the intervention time in this study, both teachers and therapists were asked not to perform activities focusing on emotion recognition.

The first criteria to divide the participants in groups was their age. However, some of the children in the clinics were not able to attend sessions twice of week so they were included in G3. The second criteria was gender. Statistical data shows that on average there is a ratio of 1 girl to 6 boys with high-functioning ASD (Johnson *et al.*, 2007). For this reason it was only possible to include 9 girls in the sample. It was not possible to balance the number of girls in each group, due to their unavailability to attend sessions twice a week.

The children's mean age (M) and the corresponding standard deviation (SD) in each group was: G1 - M = 6.8 years old; SD = 1.5; G2 - M = 7.5 years old; SD = 1.4; G3 - M = 7.8 years old; SD = 1.2. The percentage of male (M)/female (F) children in each group was: G1 - M = 80.0%, F = 20.0%; G2 - M = 93.3%, F = 6.7%; G3 - M = 66.7%, F = 33.3%. The percentage of children who verbalise was: G1 = 66.7%; G2 = 53.3%; G3 = 60.0% and the percentage of children who already performed activities focusing on emotion's recognition and identification, included in their school curriculum or therapeutic intervention was: G1 = 53.3%, G2 = 60.0%; G3 = 66.7%. According to the children's teachers and therapists, the type of reinforcement of the children participating in the study was: G1 - Verbal = 13.3%; Movement = 6.7%; Sound = 0.0%; Verbal + Movement = 66.7%; Verbal + Movement + Sound = 13.3%; G2 - Verbal = 40.0%; Movement = 6.7%; Sound = 6.7%; Verbal + Movement = 40.0%; Verbal + Movement + Sound = 6.7%; G3 - Verbal = 46.7%; Movement = 6.7%; Sound = 0.0%; Verbal + Movement = 46.7%; Verbal + Movement + Sound = 0.0%.

It was not possible to level the children's characterisation in every group. Having this in mind, the discussion of the results is going to take this fact into account.

The game scenarios used in this study were the ones tested in Chapter 4, which were described in sections 4.6.1 and 4.7.1: Recognize, Imitate Me, and Storytelling. Each scenario had its individual goals, but they had in common the development of emotion recognition skills.

### Procedures

Similarly to the study presented in Chapter 3, the phases presented in section 3.2.5 were used in this study. The familiarisation phase took place in each school and clinic during a usual day of activities or intervention session, and the experimenter had the opportunity to interact with the children in a group context for at least two hours. The task performed in the pre- and post-test was presented in section 4.6.1 and summarily consisted in matching 5 PECS cards representing five basic emotions to 5 photographs of a man (pre-test) or a woman (post-test) showing the same facial expressions. This task was performed twice to avoid that the order of cards' delivery influenced the number of attempts and the time needed to complete the task. In the practice phase, the game scenarios performed by the children were the ones presented in Chapter 4: Recognize - to identify and label facial expressions and gestures matching emotions (section 4.6.1), Imitate Me - to reproduce a facial expression representing an emotion (section 4.7.1), and Storytelling - to evaluate the affective state of a character at the end of a story (section 4.7.1). A total of eight sessions were performed with each child, being the first and second session, and the seventh and eighth session performed in the same day. The experimenter interacted with the children twice a week, during three weeks with each child. When any of the children had to miss his/her session, it was re-scheduled. The children missing more than two sessions were excluded from the experiments. The game scenarios were performed as presented in the following list:

- Session 1: Pre-test;
- Session 2: Recognize;
- Session 3: Recognize + Imitate Me;
- Session 4: Recognize + Imitate Me;
- Session 5: Imitate Me + Recognize + Storytelling;
- Session 6: Imitate Me + Storytelling;
- Session 7: Storytelling;
- Session 8: Post-test.

The distribution of the game scenarios in such a way took into account the experience taken from Chapters 2, 3, and 4, and it is based on the following points. Regarding the difficulty level of the game scenarios, it was considered by the professionals in the focus groups presented in the section 4.2 that the Recognize activity would be the basic task, followed by the Imitate Me activity, since the latter involved the identification and then the imitation of facial expressions. Considering, that the children had to identify the character's affective state in a story, the Storytelling activity was ranked harder for children with ASD. The game scenarios were presented an approximate number of times (four times for the Recognize and Imitate Me game scenarios, and three times for the Storytelling game scenario), and trying to introduce new factors in each session to keep the child motivated. Each session with the children took between 5 and 15 minutes, according to the number of game scenarios the children had to perform. No more than one minute passed between one scenario and the following one.
To ensure inter-rater reliability, 10% of the videos were re-coded by a second independent coder, resulting in a Cohen's kappa k = 0.72. This is acceptable, as having a Cohen's kappa value higher than 0.60 suggests a good agreement between the raters (Bakeman & Gottman, 1997).

### 5.2.3 Results

This section presents the results regarding the children's eye gaze and the joint attention time. In addition, the performance in the game scenarios is presented, as well as the comparison between the pre- and post-test using the performance task (see section 4.6.1). Since the obtained data does not follow a normal distribution, non-parametric tests were used to statistically analyse the acquired data. Whenever the data reports to the comparison between the two groups, Mann-Whitney U tests are used to compare independent data from each group (e.g. first session G1 vs. first session G2). The comparison of sessions in the same group represents dependent data since they were performed by the same child (e.g. G1: first session vs. last session) using Wilcoxon tests. From now on, these comparisons will be distinguished presenting them as comparison between groups (Mann-Whitney U tests) and comparison in each group (Wilcoxon tests).

#### Eye gazing percentage along all the sessions

Fig. 5.11 represents the eye gaze behaviour performed by children in G1 and in G2 along all the sessions.
Comparing the first session of the two groups, where only the Recognize game scenario was performed, it was verified that the children in G1 gazed 52.5% of the time at the robot, and the children in G2 gazed 59.0% of the time at the task's material, in this case the rackets. In the remaining sessions, the percentage of time the children in G1 gazed at the robot was on average 22.1% and the percentage of time the children in G2 gazed at the task's material was on average 23.1%.
The Imitate Me game scenario does not employ any material, such as the rackets or the visual cue in the Storytelling game scenario. Children in G1 maintained their focus on the robot, gazing at it on average 30.5% along four sessions, and children in G2 looked at the experimenter on average 23.3% of the time.
The eye gaze behaviour between G1 and G2 follow a very similar pattern in the Storytelling game scenario. At this time the children in both groups were acquainted with the experimenter (and with the robot in G1), and their focus of attention was directed to the task's material, in this case the image used as the visual cue of the social story. On average, the children in G1 gazed at the task's material 39.2% and at the robot 15.1% of the time along the three sessions, and children in G2 gazed at the task's material on average 50.0% of the time.
Using the data presented in Fig. 5.11 and particularising it in each game scenario, the joint attention time was calculated. Joint attention time is the sum of the time the children looked at the robot (in case of G1), at the task's material, and at the experimenter.

#### Comparison of joint attention time

A Mann-Whitney U test was used to compare the average percentage of joint attention time between children in G1 and in G2 along the sessions (Fig. 5.12).
Significant differences were found overall the sessions regarding the joint attention time ($p = .05$). The children in G1 were focused on the interaction on an average of 83.3% of the time while the children in G2 were focused on average 73.6% of the time.
In the Recognize game scenario, no significant differences were found between G1 and G2 ($p = .386$) with 51.8% of joint attention time to G1 and 45.6% to G2. In the Imitate

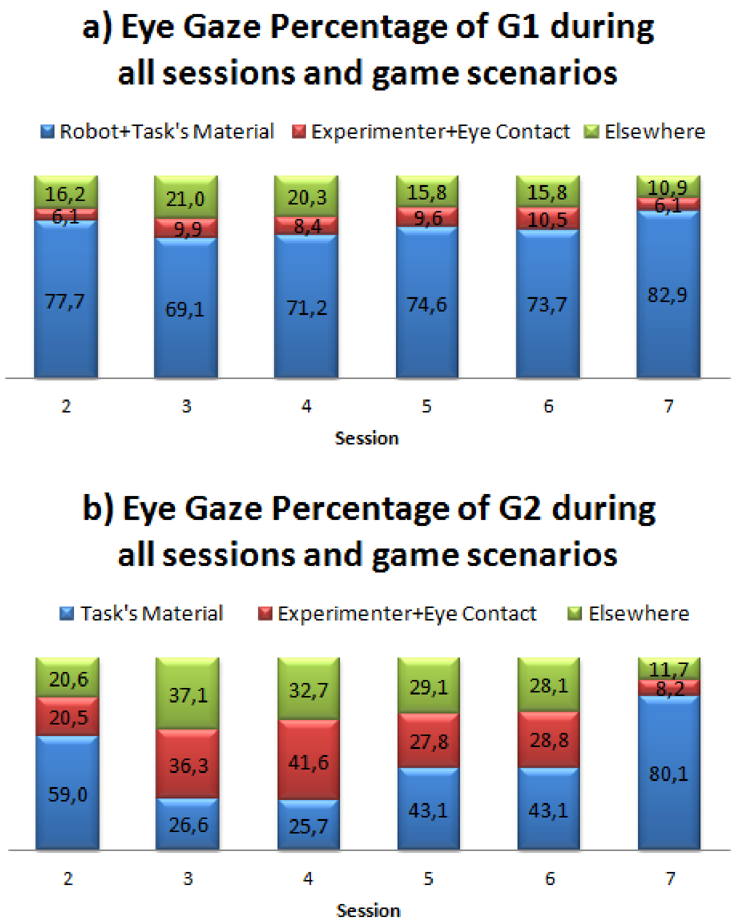


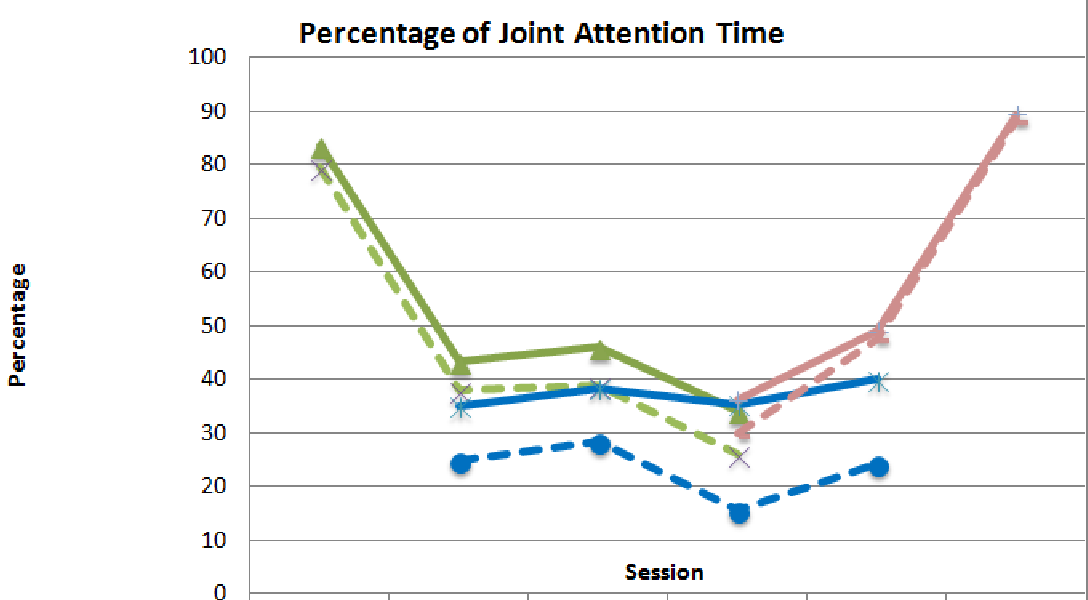

FIGURE 5.11: Eye gaze time of G1 and G2 along all the sessions. Children in G2 gazed for longer at the experimenter, but overall children in G1 are more focused on the task. Both groups follow the same patterns of behaviours, but in the Imitate Me game scenario significant differences were found between the groups.

Me game scenario significant differences were found ($p = .021$) when comparing the joint attention time of G1 (37.3%) with G2 (23.3%). The Storytelling game scenario did not show significant differences ($p = .513$) between the two groups (G1: 58.3%; G2: 55.3%).

A Wilcoxon test was used to compare the percentage of joint attention time in the first and the last session of each game scenario (Fig. 5.13).

Regarding the Recognize game scenario, significant differences were found for both groups (G1: $p < .001$; G2: $p < .001$) comparing the first to the last session. In both cases, the percentage of joint attention time decreased drastically from 83.6 to 34.2% for G1, and from 79.4 to 26.0% in G2. In the Imitate Me game scenario, no significant differences were found in G1 ($p = .070$) or in G2 ($p = .570$). The percentage of joint attention time varied from 35.1 to 40.1% in G1, and from 24.9 to 24.2% in G2. Finally, in the Storytelling scenario, for both groups significant differences were found

(G1: p <.001; G2: p <.001) when comparing the percentage of joint attention time of the first and the last session, increasing from 36.3 to 89.5% in G1 and from 29.9 to 88.3% in G2.



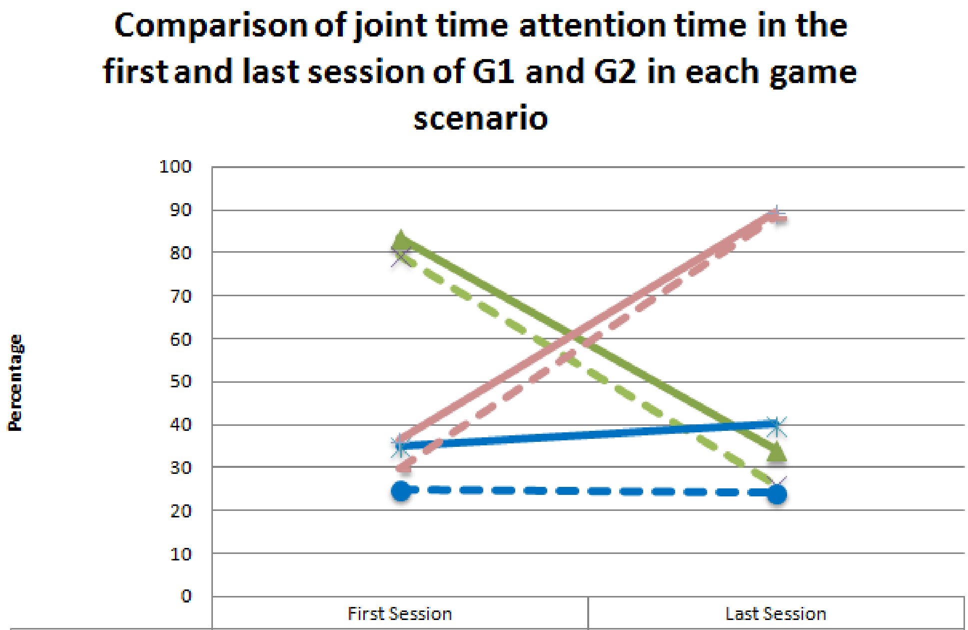

| | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Recognize G1 | 83,6 | 43,5 | 46,1 | 34,1 | | |
| Recognize G2 | 79,4 | 38,0 | 38,8 | 26,0 | | |
| Imitate Me G1 | | 35,1 | 38,4 | 35,4 | 40,1 | |
| Imitate Me G2 | | 24,9 | 28,4 | 15,7 | 24,2 | |
| Storytelling G1 | | | | 36,3 | 49,0 | 89,5 |
| Storytelling G2 | | | | 29,9 | 47,7 | 88,3 |

FIGURE 5.12: Comparison of the joint attention time percentages of G1 and G2 along all the sessions. The joint attention time increased more in the Storytelling game scenario.

#### Performance in the game scenarios

The percentage of successful, unsuccessful answers and unanswered prompts performed by the children in G1 is presented in Fig. 5.14 and by the children in G2 in Fig. 5.15. Mann-Whitney U tests were used to compare the percentage of successful answers performed by the children in G1 and in G2.

When comparing the first session of each game scenario in both groups, no significant differences were found in the Recognize game scenario (p = .755), in the Imitate me game scenario (p = .135) nor in the Storytelling game scenario (p = .427). However, comparing the last session of each game scenario in both groups, significant differences were found in the Imitate me game scenario (p = .014) and in the Storytelling game




| | First Session | Last Session |
|---|---|---|
| G1 Recognize | 83,6 | 34,1 |
| G2 Recognize | 79,4 | 26,0 |
| G1 Imitate Me | 35,1 | 40,1 |
| G2 Imitate Me | 24,9 | 24,2 |
| G1 Storytelling | 36,3 | 89,5 |
| G2 Storytelling | 29,9 | 88,3 |

FIGURE 5.13: Percentage of joint attention time of the first and the last session of each activity and overall.

scenario (p = .006). There was no significant differences in the last session of the Recognize game scenario (p = .660).

Fig. 5.16 compares the successful answers between the groups and according to each game scenario.

Using a Wilcoxon statistical test, the first and the last session of each group were compared, in each game scenario (e.g. Performance of Session 2 and Session 5 in the Recognize game scenario).

When comparing the first session to the last session in the Recognize game scenario, significant differences were found for G1 (p = .013) but not for G2 (p = .069). The same was verified regarding the Imitate Me game scenario (G1: p = .001; G2: p = .063) and the Storytelling game scenario (G1: p = .001; G2 = p = .868).

On average the performance of G1 in the Recognize game scenario increased by 23% (from 50.5 to 73.4%) while the performance of G2 only increase by 9.2% (from 52.5 to 61.6). In the Imitate Me game scenario, the performance of the children in G1 increased on average by 16.2% (from 67.5 to 83.7%) and increased only by 7.6% in G2 (from 54.3 to 62.0%). In the Storytelling game scenario, there was an increase in the performance of the children in G1 by 19.5% (from 62.7 to 82.3%) and a decrease by 0.4% in G2 (from 51.8 to 51.4%)

Besides comparing the first and the last session in each group and between groups, it is important to verify if the number of successful answers (SA) overcame the children's number of unsuccessful and unanswered prompts (UUP) along the sessions.

There was no significant difference when comparing the number of SA with the number of UUP in the first session of the Recognize game scenario performed by children in G1. In the same group, significant differences were found in the last session of this game scenario comparing the number of SA with the number of UUP ($p = .005$). Both for the first and for the last session of the Imitate Me game scenario, the number of SA overcome the number of UUP (first session: $p = .010$; last session: $p = .001$) in children in G1. In the Storytelling game scenario, significant differences were not found in the first session ($p = .154$) but they were found in the last session ($p = .003$).

The same analysis comparing the number of SA and UUP by children in G2 was performed and no significant differences were found.

**Comparison of the pre- and post-test data between G1, G2, and G3**

As mentioned in section 5.2.2, a third group of children participated in this study, performing only the pre- and the post-test. Before and after the experimental procedure which included the performance of the three game scenarios, the children of the three groups completed a performance task (for details, see section 4.6.1). Fig. 5.17 presents the average number of attempts and the time children in every group took to complete the performance task twice.

No significant differences were found between any of the three groups when comparing the number of attempts to match the two series of cards representing emotions in the pre- and in the post-test (i.e., number of attempts in the pre-test: G1 vs. G2. vs. G3 and number of attempts in the post-test: G1 vs. G2. vs. G3). In addition, significant differences were not found when comparing the duration of the pre- with the post-test in each group (i.e., duration of the pre-test: G1 vs. G2. vs. G3 and duration of in the post-test: G1 vs. G2. vs. G3).

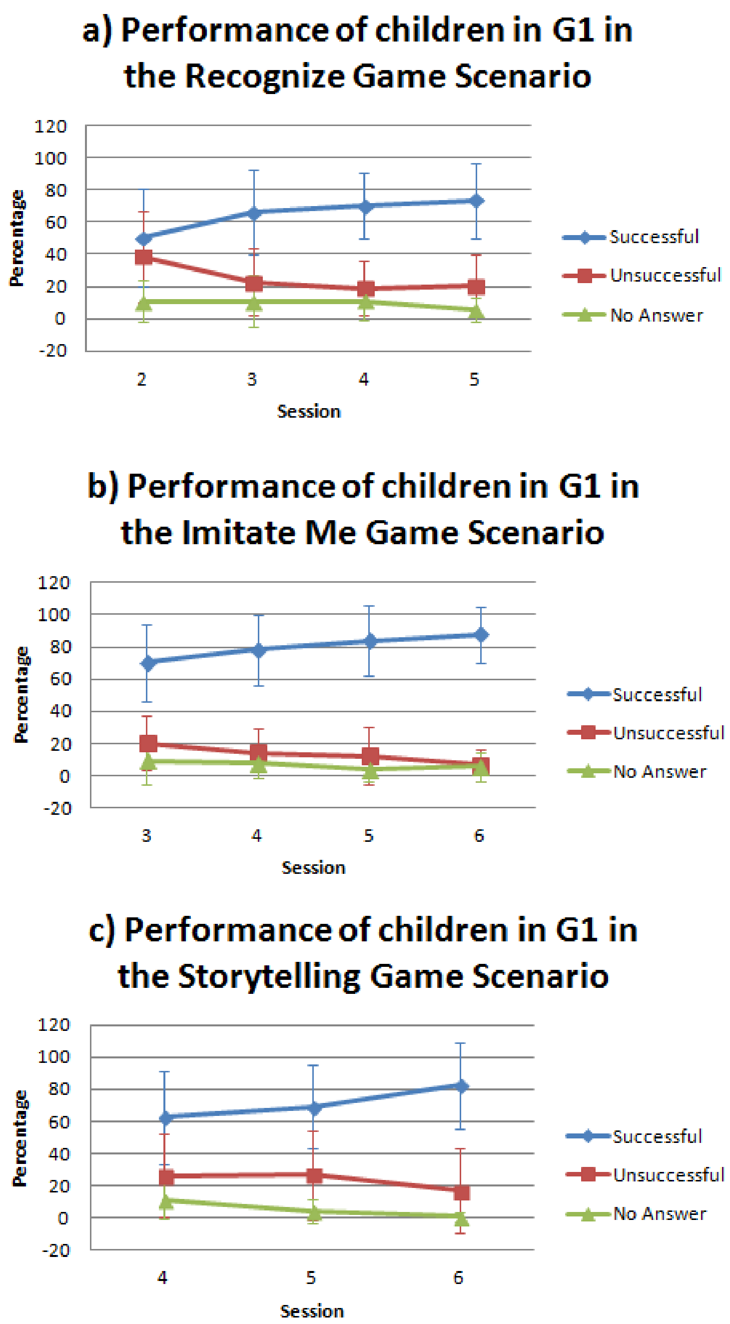



FIGURE 5.14: Comparison of the performance of the children in G1 along all the sessions. In all game scenarios the percentage of successful answers increased along the sessions.

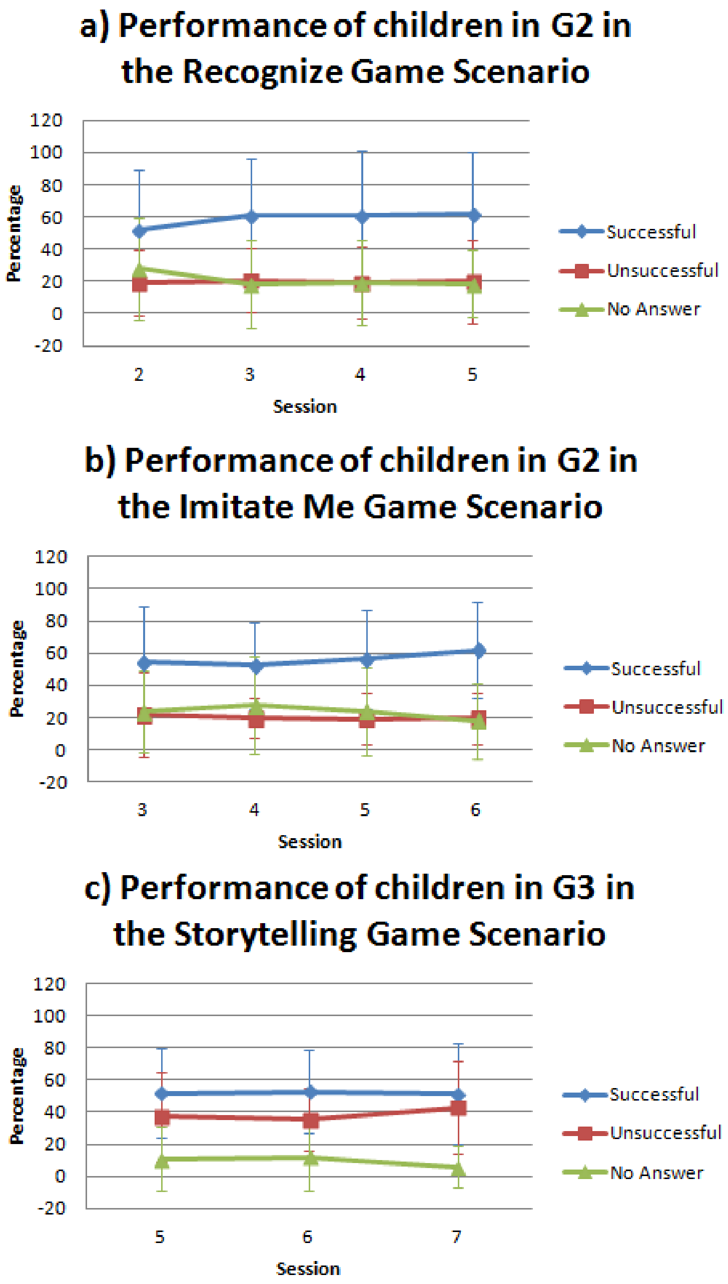



FIGURE 5.15: Comparison of the performance of the children in G2 along all the sessions. There was no difference in the percentage of successful answers performed by children in G2 along the sessions in all game scenarios.

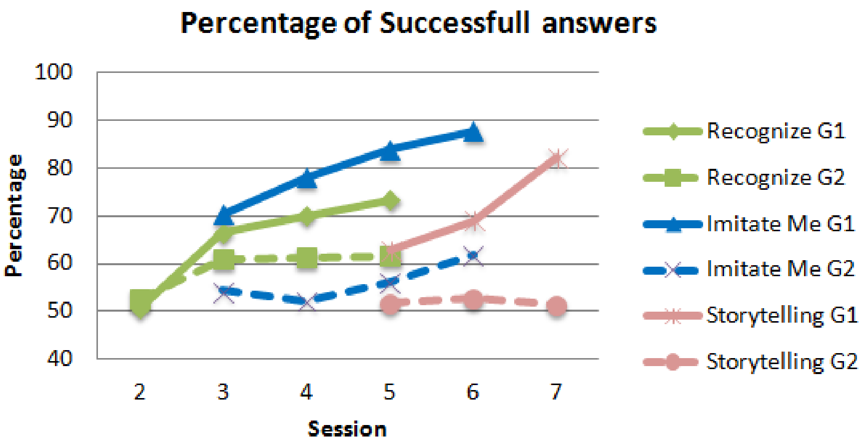



FIGURE 5.16: Percentage of successful answers along all the sessions, per game scenario in each group. The percentage of successful answers of children in G1 is significantly different from the first to the last session in each game scenario. The same is not verified for children in G2.

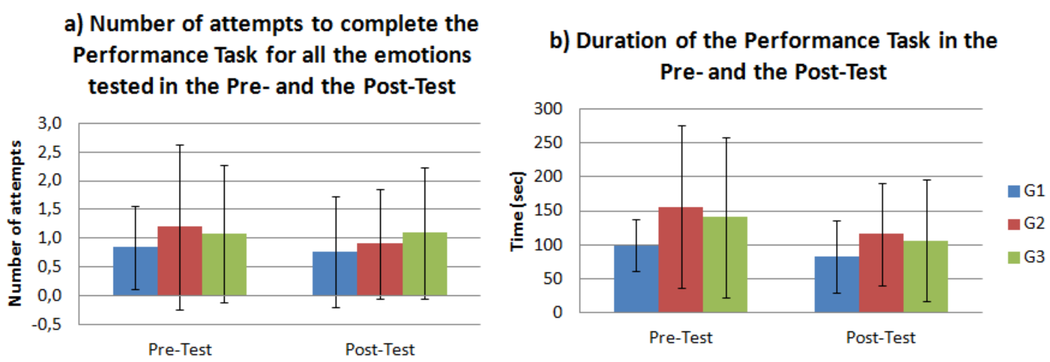



FIGURE 5.17: Number of attempts and duration in the performance task by children in G1, G2, and G3. There was no difference in the number of attempts to complete the task, but significant differences were found regarding the time the children took to finish the task.

However, significant differences were found in the time the children took to complete the task (i.e., time in the pre-test vs. time in the post-test). In G1, the time children took to complete the task decreased from the pre- to the post-test (pre-test: 99.3 seconds; post-test: 82.0 seconds) with significant difference ($p = .017$). The same was verified in G2 and G3. The duration of the performance task decreased from 155.7 to 75.1 seconds in G2 ($p = .031$) and from 118.4 to 89.7 seconds in G3 ($p = .026$).

### 5.2.4 Discussion of the Results

This study is focused on two primordial behaviours which are seriously impaired in children with ASD: eye gaze and emotion recognition.
When evaluating the children's behaviours regarding eye gaze, it was verified that overall children in G2 gazed at the experimenter for longer than children in G1 in each game. However, children in G1 spent less time looking elsewhere, focusing their attention on the task and on the robot (Table 5.10).

TABLE 5.10: Statistical comparison of the joint attention time. Scenarios: R = Recognize; I = Imitate Me; S = Storytelling.

| Behaviour | Group(s) | Sessions | Scenarios | p | Differences |
|---|---|---|---|---|---|
| Joint Attention Time | G1 vs. G2 | overall average | All | = .050 | G1: 83.3%<br>G2: 73.6% |
| | | average of the sessions | R | >.050 | G1: 51.8%<br>G2: 45.6% |
| | | | I | = .021 | G1: 37.3%<br>G2: 23.3% |
| | | | S | >.050 | G1: 58.3%<br>G2: 55.3% |
| | G1 | first vs. last | R | <.001 | first: 83.6%<br>last: 34.2% |
| | | | I | = .070 | first: 35.1%<br>last: 40.1% |
| | | | S | <.001 | first: 36.3%<br>last: 89.5% |
| | G2 | first vs. last | R | <.001 | first: 79.4%<br>last: 26.0% |
| | | | I | >.050 | first: 24.9%<br>last: 24.2% |
| | | | S | <.001 | first: 29.9%<br>last: 88.3% |

An unexpected result concerns the decrease of the joint attention time in the Recognize game scenario, comparing the first to the last session. Both groups follow the same pattern, indicating that the robot did not have an influence on this result. The difference between the first session of the Recognize game scenario and the remaining sessions was that the first session of the Recognize game scenario was in fact the first day when the experimenter interacted individually with the child. In addition, in the remaining sessions, the children performed at least one more game scenario. On one hand, these two combined facts may have influenced the interest of the children in the overall game scenario. On the other hand, the first session can be identified as an outlier. It was the first time the children interacted with the experimenter and participated in the procedure, and two main tools attracted their attention: the robot in G1 and the rackets in G2. The children spent one session exploring these materials, increasing the percentage of joint attention time, and they spent the following sessions focused on performing the game. The fact that the joint attention time decreased in the fourth session may also be related to the acquaintance of the children with the task and with knowing they were going to perform a new task.

Regarding the Imitate Me game scenario, the robot was indeed a tool that attracted the children's attention and this was maintained along the sessions. There was in fact an interest in the source of information provided from the robot's face.

With respect to the Storytelling game scenario, the image used as the visual cue attracted similarly the attention of the children in G1 and in G2.

Concerning the children's performance in the game scenarios (Tables 5.11 and 5.12), it is understandable that when comparing the first session of each game scenario between groups there was no difference. The children were theoretically at the same level in the beginning of the procedure. The children were assigned to each group, randomly only taking into account their age. In the Recognize game scenario, the children in G1 achieved a better performance than children in G2 but without significant difference. Nevertheless, children in G1 gave more than 10% more successful answers in the Recognize game scenario than children in G2 in the last session and the number of successful answers exceeded the sum of unsuccessful answers with the unanswered prompts. In general, children in G1 kept improving along the sessions and differences were found when comparing the first to the last session in each group. It indicates that in fact the use of the robot was a beneficial tool to promote the acquisition of the emotion recognition skill, especially because this was verified in G1 and not in G2, for all the game scenarios.

The results from the pre- and the post-tests (Table 5.13) indicate that children were faster to complete the task in the post-test. However, there was no difference in the number of attempts to complete the task in all groups, which indicate that the children still had difficulty to generalize the knowledge acquired in the experimental procedure.

TABLE 5.11: Statistical comparison of the children's percentage of successful answers. Scenarios: R = Recognize; I = Imitate Me; S = Storytelling.

| Measure | Groups | Sessions | Scenarios | p | Differences |
|---|---|---|---|---|---|
| Performance (Percentage of successful answers | G1 vs. G2 | first vs. first | R | >.050 | G1: 50.5%<br>G2: 52.5% |
| | | | I | | G1: 67.5%<br>G2: 54.3% |
| | | | S | | G1: 62.7%<br>G2: 51.8% |
| | | last vs. last | R | = .66 | G1: 73.4%<br>G2: 61.6% |
| | | | I | = .014 | G1: 83.7%<br>G2: 62.0% |
| | | | S | = .006 | G1: 82.3%<br>G2: 51.4% |
| | G1 | first vs. last | R | <.013 | first: 50.5%<br>last: 73.4% |
| | | | I | = .001 | first: 67.5%<br>last: 83.7% |
| | | | S | <.001 | first: 62.7%<br>last: 82.3% |
| | G2 | first vs. last | R | >.050 | first: 52.5%<br>last: 61.6% |
| | | | I | | first: 54.3%<br>last: 62.0% |
| | | | S | | first: 51.8%<br>last: 51.4% |

### Summary of Hypotheses and Implications

The study presented in this section targeted the analysis of the joint attention time and the children's performance focusing on emotion recognition skills. As a comparative study, the goal was to verify if the robot had any measurable influence in game scenarios which aimed to encourage the identification and labelling of emotions. Regarding the research questions presented in the beginning of this section, here highlighted in bold, the following implications were found:

Table 5.12: Statistical comparison of the average percentage of successful answers (SA) vs. the average percentage of unsuccessful answers plus unanswered responses (UUP). Scenarios: R = Recognize; I = Imitate Me; S = Storytelling.

| Measure | Groups | Sessions | Scenarios | p | Differences |
|---|---|---|---|---|---|
| SA vs. UUP | G1 | first | R | >.050 | SA: 52.7% UUP: 47.3% |
| | | | I | = .010 | SA: 70.7% UUP: 29.3% |
| | | | S | >.050 | SA: 62.4% UUP: 37.6% |
| | G1 | last | R | >.050 | SA: 74.4% UUP: 8.3% |
| | | | I | = .001 | SA: 89.1% UUP: 10.9% |
| | | | S | <.003 | SA: 82.0% UUP: 18.0% |
| SA vs. UUP | G2 | first | R | >.050 | SA: 49.2% UUP: 50.8% |
| | | | I | | SA: 51.0% UUP: 49.0% |
| | | | S | | SA: 55.6% UUP: 44.4% |
| | G2 | last | R | >.050 | SA: 62.2% UUP: 37.8% |
| | | | I | | SA: 57.1% UUP: 42.9% |
| | | | S | | SA:54.9% UUP: 45.1% |

Table 5.13: Statistical comparison of the children's performance in the pre- and post-test. No difference was verified between the three groups and difference was found in all the three groups regarding the duration of the task.

| Measure | Groups | Sessions | p |
|---|---|---|---|
| Number of attempts to complete the task | G1 vs. G2 vs. G3 | pre-test post-test | >.050 |
| Duration | G1 vs. G2 vs. G3 | pre-test post-test | >.050 |
| | G1<br>G2<br>G3 | pre-test vs. post-test | = .017<br>= .031<br>= .026 |

(a) **Can a humanoid robot contribute to develop visual emotion recognition in children with ASD?:** The number of successful answers in G1 exceeded largely the sum of the unsuccessful answers with the unanswered prompts in the Recognize game scenario, while in G2 this was not verified. This is also verified when significant differences were found comparing the first to the last session in this game scenario in G1 but not in G2. However, the results comparing the pre- to the post-test were not conclusive since no difference was found regarding the number of attempts to complete the task for all the three groups, but there were statistical differences when comparing the time children took to accomplish the task for all groups. This might indicate that the children acquired the skill but had difficulty to generalize it. The expectations regarding this research question were partially fulfilled.

(b) **Can a humanoid robot with the capability of displaying facial expressions elicit facial expressions' imitation skills in children with ASD?:** The results regarding the performance of the children in the Imitate Me game scenario indicate that children in G1 performed significantly better than children in G2. This was verified when comparing the number of successful answers to the sum of unsuccessful answers with the unanswered prompts, but also comparing the success between the first and last session of the game scenario, and between groups. The expectations regarding this research question were fulfilled.

(c) **Can a humanoid robot help children with ASD to attribute mental states and to identify others' affective state?:** Similarly to the Imitate Me game scenario, the children in G1 performed better than children in G2, so the expectations regarding this research question were accomplished. The performance of the children in G1 was 30% higher than the children's performance in G2, after the procedure. Differences were observed only in G1 between the first and the last session of this game scenario, which strongly indicated that the robot helped the children understand the perspective of the character in the story.

(d) **How does the use of a humanoid robot influence eye gaze and joint attention time in children with ASD in an interaction with another person?:** The eye gaze behaviour analysis indicated that children in G1 were focused on the interaction for longer than children in G2. In fact, children in G1 spent less time looking elsewhere, focusing their attention on the task and on the robot. The expectations regarding this research question consisted in observing an increased joint attention time in G1 compared to G2 along the sessions. On average and taking into account all the game scenarios and the total of six sessions the children performed in this study, the data confirmed that children in G1 were more involved in the sessions than children in G2. Comparing the game scenarios individually, divergent results were obtained. For both groups the joint attention time decreased from the first to the last session in the Recognize game scenario. No significant differences were found in the Imitate Me game scenario. In the Storytelling game scenario the increase of joint attention was significantly different for both groups, increasing the joint attention time from the first to the last session in each group. The expectations regarding this research question were partially fulfilled.

## 5.3 Summary and Conclusions

The analysis of verbal and non-verbal behaviours performed by children with ASD while engaged in a triadic interaction and acquiring emotion recognition skills was a study parallel to the one which presented the results from the children's performance. Even with the sample balanced for verbalisation between the two groups, the fact that some of the children only were able to perform vocalisations influenced the statistical analysis. In addition, the game scenarios or the procedure used in this study were not specific to encourage verbal communication. When testing this particular behaviour, initial incentives should be provided for the children to encourage them to perform verbal behaviours and the game scenario itself should provide the opportunity and encourage the children to verbalise.

However, this research showed interesting results regarding the display of non-verbal behaviours by children with ASD in a triadic interaction where a robot was used as a social mediator. The non-verbal behaviour exhibited more often by the children was leaning forwards to get closer to the object of interest, and this behaviour was showed more often by children in G1 than children in G2. The Imitate Me game scenario provided appealing results indicating that the children in G1 were specially engaged, when comparing the two groups. In addition, simultaneous non-verbal behaviours were more predominant in the group of children who interacted with the robot.

The analysis of joint attention time allowed the identification of the children's main focus of attention. Furthermore, several measures indicated a higher joint attention time from children in G1 comparing to the children in G2.

The children's performance in the three game scenarios provide strong evidence regarding the robot as a valuable tool to encourage the acquisition of emotion recognition skills by children with ASD. This learning was made at three different levels either by identifying and labelling facial expressions and the corresponding gestures, imitating facial expressions and inferring the affective state of another person. However, it was not possible to verify if this new skill was generalized to other contexts.
The studies presented in this chapter provided strong results on the evolution of the children in G1 performing the Storytelling game scenario. This game scenario had the specific goal of identifying the affective state of the character at the end of the social story and the results showed a better performance of children, comparing:

- the first to the last session of G1;
- the last session of G1 to the last session of G2;
- the successful answers to the sum of unsuccessful answers and the unanswered prompts of G1;
- the performance of the children in G1 increased by 19.53% on average (from 62.7% to 82.3%).

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# Chapter 6

# Conclusions and Future Work

This research concerns the application of humanoid robots for socio-emotional skills development in children with ASD. These children present difficulties in social communication and tools to attract their attention are fundamental to develop a wide range of social skills. In the research presented in this thesis, these skills included eye gaze, tactile interaction, verbal and non-verbal communication, and recognition of emotions. Triadic interactions aimed to be established between the child with ASD and the experimenter with the robot as the common object of attention. The conclusions regarding this research are summarized in the following items corresponding to each research goal:

**Goal 1: to verify if a humanoid robot can help children with ASD to learn appropriate physical social engagement, facilitating the ability to acquire knowledge about human body parts:**

The development of the child's physical, emotional, and psycho-social areas is in part promoted by touch, since tactile interaction is elementary and necessary for a complete emotional formation. Touch is also a form of conveying affectionate feelings or expressing pain or discomfort and the comprehension of the different types of physical contact helps children to build trust relationships, based on the exchange of support and mutual confidence. When analysing the interplay of children with ASD aiming to promote appropriate tactile interaction, the robot proved to be a useful tool, since besides attracting significantly the children's attention, the children touched the robot gently more often. On average, the sum of gentle touches was 8.5 times greater than harsh touches on the robot and 23.6 times on the experimenter. Comparing the first to the last session, eye gazing towards the experimenter increased fivefold with significance. Along the sessions, the children significantly increased their attention on the experimenter, gazing more often and for longer, and they improved their knowledge regarding human body parts, showed by significant differences in the questionnaires filled in by the teachers who daily accompany the children.

**Goal 2: to create a set of game scenarios using a humanoid robot as the main tool to develop socio-emotional skills in children with ASD:**
With the experience from the research performed in Chapter 3 and the feedback from several professionals who work directly with children with ASD, a set of game scenarios was created. The final design and implementation of the game scenarios took into account the experimentation of the game scenarios with a small sample of children with ASD and its corresponding improvement. The input from the professionals was important especially to define which kind of activities could be built and the difficulties the children might have performing them. Equally important was to guarantee that the robot could convey recognizable facial expressions. These were evaluated by typically developing children and adults and the overall recognition rate was higher than 70.0% for typically developing children and almost 90.0% for adults. Summarizing, the overall process consisted in consulting-designing-testing-updating and repeating this process until obtaining the desired result.

**Goal 3: to evaluate the use of a humanoid robot, as a tool to teach recognition and labelling of emotions:**
The identification of emotions was made at three levels: labelling, imitating, and inferring internal states of others. In the first game scenario the children managed to label the facial expressions and gestures performed by the robot. Children who performed the game scenario with the robot had 10% more successful answers than the children who performed the game scenario without the robot. Significant improvements were observed in the Imitate me game scenario with 20% more successful answers for children who interacted with the robot. Similarly, in the Storytelling game scenario, children who performed the game scenario with the robot had 30% more successful answers than the children who performed the game scenario without the robot. The more pronounced difference was verified in the Storytelling game scenario, classified by the professionals who participated in the focus groups as the most difficult task for the children. The children managed to identify how the character of the story felt at the end

of the story, more easily when it was told by the robot than when it was told by the experimenter.

**Goal 4: to understand if and how a humanoid robot could promote triadic interactions between a child with ASD and another person:**
The children who interacted with the robot performed several social behaviours typical from social interactions. No differences were found regarding verbal communication, but the children showed several non-verbal behaviours indicating their interest in the task. In fact, children who interacted with the robot performed between 4 and 5 times more simultaneous non-verbal behaviours than children who performed the game scenario without the robot. Moreover, the joint attention time from children who interacted with the robot was significantly higher compared to the children who did not interact with the robot.

As highlighted in section 2.2.1, joint attention is a weakness for children with ASD in almost all steps of their growth and this influences non-verbal behaviours such as smiling, eye gaze, following gaze, or pointing. Children with ASD also present limitations with respect to understanding the perspective of others, showing difficulties inferring mental states in the basis of the external behaviour shown by the other. For this reason, showing empathy is challenging for children with ASD.
Imitating is also a main difficulty of children with ASD as it was stated in section 2.2.2. This deficit influences the cognitive skill of attributing mental states in order to predict behavioural outcomes and to imitate affective facial expressions.
The type of intervention presented in section 2.2.4 was adapted to include a humanoid robot aiming to form a triadic interaction between the child with ASD and an adult using the robot as an object of joint attention. The physical structure was arranged to decrease distracting factors and to intervene in individual context. A visual support was used to introduce the small changes in the daily routine of the children. The results showed that adding a robot to the intervention was an advantage since in some behaviours children with ASD who interacted with the robot performed better than the children who did not. Hence, the research questions (RQ) presented in section 1.2.1 were answered, and the proposed hypotheses were tested. Not all expectations were satisfied, but the answers to the research questions may indicate future paths to follow:

**RQ 1: Can the robot elicit the ability to acquire knowledge about human body parts and help teach children with ASD appropriate physical (tactile) social engagement?**

It was hypothesised that the use of a robot could help children with ASD to learn the name of different body parts and to encourage them showing appropriate physical behaviours. In fact, children who initially were not able to identify some of the body parts in the pre-test, showed an improvement of their knowledge, tested in the post-test. Additionally, the children touched the robot mostly in a gentle way;

**RQ 2: How can a humanoid robot contribute to develop emotion recognition skills in children with ASD using game scenarios about labelling, imitation and inference of emotions?**

It was expected that children performed better when participating in game scenarios with a robot and an adult comparing to children who only interacted with an adult. This expectations were met since the children who interacted with the robot showed a higher performance when they had to label and imitate emotional facial expressions. Additionally, a better performance was verified when inferring the affective state of a character by children interacting with the robot. The children interacting with the robot were more successful comparing the first to the last session of each game scenario, and between groups. Only with children who interacted with the robot a difference between the first and the last session of the Storytelling game scenario was observed, which strongly indicated that the robot helped the children understand the perspective of the character in the story;

**RQ 3: Does the verbal and non-verbal communication of children with ASD change in an interaction with a humanoid robot and other person?**

The expectations regarding this research question were related to a longer and more frequent verbal and non-verbal interaction from children who interacted with a robot and the experimenter comparing to the group of children who only interacted with the experimenter. These expectations were partially met since no differences were found between the groups with regards to verbal behaviours. However, children interacting with the robot displayed more non-verbal behaviours indicating social engagement than children interacting only with the adult;

**RQ 4: How does the use of a humanoid robot influence eye gaze and joint attention time in children with ASD in an interaction with other person?**
It was hypothesised that the children increased their eye gaze towards the experimenter along the sessions and would participate in joint attention behaviours for longer periods of time and more frequently when performing activities with a robot and an adult comparing to children who only interact with an adult. In fact, the children showed significantly more gaze directed towards the robot in the study presented in Chapter 3, and joint attention increased over sessions. Similar results were obtained in the study presented in Chapter 5. Children interacting with the robot spent less time looking elsewhere, focusing their attention on the task and on the robot. An increased joint attention time by children interacting with the robot was observed compared to the children in the group without the robot.

To summarize, this thesis contributed to several research and applicative domains:

**Robot-Assisted Play:** a methodological approach of how to design, conduct and analyse robot-assisted play with the specific target group of children with ASD was proposed. This approach was consistently used throughout the presented experimental research;

**Assistive Technology:** the semi-autonomy implemented in the robot allowed the automatic response to the children's tactile interaction and answers to the robot's prompts, giving at the same time liberty to the experimenter to control the intervention session. The developed game scenarios can be tailored to each child repeating the prompt as many times as necessary, and giving the child their preferred reward. Additionally, some of the main difficulties pointed out by the professionals while developing emotion skills in children with ASD were tacked, such as: attracting the child's attention, putting themselves in place of other, and associating specific situations to emotions;

**Developmental Psychology:** combining three main difficulties of children of ASD - emotion recognition, imitation and emotional state inference - the use of the robot proved to be a useful tool to assist children with ASD to improve these social skills, while helping them focusing their attention;

**ASD Research:** the conducted studies may lead to a new method in ASD intervention, focusing on emotion recognition skills and on appropriate tactile interaction. The developed setup and the experimental procedures can be used by professionals who follow children with ASD. The contributions consist in adapting pre-existing tasks with a new element which main goal is to attract the children's attention.

## 6.1 Challenges

As the name implies, autism is defined by a spectrum and this fact represents itself a challenge. It makes it harder for the experimenter to follow the same procedure with each child. Some social adaptation was needed, but always guaranteeing that the constraints of the interaction were the same for all the children.

The hardest obstacle to overcome during this research, and most likely whenever observing human behaviour, was to perform the video analysis of the intervention sessions. This form of data collection is extremely time consuming, greatly exhausting, and it has to be done carefully. After structuring the coding scheme for the exploratory studies, the process of training an independent rater to code the behaviours in the videos was very important so the data was correctly imported.

To perform an experimental study with 45 children was for sure a challenge, which was necessary in order to test the validity of the approach, interventions, and their impact on the target population. Moreover, most robot-children interaction studies remain at the case study level, with a small sample of participants. To guarantee a significant and convincing impact of the research for the professionals and research community, demonstrating and testing the developed scenario with a large sample was crucial.

The investment in this study was high, since all the experiments were performed by the same person. This included setting up the session rooms in each different school or clinic, conducting the experiments, activating the cameras, and monitoring the children following always the same procedure. In addition, this research involved for the final study travelling more than 5000 km and spending more than 100 hours for the experimental procedure, from setting the room to performing the game scenarios. 270 experiments were conducted originating 1350 minutes of video footage in total.

Even with the above mentioned challenges, the results presented in this thesis and the feedback from the professionals after the conclusion of the procedures are very encouraging to continue this line of research.

### 6.1.1 Learning Outcomes from the Study

Multidisciplinary research is definitely important, however difficult. Investigating a different area of knowledge involves a great deal of commitment and persistence.

The reinforcement given by the robot or by the experimenter was one of the essential parts of the game performance. The reinforcement encouraged the child to interact and the children seemed to enjoy the interaction. Even with strong difficulties in the human-human interaction, it was with great surprise that some of the children, after some sessions, interacted verbally with the experimenter sharing situations where they felt afraid, happy, sad, surprised or angry. Additionally, many children when listening to ZECA's stories asked more about it, for example, if he would go to school and in which grade he was.

Informally, some parents and therapists reported that the children while and after interacting with ZECA changed their behaviours, for example, showing an emotional face during intervention when they assumed the therapist was happy or sad. As one example of the interest the robot provoked in the children, after a few weeks of finishing the procedure with one child, the experimenter met him again in one of the clinics where more sessions were being performed. When he identified the box where he knew ZECA was, he would not leave the room, asking to play with ZECA.

These are, of course, small examples of how a different tool can impact the intervention of children who interpret the world differently. The role of engineers and therapists is to work together so this tool becomes widely usable for these children.

## 6.2 Future Work

Further developments could be divided into short and long term research. Regarding short term research, the developed game scenarios with the robot could be used in small groups context. The research presented in this thesis has already shown the potential of the robot to encourage the interaction between a child with ASD and an adult, in an individual context, and it would be interesting to observe how the children with ASD would split their attention and would interact in small groups.

Additionally, several experiments could be conducted to narrow down the beneficial factors of the robot, and testing their impact. For example, an experiment could investigate the impact of the added gestures corresponding to the facial expressions, to verify if their addition provides a differential effect or not. In addition, in the Storytelling game scenario, the performance of the children could be evaluated when the storyteller uses facial expressions or not. Still related to this game scenario, measuring the change in the children's emotional vocabulary used before and after the intervention could be a useful procedure to evaluate the benefits in terms of generalisation.

As previously suggested, other scenarios or a different procedure can be employed to try and encourage the children to verbalise more often, balancing between verbal and non-verbal emphasis of the robot's behaviours.

Concerning long term research and as it was stated in Chapter 1, the interaction promoted in this thesis was based on a prompt-answer-reward process. This means that the robot followed always the same steps, being simple and predictable.

Further research can employ a system which adapts the robot's behaviour to the child's actions during an intervention session. The adaptation can be based on a predictive model using a database of non-verbal behaviours, eye movements' analysis and the child's performance.

Additionally, instead of using image processing to acquire the children's answer, which sometimes can be difficult if the child do not have enough fine motor coordination skills, objects based on playware technology can be used instead. Playware is defined as intelligent technology for children's play and playful experiences for the user. This technology emphasizes the role of interplay between morphology and control using processing, input, and output.

This would lead to a hybrid approach composed by robots and playware technology to interact with children with ASD. The focus of this research will still involve the promotion of social interaction behaviours between a child with ASD and other person, using technology as a tool and object of shared attention. In order to make a significant and substantial contribution to the literature, the following goals may be pursued:

**Goal 1:** to evaluate the use of objects based on playware technology in a human-robot interaction scenario;

**Goal 2:** to modify the robot's behaviour according to eye movements patterns from children with ASD;

**Goal 3:** to modify the robot's behaviour according to non-verbal actions from children with ASD;

**Goal 4:** to equip a humanoid robot with a statistical model which predicts the behaviour of a child with ASD based on previous non-verbal behaviours, eye movements and manipulation of objects based on playware technology;

**Goal 5:** to evaluate the social interaction between the child with ASD, the robot and the experimenter, using the developed system.

This research will provide autonomy to an object which already has been used to successfully attract the attention of children with ASD. This autonomy can lead to an increased awareness for social interactions of the child based on different modalities and key react behaviours from the robot.

The differences in the children's behaviour in a human-robot interaction scenario when objects based on playware technology are added can be evaluated, as well as the differences in the children's behaviour when the robot adapts its behaviour according to the children's eye movements and non-verbal actions.

The hypotheses will address whether the children with ASD will be more engaged in the human-robot interaction with objects based on playware technology, when the robot adapts its behaviour to the children's eye movements and to the children's non-verbal actions.

This research may be the next step from the predictable prompt-answer-reward process, since an adaptive robot would provide a controlled environment for the children who pass the first steps, the research presented in this thesis. This could lead to a deeper understanding of agency through several interactions with a less predictable and more "natural" agent. Hopefully, this can be a platform for slow incremental progress in social interaction and emotional skills development for children with ASD.

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# Appendix A

# Material used in the study presented in Chapter 3

- Consent Form
- Flow Charts
- Structured Interview - Instruction Sheet and Observation of videos
- Observational Grid
- Questionnaire

## A.1 Consent Form

Dear Parent,

Prof. Kerstin Dautenhahn and I of the University of Hertfordshire are involved in the Aurora project, which is an ongoing project at the University for the last 12 years that aims 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. A special focus is given to the role of the robots as Śsocial mediators', i.e. allowing the child to play with other children or adults.

As part of previous work (e.g Aurora, IROMEC, ROBOSKIN) we have run trials in the past 12 years at several schools including Southfield school as well as a number of the National Autistic Society's schools. With the support of Mr. Deacon and his team, we will be running more trials. These will involve sessions of 10-15 minutes duration, where the children can play with the robot, 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. The Aurora project have the approval of the University of Hertfordshire Ethics Committee.

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

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

Thank you for your support

Dr. Ben Robins (Senior Research Fellow)

Day telephone no. - 01707 xxxxx
Mobile number - 07850 xxxxxx

- - - - – - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

I give permission for my child                                   to take part in trials of the Aurora project, 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:

## A.2 Flow Charts

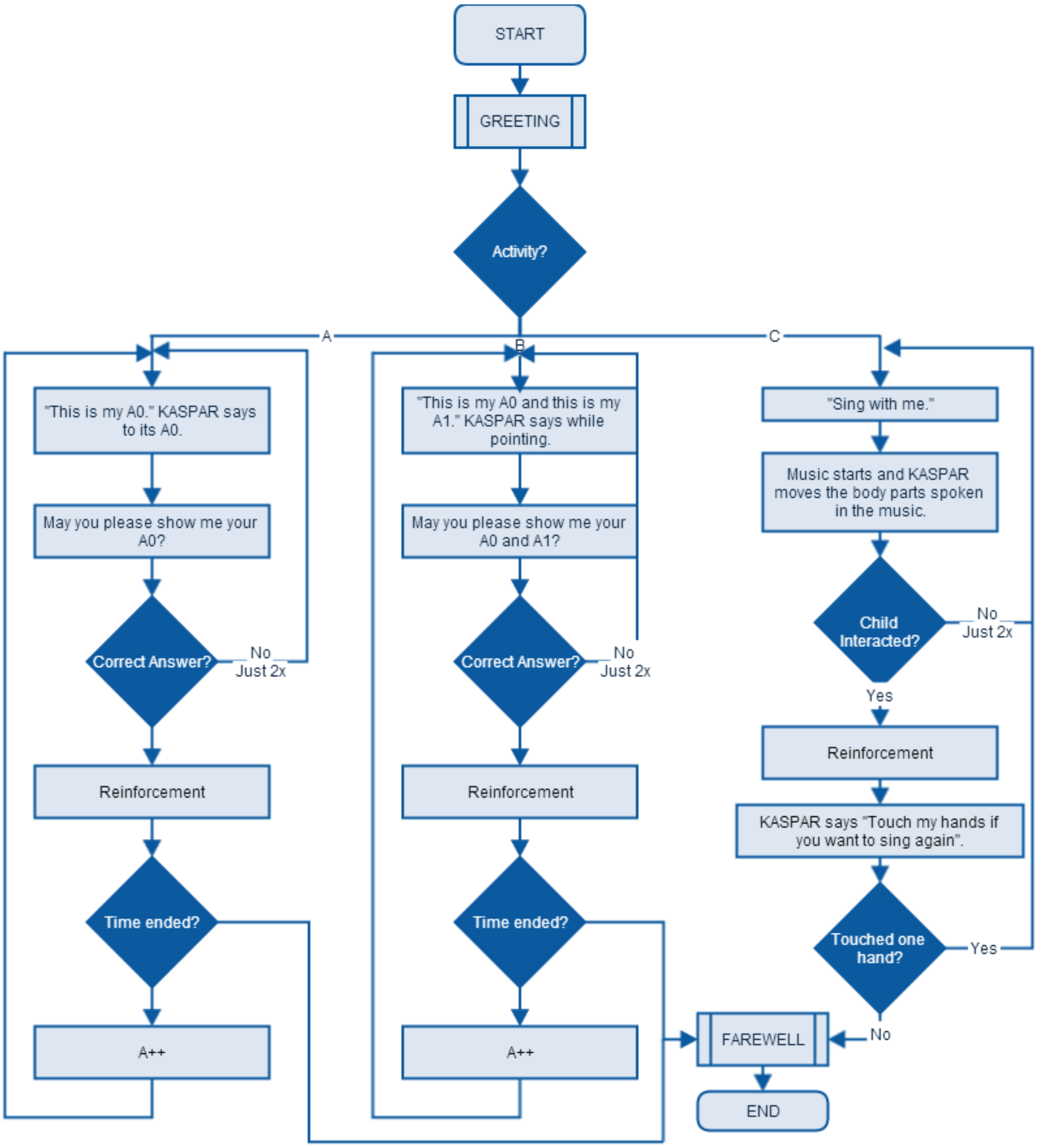


FIGURE A.1: Algorithm showing the progress of the activities during the sessions.

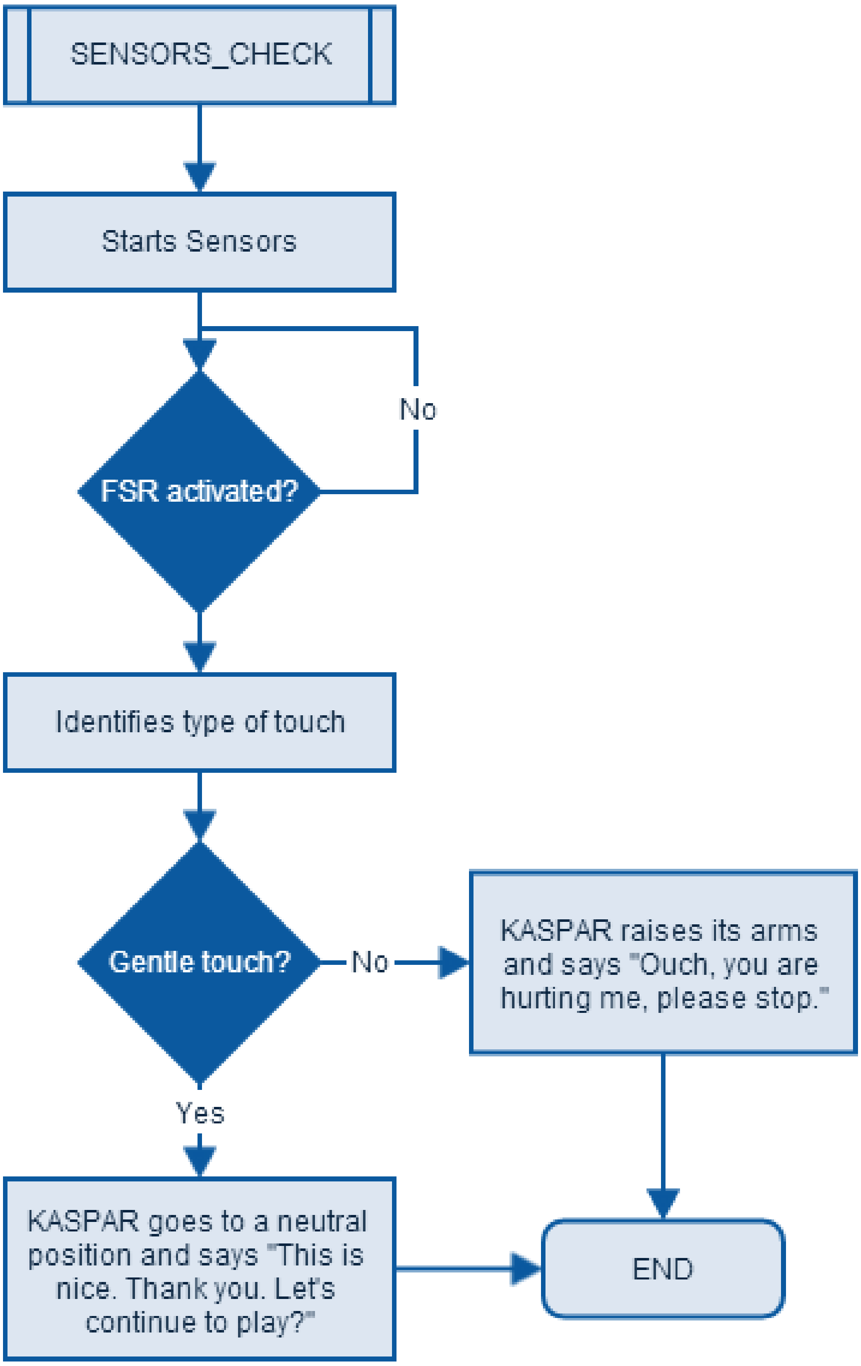


FIGURE A.2: Algorithm showing the performed processes when KASPAR is touched.

## A.3 Structured Interview - Instruction Sheet and Observation of videos

Thank you very much for your interest in our research and for your time. Your feedback is very important for our work, because it will help us to better understand the children's behaviours. It will enable us to look at our results from a different perspective.
In the study at hand, we intend to investigate whether KASPAR can fulfil its role as a social mediator and improve interaction between am autistic child and another person. We also wanted to test if KASPAR can help to improve body awareness in children with ASD and if the robot can help children with ASD to teach appropriated physical social engagement. In the play scenarios, the children interacted with the robot, and the robot named body parts and asked them to show it their corresponding body parts. In the last activity a song about body parts was performed together.
We would like to ask you to watch one video of the first session and another one from the last session. For each of two the children, we would like to ask you to write down any comments that you would find interesting and that correspond to the following two questions:
- taking your prior experience with the children into consideration, how would you describe the reaction of the child towards the robot (good, bad, indifferent)? Please explain briefly.
- what usual or unusual behaviours of the child were performed in the video?

**Guidelines for the Structured Interview for the teacher at the Southfield School**

Estimated time: 2 videos/children (select 4 min/video) = 2 x 4 x 8 children = 64 min. + time of discussion 1h = 2h

**Introduction - Generic Questions**

- ask about her last week in the school;
- ask about her motivation to work in children with special needs;
- ask about what she feels is difficult while helping children with special needs.

**Past Experience with the children**

- evaluate her prior experience;
- ask specifically for the children she has interacted with, how well does she know them

**Present**

- how do you compare the child's social behaviour seen in the video to how he behaves towards teachers and children in the classroom? (tactile interaction, eye gaze, playing with others, ...)
- from your perspective, what are the main differences in the boy's behaviour in the two videos you have seen? (ask for each child)
- talk about specific behaviours performed by the boy that I saw that were different: Do you think the robot had influence in the behaviours?

**Future**

- do you have the impression any of the changes you have seen could be lasting?
- what is your general impression of the effect KASPAR has on the children?

Table A.1: Behavioural changes of the children highlighted in the structured interview used in study presented in chapter 3

| Child | Before (1st Session) | After (...) |
|---|---|---|
| 1 | He only looked at the robot. | He looked me in the eyes and talked with the experimenter. |
| 2 | He kept asking "What's the time?" and repeating the last sentence/-word of the experimenter. He almost could not point to his body parts (when he did it was after the the experimenter's prompts, showing the body part). He said he did not want to play with KASPAR. He kept his gaze on KASPAR, and only looked at the experimenter, if she was talked with him. | He never asked the time, and few were the times he repeated the last sentence/word of the experimenter. He could point to his body parts, almost immediately after the request. He said he wanted to play with KASPAR. After every prompt of KASPAR, the child would look at the experimenter to show her the answer. |
| 3 | He made no eye contact or spoke with the experimenter. He almost did not say a word during this session. | For several times he smiled at the experimenter. He answered to the experimenter's questions and smiled several times. |
| 4 | He showed his body parts in a very harsh way. From half of the session he kept pointing to his body parts while leaning on himself. He hardly looked at the experimenter. | He showed his body parts in a gentle way. He sat straight and pointed to his body parts. He looked several times at the experimenter and smiled a lot. |
| 5 | He kept running away from the room. He almost did not touch the robot. He did not manage to show any body parts | He wanted to return to the room after the session was over and he grabbed the experimenter's hand to seat down and continue the session. He touched the robot a lot of times (sometimes a bit rough), holding his face with his hands and rubbing his nose on KASPAR's nose. He was able to show some body parts. |
| 6 | He did not used verbal communication to interact with the experimenter. | He answered to simple questions made by the experimenter. |
| 7 | Sometimes, he seems to look happy, when KASPAR was sad. | If he was a bit rough with KASPAR, he would say "I am sorry". |
| 8 | (The teacher did not comment on this child, since she never interacted with him). | |

## A.4 Observational Grid

TABLE A.2: Observational grid used in study presented in chapter 3

| Child | Notes |
|---|---|
| What was the first reaction of the child when he saw KASPAR? | |
| Did the child touch the robot in the first 5 minutes of the session? | |
| The child manage to perform the task? | |
| Did the child interact with the researcher? | |
| How did the child respond to the change of task? | |
| Any special circumstances? | |

## A.5 Questionnaire

**IDENTIFICATION OF THE CHILD**

- Name of the Child:

**IDENTIFICATION OF THE PERSON WHO IS COMPLETING THE QUESTIONNAIRE**

- Name:

O Guardian O Teacher O Therapist O Psychologist O Medical Doctor O Other

Use the following scale and circle the most appropriate number for each sentence: **1. Never; 2. Rarely; 3. Occasionally; 4. Frequently; 5. Always; n.a. not applicable**

Table A.3: Questionnaire used in study presented in Chapter 3

| Statement | 1 | 2 | 3 | 4 | 5 | n.a. |
|---|---|---|---|---|---|---|
| 1. How often does the child react positively to human touch with a known partner?* | | | | | | |
| 2. How often does the child react positively to human touch with an unknown partner?* | | | | | | |
| 3. Does the child use his/her hands to explore novel/unknown objects?* | | | | | | |
| 4. Does the child use other parts of his/her body to explore new/known objects?* | | | | | | |
| 5. Can the child identify verbally at least one part of his/her body? | | | | | | |
| 6. Can the child point to at least one part of his/her body when asked to do so? | | | | | | |
| 7. Can the child point or identify parts of his/her body in any way? | | | | | | |
| 8. Can the child control his/her force while interacting with other children? | | | | | | |
| 9. Does the child perform eye contact while interacting physically with other people? | | | | | | |
| 10. Does the child wait for his/her turn while performing a favourite task? | | | | | | |
| 11. Does the child wait for his/her turn while performing a mandatory task? | | | | | | |
| 12. Does the child use objects to attract attention of other people? | | | | | | |

*Please put further comments in the box below please.

| Statement | 1 | 2 | 3 | 4 | 5 | n.a. |
|---|---|---|---|---|---|---|
| 13. Does the child seem to enjoy tactile stimuli?* | | | | | | |
| 14. Is the child able to distinguish by touch differences in texture, such as rough or smooth surfaces?* | | | | | | |
| 15. Does the child understand his/her location and the location of objects in relation to his/her body?* | | | | | | |
| 16. Does the child direct body parts in a purposeful manner in response to spatial directions? | | | | | | |
| 17. Does the child direct individual body parts in a purposeful manner in response to spatial directions? | | | | | | |
| 18. Is the child aware of his/her body position/movement (e.g. in imitation games s/he is aware of the position of his/her body parts)? | | | | | | |
| 19. Is the child able to know without looking where each part of the body is and how it is moving through space. | | | | | | |

Did you notice any changes in the child's behaviour from the moment he started interacting with KASPAR? Which?

Comments:

# Appendix B

# Material used in the study presented in Chapter 4

- Questionnaire to professionals
- Technical Drawings of the Robot
- List of Action Units and Action Descriptors
- Use Case Diagrams
- Sequence Diagrams
- Social Stories
- Visual cues used with the Social Stories

## B.1 Questionnaire to professionals

- Name:
- O Guardian O Teacher O Therapist O Psychologist O Medical Doctor O Other
-Number of years supporting children with ASD:
- Q1: How do you develop emotional recognition? In what ways do you teach feelings; happy, sad, angry, etc.?
- Q2: What are the main difficulties while developing emotion skills in children with ASD?
- Q3: Which kind of materials are used to develop these skills?
- Q4: Is the recognition of emotions a goal of the educational program of the children in your school/association?
- Q5: Is this attendance done together with other children or individually?
- Q6: If possible, suggest us two or three activities performed by you with children with ASD, to develop emotional recognition.
- Further comments:

## B.2 Technical Drawings of the Robot

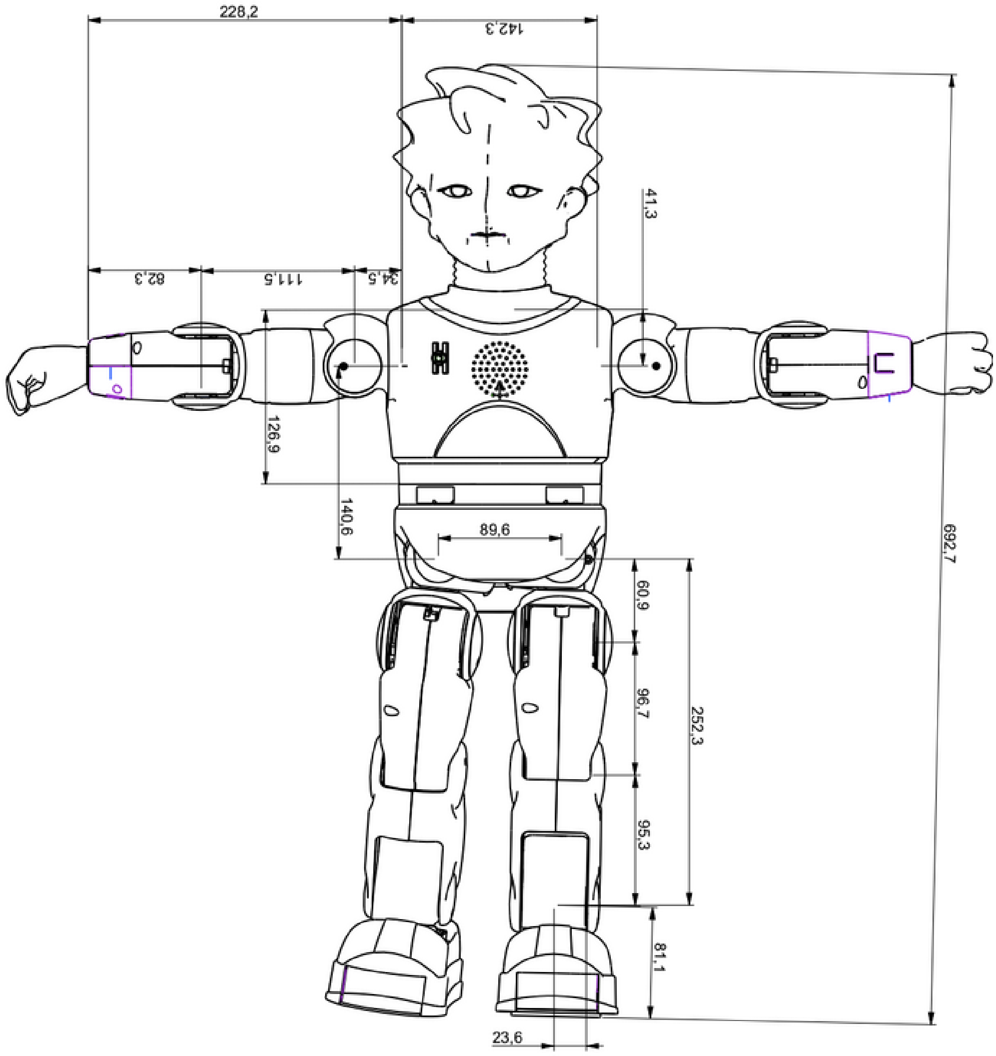


FIGURE B.1: Robot Technical Drawings showing its entire body.

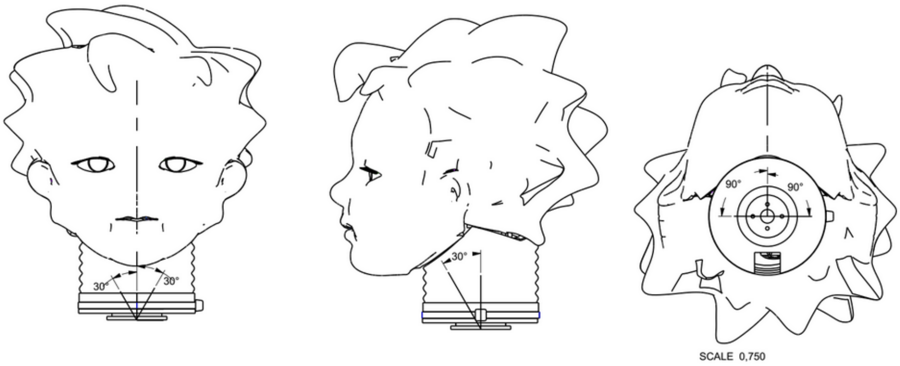


FIGURE B.2: Robot Technical Drawings showing specifically its head.

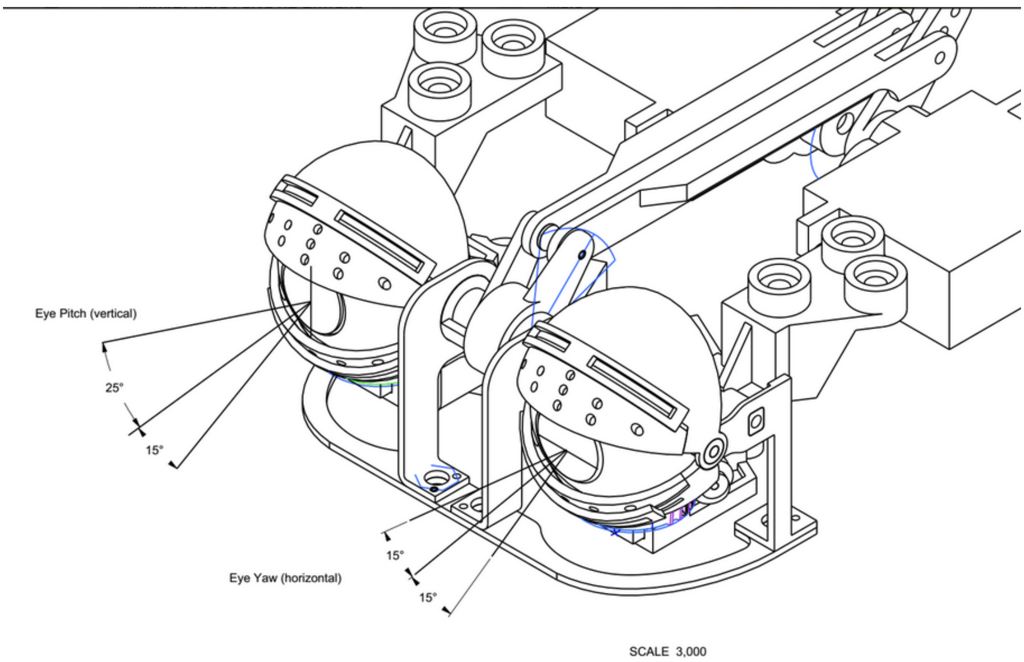


FIGURE B.3: Robot Technical Drawings showing the details of the cameras in the robot's eyes.

## B.3 List of Action Units and Action Descriptors

Table B.1: List of Action Units and Action Descriptors (with underlying facial muscles)

| AU # | FACS Name | Muscular Basis |
|---|---|---|
| - 0 | Neutral face | |
| 1 | Inner Brow Raiser | frontalis (pars medialis) |
| 2 | Outer Brow Raiser | frontalis (pars lateralis) |
| 4 | Brow Lowerer | depressor glabellae, depressor supercilii, corrugator supercilii |
| 5 | Upper Lid Raiser | levator palpebrae superioris, superior tarsal muscle |
| 6 | Cheek Raiser | orbicularis oculi (pars orbitalis) |
| 7 | Lid Tightener | orbicularis oculi (pars palpebralis) |
| 8 | Lips Toward Each Other | orbicularis oris |
| 9 | Nose Wrinkler | levator labii superioris alaeque nasi |
| 10 | Upper Lip Raiser | levator labii superioris, caput infraorbitalis |
| 11 | Nasolabial Deepener | zygomaticus minor |
| 12 | Lip Corner Puller | zygomaticus major |
| 13 | Sharp Lip Puller | levator anguli oris (also known as caninus) |
| 14 | Dimpler | buccinator |
| 15 | Lip Corner Depressor | depressor anguli oris (also known as triangularis) |
| 16 | Lower Lip Depressor | depressor labii inferioris |
| 17 | Chin Raiser | mentalis |
| 18 | Lip Pucker | incisivii labii superioris and incisivii labii inferioris |
| 19 | Tongue Show | |
| 20 | Lip Stretcher | risorius w/ platysma |
| 21 | Neck Tightener | platysma |
| 22 | Lip Funneler | orbicularis oris |
| 23 | Lip Tightener | orbicularis oris |
| 24 | Lip Pressor | orbicularis oris |
| 25 | Lips Part | depressor labii inferioris, or relaxation of mentalis or orbicularis oris |
| 26 | Jaw Drop | masseter; relaxed temporalis and internal pterygoid |

## B.4 Use Case Diagrams

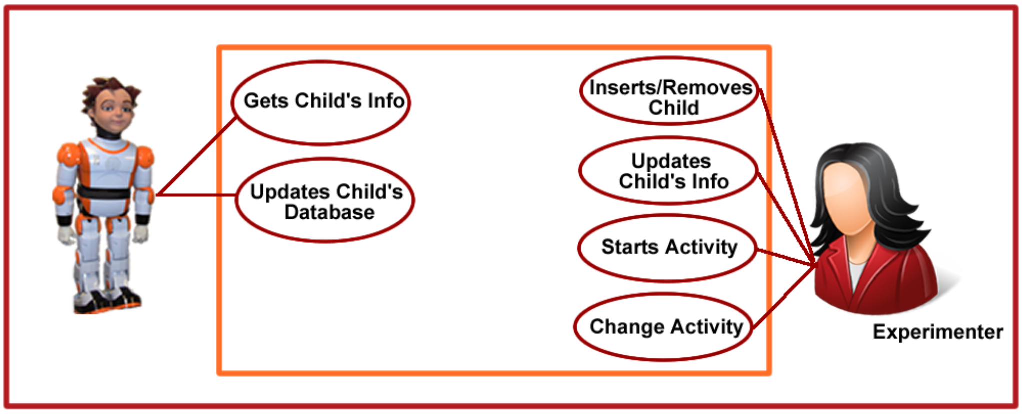


FIGURE B.4: Use Case Diagram for the System Configuration.

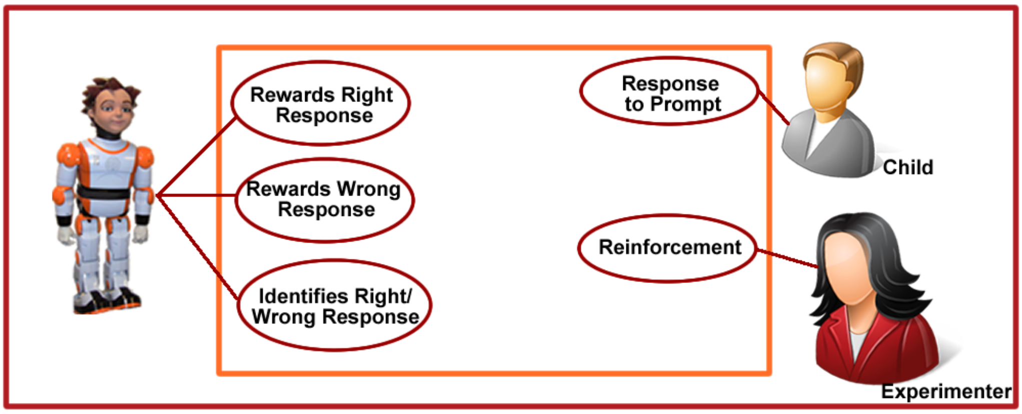


FIGURE B.5: Use Case Diagram for the Reward Process.

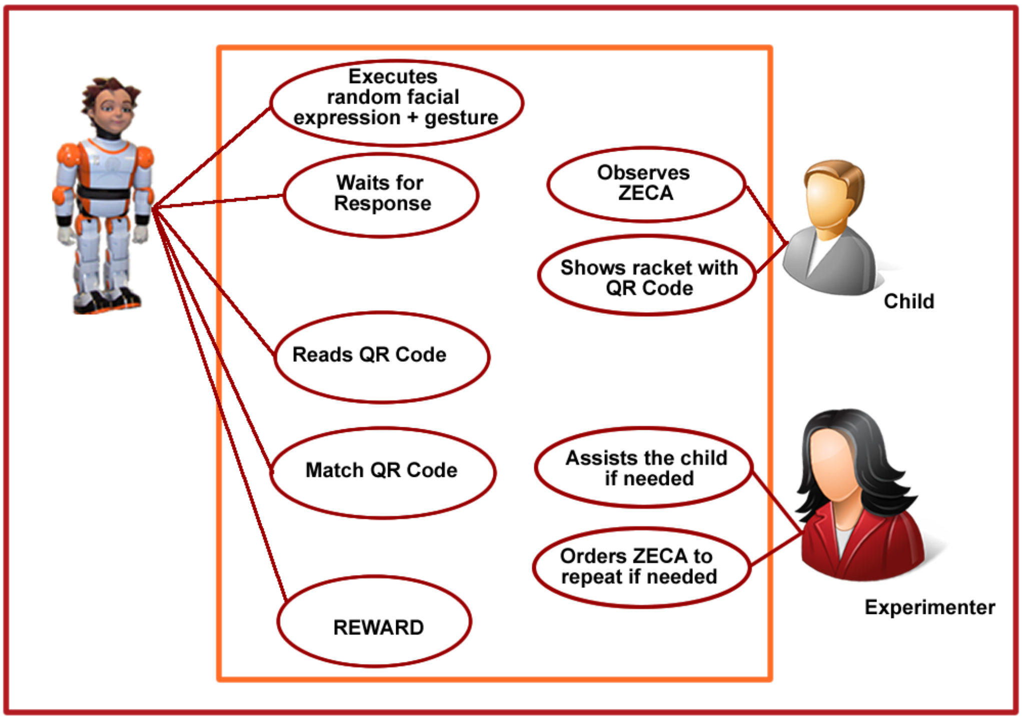


FIGURE B.6: Use Case Diagram for the Recognize Game Scenario.

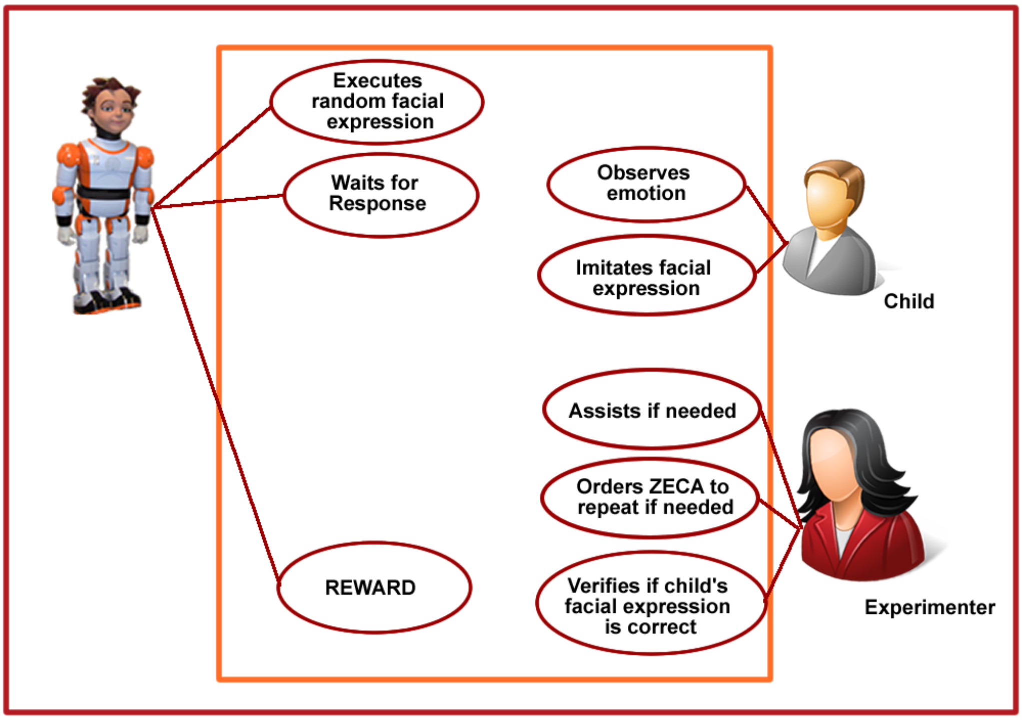


FIGURE B.7: Use Case Diagram for the Imitate Me Game Scenario.

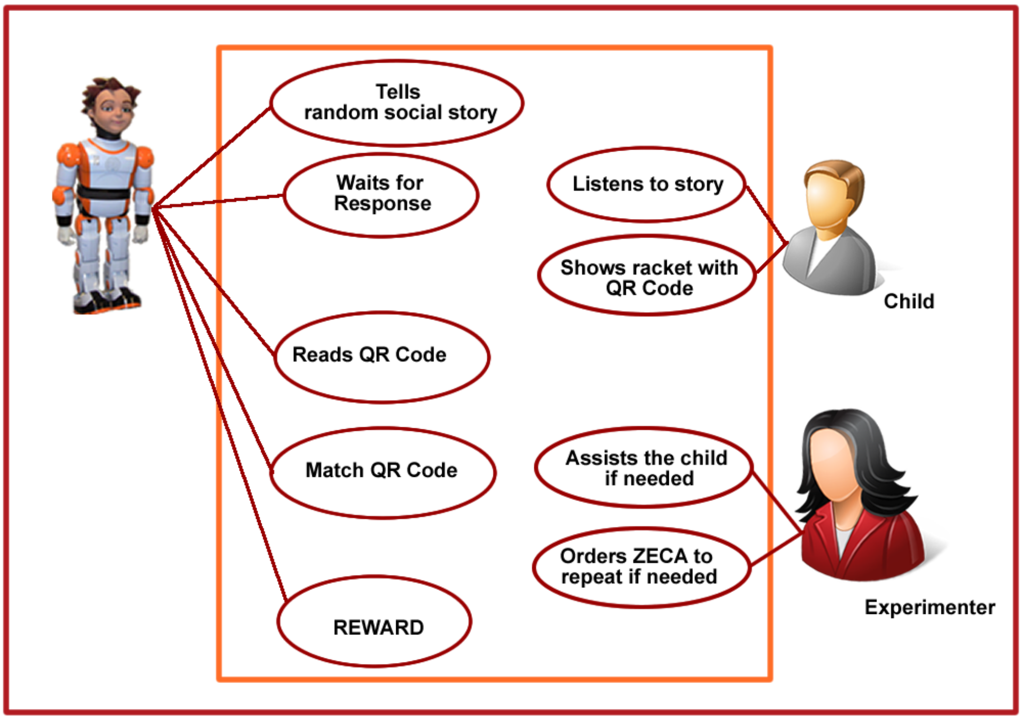


FIGURE B.8: Use Case Diagram for the Storytelling Game Scenario.

## B.5 Sequence Diagrams

TABLE B.2: Sequence Diagram for the System Configuration.

**Actor(s):** Robot, Experimenter;
**Primary Actor:** Experimenter;
**Goal(s):** To select child's database on the system and update data;
**Precondition(s):** The child needs to registered otherwise a new file need to be created;
**Trigger:** Experimenter starts the application;
**Main Scenario:** System Configuration.

| Robot | Experimenter |
|---|---|
| | 1. Turns on Robot |
| 2. Robot is ON | 3. Selects Child's file |
| 4. Gets Child's info | 5. Changes Child's information |
| 6. Updates Child's database | |
| **Alternative Scenario 1:** | |
| | 3. Inserts new Child's Info |
| 4. Updates Child's database | |
| **Alternative Scenario 2:** | |
| | 3. Removes Child |
| 4. Updates Child's database | |
| **Alternative Scenario 3:** | |
| | 3. Exports Child's Info |
| 4. Updates Child's database | |

Table B.3: Sequence Diagram for the Reward.

**Actor(s):** Robot, Child with ASD, Experimenter;
**Primary Actor:** Child with ASD;
**Goal(s):** Robot's Reward for the Child;
**Precondition(s):** The child responded to a robot's action;
**Trigger:** Correct or incorrect response of the Child;
**Main Scenario:** Reward.

| Robot | Child | Experimenter |
|---|---|---|
| | 1. Answers to prompt. | |
| 2. Identifies type of answer (correct/incorrect) | | |
| 3. Shows Right/Wrong reward | | 4. Reinforcement (if needed) |
| 5. Update Child's database | | |
| **Alternative Scenario 1:** | | |
| | 1. There is no response | 2. Reinforcement |
| 3. Repeats the instruction | 4. Responses to prompt. | |
| 5. Identifies type of response (correct/incorrect) | | |
| 6. Shows Correct/Incorrect reward | | 7. Reinforcement (if needed) |
| **Alternative Scenario 2:** | | |
| | 1. There is no response | 2. Reinforcement |
| 3. Repeats prompt | 4. There is no response | 5. Reinforcement |
| 5. Changes prompt | | |

**Extensions:** The experimenter should have the sensibility, observing and deciding if the robot needs to repeat the prompt one more time (after the one already performed). The experimenter will command the robot using a wireless numeric keypad.

TABLE B.4: Sequence Diagram for the Recognize Game Scenario.

**Actor(s):** Robot, Child with ASD, Experimenter;
**Primary Actor:** Child with ASD;
**Goal(s):** To develop emotion recognition skills in children with ASD;
**Precondition(s):** The child greeted the robot and he/she is ready to start the session;
**Trigger:** Activity initiated;
**Main Scenario:** Recognize Game Scenario.

| Robot | Child | Experimenter |
|---|---|---|
| 1. Executes random facial expression + gesture<br>3. Waits for response<br><br>5. Reads QR Code<br>6. Matches QR Code<br>7. REWARD<br>8. Updates Child's database | 2. Observes emotion<br><br>4. Shows racket with QR Code | Reinforcement when needed and controls using wireless keypad |

**Extensions:** The experimenter will be able to control the activity using a wireless numeric keypad: Repeat previous prompt, stop all, repeat, pause, change activity. These commands will only be used if necessary. At the same time, the robot should be able to perform the game scenario and to receive the commands.

TABLE B.5: Sequence Diagram for the Imitate Me Game Scenario.

**Actor(s):** Robot, Child with ASD, Experimenter;
**Primary Actor:** Child with ASD;
**Goal(s):** To develop emotion recognition skills in children with ASD;
**Precondition(s):** The child greeted the robot and he/she is ready to start the session;
**Trigger:** Activity initiated;
**Main Scenario:** Imitate Me Game Scenario.

| Robot | Child | Experimenter |
|---|---|---|
| 1. Executes random facial expression | 2. Observes emotion | Reinforcement when needed and controls using wireless keypad |
| 3. Waits for response | 4. Imitates facial expression | 5. Verifies if the child's facial expression is correct |
| 6. REWARD<br>7. Updates Child's database | | |

**Extensions:** The experimenter will be able to control the activity using a wireless numeric keypad: Repeat previous prompt, stop all, repeat, pause, change activity. These commands will only be used if necessary. At the same time, the robot should be able to perform the game scenario and to receive the commands.

Table B.6: Sequence Diagram for the Storytelling Game Scenario.

| | | |
|---|---|---|
| **Actor(s):** Robot, Child with ASD, Experimenter;<br>**Primary Actor:** Child with ASD;<br>**Goal(s):** To develop emotion recognition skills in children with ASD;<br>**Precondition(s):** The child greeted the robot and he/she is ready to start the session;<br>**Trigger:** Activity initiated;<br>**Main Scenario:** Storytelling Game Scenario. | | |
| Robot | Child | Experimenter |
| 1. Tells random social story | 2. Listens to the story | 3. Provides visual cue corresponding to the story |
| 3. Waits for response<br>5. Reads QR Code<br>6. Matches QR Code<br>7. REWARD<br>8. Updates Child's database | 4. Chooses racket with QR Code | Reinforcement when needed and controls using wireless keypad |
| **Extensions:** The experiment will be able to control the activity using a wireless numeric keypad: Repeat previous prompt, stop all, repeat, pause, change activity. These commands will only be used if necessary. At the same time, the robot should be able to perform the game scenario and to receive the commands. | | |

## B.6 Social Stories

TABLE B.7: Social stories used in the Storytelling game scenario.

| # | Emotion | Story |
|---|---|---|
| 1 | Anger | My sister is called Alice. Alice plays with me in the playground. Today, when we were playing, Alice took my ball. I hate when Alice does this, so I was very angry. |
| 2 | Anger | In the classroom, I like to play with my blocks. My sister Alice sits next to me every day. Alice knocked down my blocks, on purpose. I was very upset. |
| 3 | Anger | Every day I play games with my friends in the classroom. I love to do puzzles, but when I lose a piece, I can not finish the puzzle and it makes me very angry. |
| 4 | Fear | At the end of dinner I go to my room. When I'm lying in bed, ready to sleep, my mom turns off the light. So, I see shadows on the wall, I can not sleep and I'm scared. |
| 5 | Fear | On Sundays I go for a walk with my parents. When the weather is nice, we go to the park and we play a lot. One day, while playing football, I was away and when I did not see my parents any more. I was very scared. |
| 6 | Fear | I go with my mother shopping. I like to choose the yogurts that I eat. Today, at the exit of the supermarket, a very large dog began barking very loud. I was shaking. |
| 7 | Joy | Every day in the morning I go to school. I enjoy playing with my friends. My teacher said I did a good job. It is good to do what we like. |
| 8 | Joy | Today I went for a walk and to play football with my friends from school. To play football is great fun and makes me smile. I smile when I do activities I like, and that makes me happy. |
| 9 | Joy | In my school, there are many computers. Sometimes another child is using the computer and I have to wait. It is so nice when it is my turn to use the computer. |
| 10 | Sadness | When I was playing in the playground, I fell on the floor. My arm and my leg were hurting a lot. I had a big scratch, and I could not stop crying. |
| 11 | Sadness | I like to play when I'm home. Today I took my ball and played with the ball in the living room. I kicked strongly the ball and broke a window. My mother me grounded and I cried. |
| 12 | Sadness | My friend is called John. John did not come to school today. I asked my teacher for John, and the teacher said that John is sick. That day I had to play alone. |

Social stories used in the Storytelling game scenario (cont.).

| | | |
|---|---|---|
| 13 | Surprise | Every day, I go to school. One day when I entered the classroom, everyone screamed "Congratulations Zeca!" Because it was my birthday. I was so amazed. |
| 14 | Surprise | One day, we played an interesting game in the classroom. During the game, my sister Alice tapped me on the arm. But soon after, Alice apologized to me and I was very surprised. |
| 15 | Surprise | I love Christmas. And like very much when me and my sister Alice open our Christmas presents. When I opened the greatest gift and I saw the toy I wanted I was really amazed. |

## B.7 Visual cues used with the Social Stories

FIGURE B.9: Story # 1.

FIGURE B.10: Story # 2.

Figure B.11: Story # 3.

Figure B.12: Story # 4.

Figure B.13: Story # 5.

FIGURE B.14: Story # 6.


FIGURE B.15: Story # 7.

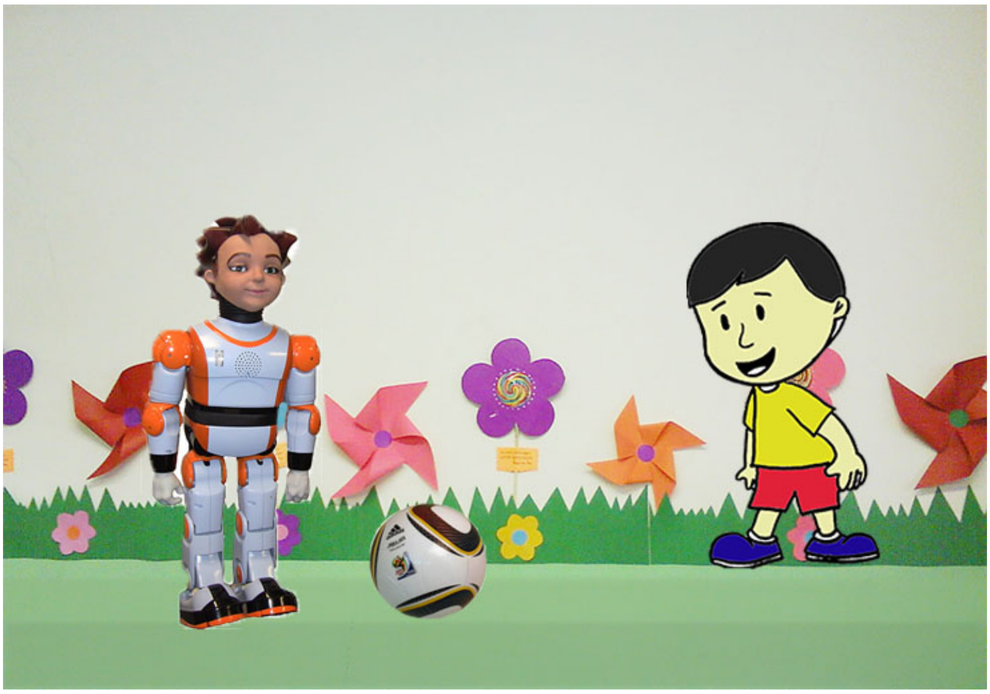

Figure B.16: Story # 8.

Figure B.17: Story # 9.

FIGURE B.18: Story # 10.

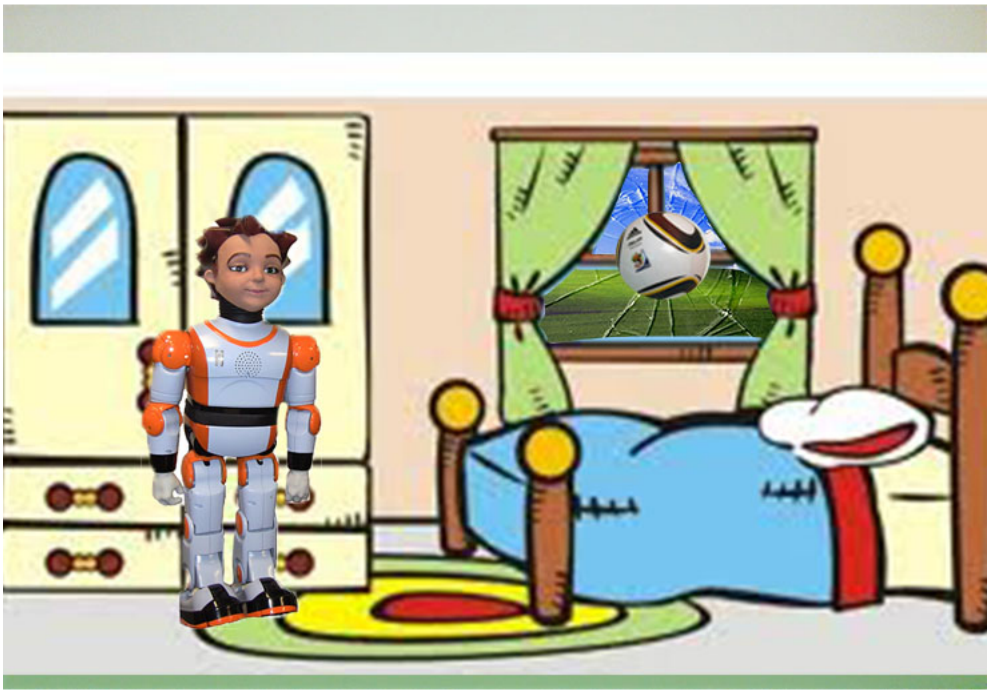

FIGURE B.19: Story # 11.

FIGURE B.20: Story # 12.


FIGURE B.21: Story # 13.


FIGURE B.22: Story # 14.

FIGURE B.23: Story # 15.

# Appendix C

# Material used in the study presented in Chapter 5

- Ethical Committee's Documents
- Consent form delivered to the children's parents

## C.1 Ethical Committee's Documents

Proc. N.º: 2187/2014 | 1

COMISSÃO NACIONAL DE PROTECÇÃO DE DADOS

AUTORIZAÇÃO Nº 5344 /2014

I. Pedido

**Sandra Cristina Cunha Costa** notificou à Comissão Nacional de Protecção de Dados (CNPD) um tratamento de dados pessoais com a finalidade de realização de um estudo observacional utilizando a robótica social como promotora do desenvolvimento socio-emocional em crianças com Perturbações do Espectro do Autismo (PEA), promovendo o reconhecimento de expressões faciais e as emoções correspondentes, fomentando interacções sociais e de comunicação.

A ferramenta utilizada na investigação consiste num robô humanóide denominado "ZECA" (*Zeno Engaging Children with Autism*), que agirá em contexto individual com as crianças.

O estudo pretende incluir aproximadamente 45 crianças com PEA de alto funcionamento, com idades compreendidas entre os 6 e os 10 anos e que estejam incluídas em contexto escolar: escolas do primeiro ciclo do Ensino Básico com unidades de ensino estruturado para alunos com PEA, centros de desenvolvimento e instituições que prestam apoio a estes alunos.

A amostra será dividida em 3 grupos: Grupo Experimental (G1), Grupo de Controlo 1 (G2) e Grupo de Controlo 2 (G3).
Todos os grupos realizam, no início e no fim do período experimental, um pré-teste e um pós-teste para comparar as suas competências antes e depois da intervenção. A tarefa do pré-teste e do pós-teste foi definida com apoio de profissionais com experiência na área e consiste na correspondência de uma imagem *Picture Exchange Communication System* com a fotografia de uma pessoa desconhecida, tendo em conta a expressão facial que representam.

Rua de São Bento, 148-3º • 1200-821 LISBOA
Tel: 213 928 400 Fax: 213 976 832
www.cnpd.pt

21 393 00 39
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Dias úteis das 10 às 13 h
duvidas@cnpd.pt

FIGURE C.1: Authorization of the Portuguese National Committee for Data Protection.

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O Grupo G1 realiza três tarefas com o robô, que têm como objetivo o desenvolvimento da competência do reconhecimento de expressões faciais correspondendo a 5 emoções: alegria, tristeza, surpresa, medo e raiva.
O grupo G2 realiza as mesmas tarefas sem a intervenção do robô, que será substituído pelo experimentador.
O grupo G3 realizará apenas a tarefa de pré- e pós-teste.

As crianças estão envolvidas num total de 6 sessões, duas vezes por semana, em contexto individual com o robô e o experimentador, numa sala de aula, durante 10 a 20 minutos. Os pais não estão presentes durante as sessões, mas pelo menos um profissional que acompanha regulamente a criança está disponível para colaborar caso seja necessário, devido à especificidade do espectro a que a amostra pertence.

As sessões serão gravadas em vídeo, sendo que a requerente informa que as mesmas apenas serão tornadas públicas em eventos de divulgação científica e mediante a autorização dos encarregados de educação.

Cada participante é identificado pela letra C e um número (por exemplo, C01) e cada sessão pela letra S e um número (por exemplo, S01). Assim, em todos os ficheiros associados a cada participante e sessão estes serão etiquetados com, por exemplo, "C01S01". Este é o código utilizado no "caderno de recolha de dados", que apenas será conhecido da equipa de investigação.

Aos profissionais que acompanham as crianças é solicitado o preenchimento de um questionário no qual identificam as crianças identificam, designadamente pelo nome, escola que frequentam, data de nascimento e caracterização do diagnóstico da PEA, fornecendo também uma avaliação subjectiva da criança.

Os investigadores solicitarão consentimento informado aos representantes legais dos participantes e aos profissionais que os acompanhem. Junto com a declaração de consentimento será disponibilizado documento informativo clarificando os objetivos, riscos e benefícios decorrentes do projeto de investigação, bem como a inteira

liberdade para decidir sobre a aceitação em participar ou desistir em qualquer momento.

A segurança da informação recolhida é garantida pela manutenção dos dados, processos e vídeos em local de acesso reservado, ao qual apenas os investigadores têm acesso.

II. **Análise**

Porque em grande parte referentes à saúde e à vida privada, os dados recolhidos pela requerente têm a natureza de sensíveis, razão pela qual o respetivo tratamento só pode basear-se no consentimento expresso, esclarecido e livre dos titulares dos dados, ou dos seus legais representantes nos termos do disposto no n.º 2 do artigo 7.º da Lei n.º 67/98, de 26 de outubro (Lei de Proteção de Dados - LPD).

Entende-se por consentimento qualquer manifestação de vontade, livre, específica e informada, nos termos da qual o titular ou o seu representante legal aceita que os seus dados sejam objeto de tratamento, o qual deve ser obtido através de uma "declaração de consentimento informado " onde seja utilizada uma linguagem clara e acessível.

Nos termos do artigo 10.º da LPD, a declaração de consentimento tem de conter a identificação do responsável pelo tratamento e a finalidade do tratamento, devendo ainda conter informação sobre a existência e as condições do direito de acesso e de retificação por parte do respetivo titular.

Porque haverá recolha de dados de menores, terá de haver consentimento a prestar pelos representantes legais, devendo o estudo ter em conta o superior interesse dos menores.

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A informação tratada é recolhida de forma lícita (cfr. alínea a) do n.º **1** do artigo 5.º da LPD), para finalidades determinadas, explícitas e legítimas (cfr. alínea b) do mesmo artigo).

A eventual utilização das gravações das sessões em evento fora do escopo do estudo ora notificado constitui novo tratamento de dados pessoais, pelo que estará sujeita a nova autorização desta Comissão.

## III. Conclusão

Em face do exposto, a CNPD autoriza o tratamento de dados pessoais *supra* apreciado, nos termos do n.º 2 do artigo 7.º, da alínea a) do n.º 1 do artigo 28.º e do n.º 1 do artigo 30.º da LPD, consignando-se o seguinte:

**Responsável pelo tratamento:** Sandra Cristina Cunha Costa.
**Finalidade:** Estudo observacional utilizando a robótica social como promotora do desenvolvimento socio-emocional em crianças com Perturbações do Espectro do Autismo, promovendo o reconhecimento de expressões faciais e as emoções correspondentes, fomentando interacções sociais e de comunicação
**Categoria de Dados pessoais tratados:** código de participante; mês e ano de nascimento; escola; caracterização da PEA; avaliação subjectiva do comportamento; imagem.
**Entidades a quem podem ser comunicados:** Não há.
**Formas de exercício do direito de acesso e retificação:** Junto da responsável pelo tratamento dos dados.
**Interconexões de tratamentos:** Não há.
**Transferência de dados para países terceiros:** Não há.

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**Prazo de conservação dos dados:** A chave da codificação deve ser destruída um mês após o fim do estudo.

Lisboa, 3 de junho de 2014

Luis Barroso (O Vogal, em substituição da Presidente)

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Universidade do Minho

SECVS

**Subcomissão de Ética para as Ciências da Vida e da Saúde**

Identificação do documento: SECVS – 028/2014

Título do projeto: *Projeto robótica-autismo*

Investigador(a) responsável: Dra. Filomena Maria da Rocha Menezes de Oliveira Soares, da Escola de Engenharia, Departamento de Eletrónica Industrial, Centro de Investigação Algoritmi, Universidade do Minho

Outros investigadores: Dra. Sandra Cristina Cunha Costa, Escola de Engenharia, Departamento de Eletrónica Industrial, Centro de Investigação Algoritmi; Dra. Cristina Manuela Peixoto dos Santos - Escola de Engenharia, Departamento de Eletrónica Industrial, Centro de Investigação Algoritmi; Dra. Ana Paula da Silva Pereira, Instituto da Educação, Centro de Investigação dos Estudos da Criança, Universidade do Minho.

Subunidade orgânica: Centro Algoritmi, Universidade do Minho

Outras Unidades: Escolas do primeiro ciclo do ensino básico com unidades de ensino estruturado para alunos com Perturbações do Espectro do Autismo, Centros de desenvolvimento e Instituições que prestam apoios a estes alunos

**PARECER**

A Subcomissão de Ética para as Ciências da Vida e da Saúde (SECVS) analisou o processo relativo ao projeto intitulado *"Projeto robótica-autismo"*.

Os documentos apresentados revelam que o projeto obedece aos requisitos exigidos para as boas práticas na experimentação com humanos, Projeto robótica-autismo em conformidade com o Guião para submissão de processos a apreciar pela Subcomissão de Ética para as Ciências da Vida e da Saúde.

Face ao exposto, a SECVS nada tem a opor à realização do projeto.

Braga, 02 de abril de 2014.

A Presidente

(Maria Cecília de Lemos Pinto Estrela Leão)

FIGURE C.2: Authorization of the University of Minho's Ethical Committee.

## C.2 Consent form delivered to the children's parents

(Date)

Dear Parent or Tutor,

Worldwide, researchers have been dedicated themselves to the study of robots's influence in the development of cognitive and behavioural skills in children with Autism Spectrum Disorders (ASD). The Robotica-Autismo Project financed by the Portuguese Science and Technology Foundation (SFRH/BD/71600/2010) is part of a partnership between the University of Minho and Braga's APPACDM (in English, Portuguese Association of Parents and Friends of the Mental Impaired Citizen) in 2009, which aims to use robots to improve the social life of persons with ASD. Particularly, the goal is to improve communication and social skills with the environment and other persons and with this study we want to investigate the capability of a robot to elicit emotion recognition skills.

Since sessions with the robot imply the participation of your child, so it is only possible with your authorization. We guarantee that the collected data will only be used in this investigation and in the scientific communication of the same, never exploiting those in other situations that are not related with the project. We ask then your collaboration giving your consent through the devolution of the detachable attachment.

Best Regards,

**The Director of School/Clinic,**

(Name of the Director of School/Clinic)

**The scientific coordinator of the project, UM**

Filomena Maria da Rocha Menezes de Oliveira Soares

**The PhD Student responsible for the study, UM**

Sandra Cristina Cunha Costa

**Contacts:** scosta@dei.uminho.pt; Sandra Costa: 91008XXXX

I, parent/tutor of declare to understand the goals of what it was proposed and explained to me by the researcher who signs this document. I had the opportunity to ask all the questions about the research and for all of them I got a clear answer. It was guaranteed to me that there will be no injury to the welfare rights if I refuse this solicitation, and it was given me enough time to think about this proposal.
I declare also that I authorize my child to participate in the research project "Robots in Special Education", particularly in the "Game of Emotions with ZECA", which will imply sessions of 10 to 20 minutes with adult supervision. The sessions are going to be recorded in video for post-analysis. The videos and data from the analysis will be used only and exclusively in the scientific communication of the project. Personal data and data obtain in the research are not going to be shared and they will be kept for ten yeards, after which they will be destroyed. All the personal information collected in the research are confidential and treated according to the rules regarding data protection and private life. If the parent or tutor wants, the child may abandon the project at any time. The participation of the parent/tutor, and his/her child, refuse to participate or subsequent abandonment, will not jeopardize the relationship with the team of clinicians/teachers and/or researchers. None risks for the participants are foreseen during the sessions. If the child shows discomfort, the session is finished.

(Date)

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(Complete Signature of the parent and/or tutor)

This document is composed by 2 pages e printed in duplicate: one copy for the researcher and other to the person who consents.