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Using a Humanoid Robot to Elicit Body Awareness and Appropriate Physical Interaction in Children With Autism

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Abstract In this article we describe a Human-Robot Interaction study, focusing on tactile aspects of interaction, in which children with autism interacted with the child-like humanoid robot KASPAR. KASPAR was equipped with touch sensors in order to be able to distinguish gentle from harsh touch, and to respond accordingly. The study investigated a novel scenario for robot-assisted play, with the goal to increase body awareness of children with Autism Spectrum Condition (hereafter ASC) by teaching them how to identify human body parts, and to promote a triadic relationship between the child, the robot and the experimenter. Data obtained from the video analysis of the experimental sessions showed that children treated KASPAR as an object of shared attention with the experimenter, and performed more gentle touches on the robot along the sessions. The children also learned to identify body parts. The study showed the potential that teaching children with autism about body parts and appropriate physical interaction using a humanoid robot has, and highlighted the issues of scenario development, data collection and data analysis that will inform future studies.

Keywords Assistive Technologies · Body Awareness · Human-Robot Interaction · Socially Assistive Robots

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1 Introduction

Touch can be defined as a physical or sensory quality, processed in the brain by the somatosensory cortex and mediated by the skin [1]. Our skin is crucial in discovering our social environment and the world around us. Touch is not only vital for humans during their development, but also for their general well being [2]. In a cross-cultural study it could be shown that touch played a very important and specific role in the establishment and quality of social relationships for children [3]. Tactile sensitivity is the most basic form of communication, and it may be the first sensory process to become functional. Touch is critical to typical physiological development in infants, and parent-infant bonding is shaped by tactile contact starting from the first hours after birth [4].

To accomplish suitable sensory stimulation for their proprioceptive and tactile systems to develop normally, children need several hours per day of physical play. Early in life, children learn how to understand and to identify different types of physical contact. This learning phase allows them to communicate with other children and adults, build relationships based on the exchange of mutual support and mutual confidence.

During the study presented in this article, we used the humanoid robot KASPAR, a minimally expressive child-sized robot [5]. 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 respond to gentle or harsh touches from the child. The tasks used in this study aim to teach children to identify their body parts, and increase their body awareness.

Robots have been used as tools with children with ASC (see section II) to develop and improve their social and communicative skills with encouraging results. In the present study, the robot was used as social mediator between the child and the experimenter as well as a teaching tool. The main research goal was to understand if and how the robot could promote interactions between an autistic child and another person, and whether it could facilitate the ability to acquire knowledge about human body parts. 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 their 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.

We wanted to verify if the robot could help children with ASC to learn appropriate physical social engagement. Eight children diagnosed with autism participated in seven sessions, and they were evaluated using qualitative and quantitative measures. The preliminary analysis of the observations of the first and last sessions showed that the children increased the time they looked at the experimenter. Moreover, some of the children that initially were not able to identify any of their body parts, showed a significant improvement at the end of the sessions [6]. We used the robot to enable the learning of body parts by children with autism and due to the novelty of the topic, our goal was to construct and test different scenarios. To our knowledge this is the first study that considers how to use robots in order to teach the identification and labelling of body parts to children with ASC. Hence, a key purpose was to develop scenarios, means of data collection and to learn how to analyse the data.

This article is organized as follows. In Section II the research projects will be presented that also use tactile human-robot interactions. Section III features the procedures during the experiments. Section IV and V contain the results and the discussion, respectively. Conclusions and future work are presented in Section VI.

2 Background

When robots first appeared in literature and media, they often were depicted as servants for human beings. Nowadays, robots have been used in several different applications, not only as servants but also as partners. These applications vary from education to rehabilitation or from entertainment to assisted therapy. Human-robot interaction (HRI) reflects the need for attention to multi-disciplinary problems such as motor and perceptual abilities and limitations, robot software, robot hardware characteristics and interfaces [7].

2.1 Tactile Interaction

The study presented here considers information from the robot's touch sensors to enable pre-programmed response behaviours.

Force-sensing resistors (FSR) are low-cost and robust sensors which can measure force or pressure, changing their resistance, and they are being largely used on robot applications. The detected contact should be used to produce concordant robotic behaviours, which will stimulate the interaction between the user and the robot. Robots for HRI within the current tactile HRI literature can have different shapes [8].

The baby seal Paro [9], the teddy bear Huggable [10], the robotic cat NeCoRo [11], and the child-sized robot KASPAR [5] are some examples of different artificial pets and humanoid robots designed to engage people 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 people with special needs.

Paro is used in assistive therapy, mainly with elderly patients. By using sensors incorporated in this robot, 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 [12]. The results of a study with elderly residents in a care home, during which the robot was available for over nine hours daily indicated that interaction with the seal robot increased their social interaction. Furthermore, the physiological tests showed that the reactions of the subjects' vital organs to stress improved after the introduction of the robots [13].

Huggable, a robot teddy bear, 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. The robot is able to orient itself towards the human touch through motion in its neck and shoulders [10].

The robotic cat NeCoRo is used to analyse person-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. In a study with NeCoRo, results of cross-cultural analyses of person-robot communication, as well as findings on the robot's use by children, young and older adults, and elderly persons with dementia reveal a higher level of appeal to interact with the robotic cat by older participants, the robotic cat being a more desirable companion for them than for the younger participants. People with severe levels of cognitive impairment were engaged with the robotic cat for a shorter duration than those with higher levels of cognitive functioning [11].

KASPAR is a child sized, minimally expressive humanoid that has been used in turn-taking and imitation games with children with ASC [5], to mediate interviews with children [14], to capture the temporal and spatial characteristics of tactile interactions [15], to study dyadic interaction [16], among others.

In the ROBOSKIN project robotic skin was developed to provide tactile feedback and was added to KASPAR with the goal of improving human-robot interaction capabilities in the application domain of robot-assisted play [15, 17]. Recent work in this project developed tactile play scenarios [18] 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 [19, 20].

The literature suggests that children with ASC have difficulties in learning appropriate physical social engagement. The data from the sensors on the robots provide an automatic way to identify harsh from gentle touch performed by the children during the interaction. The feedback from this data is used to identify when the tactile interaction is not appropriate. The original aspect of this study is the use of a humanoid robot to help to teach the identification and labelling of body parts to children with ASC. Comparing with the first three projects, this study differs from the research presented above by using a humanoid robot which presents advantages for the children with ASC to generalize skills while interacting with peers or adults. Regarding the ROBOSKIN project, this study introduces new game scenarios for tactile interaction and focus on the use of the robot as a tool to test the ability of children with ASC to acquire knowledge about human body parts.

2.2 Research Questions and Expectations

With this study, we will address the following research questions:

(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 of acquiring knowledge about human body parts?
(c) Can the robot help teach children with ASC appropriate physical (tactile) social engagement?

In order to answer (a), we compared the time children spent looking at KASPAR, the experimenter or elsewhere and we expected that children are more focused on KASPAR, and direct more behaviours towards the robot than towards the experimenter (e.g. eye gaze and touching).

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), we considered 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 the eyes of others).

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 ASC 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 save 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 else. The absence of frustration or physically hurtful feedback by the robot provides a pleasant experience for the children and in our opinion encourages them to engage in such interactions with others. We expect to see a decrease in harsh touches and an increase in gentle touches over the course of the experiment. This is going to be measure counting the times the child touches KASPAR or the experimenter.

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 as a facilitator of the interaction, 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 Methods

All topics regarding the experimental study are defined below, specifically ethical concerns, source of participants, undertaken procedures, characteristics of the robot, used setup, and evaluation tools.

3.1 Ethics Statement

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 (CRB) before any trial took place. Parents of the children signed an informed consent in which they were informed about the goals and applied methods of the research. The children's teachers were consulted and informed about the activities to be performed and gave suggestions intended to improve them.

3.2 Participants

The study was conducted in a local primary school for children with special needs in Hertfordshire, UK. Eight boys diagnosed with ASC, aged six to nine years old, from three different classrooms participated in the study. Although we could not obtain the children's individual diagnoses for autism, we received confirmation from their head teacher that each child had previously been diagnosed with autism by a medical professional. The experimenter did not know any of the children prior to the experiments.

3.3 Procedures

To reach our goals, four different phases were defined: familiarisation, pre-test, practice, and post-test (Fig. 1). The experiments were carried out by the first author.

Familiarisation Phase: People with ASC have problems with changes to their daily routine. Therefore, autistic children have a difficulty to accept changes to their environment [21]. For this reason, the familiarisation phase was created to decrease the effect of a new person appearing in their environment. Before starting the experiments with the robot, the experimenter attended on one day 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 practise phase. The pre-test served as a baseline to be compared with the results of the identical post-test.

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. 2). The performance task applied in the pre- and post-test used the TEACCH (Treatment and Education of Autistic and Related Communications Handicapped Children) program [22] already used in the classroom by the teachers.

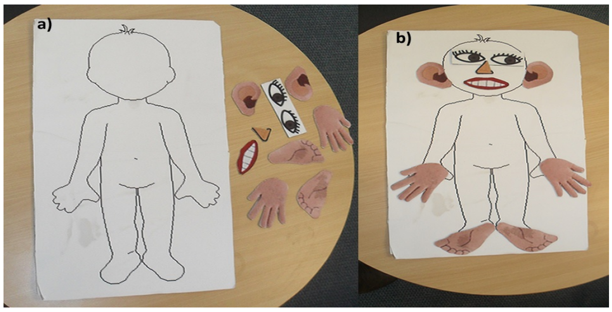


Fig. 2 Performance task in the pre- and post-test (a) Beginning of the Task, (b) Task Accomplished, (c) PECS card of KASPAR.

Practise 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 it gave the card back to the experimenter. Three different activities were created based on the ASC severity level of each child. The complexity of the activities was different, so whenever the children managed to accomplish the 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

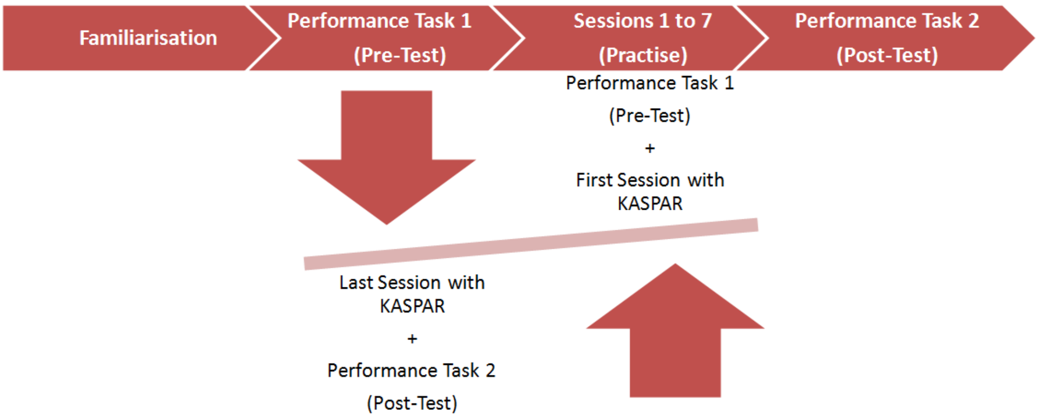


Fig. 1 The four different phases of the study.

of approximately ten minutes were performed, 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: This activity built upon the knowledge from the previous activities together with joint attention and interaction with the experimenter. The robot asked the child to sing together a song, called "Parts of me" about human body parts [23], 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 have verbal communication, she was asked to do the same gestures of 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".

3.4 The Robot

The robot KASPAR (Fig. 3 a) has been used in several studies with children with autism [16,24–26], it has also been employed in other studies with typically developing children [14,27,28].

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, eight of them on the robot's head and neck and the remaining along the arms, hands, and torso [5]. The robot has simplified but realistic human features and body parts, which made it very suitable for the present study. In Fig. 3 b), circles represent the location of the joints of the robot and, squares represent the location of the sensors on the robot.

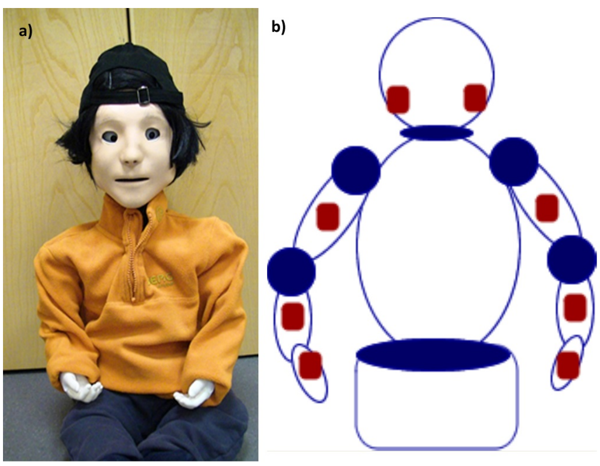


Fig. 3 The robot KASPAR. The diagram on the right shows the joints (circles) and the location of the FSR sensors (rectangles).

In our study, the robot was controlled via Wizard-of-Oz [29], 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 shown by the children, as well as the sequences of those poses. A pressed key on a wireless numeric keyboard activated a determined sequence, asking 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 FSR sensors positioned on the right and left side of the head, shoulder, wrist, hand, and foot of the robot. These FSRs 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.

3.5 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 are represented in the Fig. 4 a). The experiment took place in a familiar room in the school often used by the children for their activities (Fig. 4 b). The arrangement of the actors involved in the session (robot, child and experimenter) had into consideration a cooperative position [30]. In this arrangement of the room, two people 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.

The two cameras were placed in such a way that one recorded the face of the child and the other the experimenter during the experiments.

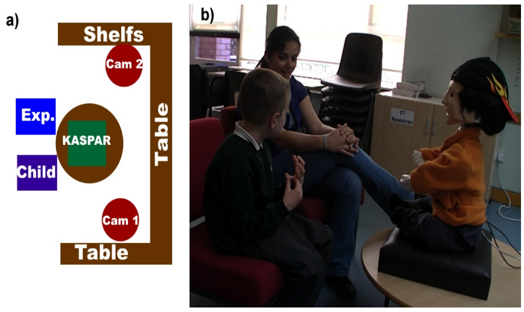


Fig. 4 Room a) Room setup schematic, b) Positioning of the participants in the room.

3.6 Evaluation Tools

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

The results regarding the questionnaires, the structured interview, a preliminary overview of the results of the behavioural analysis, specifically the comparison between the first and the last session of each child, and a brief comparison between the pre- and the post-test were already presented [6]. In this paper, we present the behavioural analysis coded from the videos of all the sessions in the Practise Phase.

3.6.1 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 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 factors reinforcing behaviours and which ones may support changes in the children's skills.

3.6.2 Behavioural Analysis

The videos produced during the sessions were analysed using the Observer XT 11 program by Noldus. To ensure inter-rater reliability 10% of the videos were recoded by a second independent coder (Cohen's kappa k = .63). This is acceptable, as having a Cohen's kappa value higher than 0.60 suggests a good agreement between the raters [31]. 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 be classified as spontaneous. If the child touched KASPAR after the experimenter said "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 our list, they were not coded. For eye contact, turning away ended the behaviour. Turning back immediately and making eye contact again counted as new behaviour. Table 1 shows the coding scheme used.

3.6.3 Comparison between pre- and post-test

We measured the time and efficiency for each child 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. 2). Additionally, we evaluated if the child needed the help of 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, she 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.

4 Results

The collected data from the behavioural analysis of all the videos, as well as an extended comparison between pre- and post-test were performed, and a descriptive evaluation was made based on the observational grids.

4.1 Behavioural Analysis

Eye gaze direction can give a clue where the children were focusing their attention. In Fig. 5 a slight decrease in eye gaze towards KASPAR is illustrated, however it always stayed above 47.3% of the total session time. Looking to other directions besides the robot or the experimenter varied between 27.26% and 39.74%. A one-way ANOVA revealed significant differences between the means of the time the children looked at KASPAR, the experimenter or elsewhere, F(2,18) = 140.32, p <.0001, and between the means of times the events looking at KASPAR and to the experimenter occurred, F(1,18) = 66.681, p <.0001. Comparing the first to the last session, eye gazing towards the experimenter increased fivefold.

A two-factor ANOVA showed no significant main effect between the children while looking at KASPAR in the overall sessions, F(7,42) = 0.966, p = .4679; but the interaction between the sessions and the average of time looking at KASPAR was significant F(6,42) = 13.597, p <.0001. Using again a two-factor analysis of variance showed a significant main effect between the children looking at the experimenter in the overall sessions, F(7,42) = 16.686, p <.0001. The interaction between the sessions and the average time looking at the experimenter was also significant F(6,42) = 5.153, p <.0001.

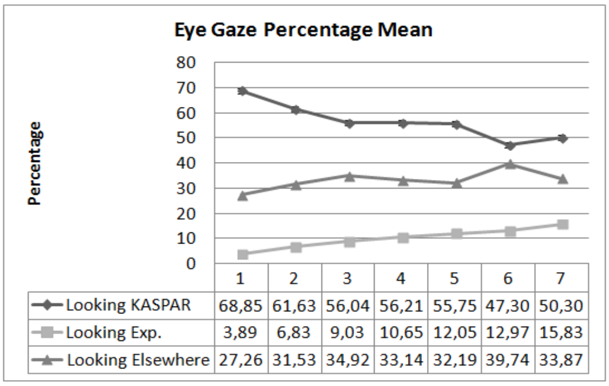


Fig. 5 Children's eye gaze during practice phase. Eye gaze towards KASPAR decreased but had the highest values, and eye gaze towards the experimenter increased during the sessions.

Figures 6 and 7 show 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 ($\chi 2$ (6, N = 1432) = 18.34, p <.05, and $\chi 2$ (6, N = 394) = 21.49, p <.05, respectively). In average, the sum of gentle touches was 8.5 times greater than harsh touches on KASPAR and 23.6 times on the experimenter. Concerning the spontaneity of the performed tactile interaction, in average, the sum of spontaneous touches was 10.3 times greater than prompted touches on KASPAR and 6.7 times on the experimenter. 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.

Following the pointing of the experimenter and pointing behaviour (with index finger) by the children was most pronounced during the first sessions. Regarding imitation, the occurrences of this behaviour decreased

Table 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)
Touching KASPAR - Activity C	Child touches robot's hands after KASPAR says "Touch my hands if you want to sing again" (from the moment the experimenter touches the child)
Experimenter touches 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
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 it 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 can ask 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
Identifying body parts	The child identifies verbally or non verbally the different body parts Prompted by the experimenter: The experimenter has encouraged the child to show the behaviour Prompted by KASPAR: The robot has encouraged the child to show the behaviour Successful: The child shows the correct body part Unsuccessful: The child fails to show the correct body part Self: The child identifies the body part on his own body Robot: The child identifies the body part on the robot Experimenter: The child identifies the body part on the experimenter 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 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 she performs the choreography of the song together with KASPAR or the experimenter

over time, having again a higher value until the fourth session. As a remark, we should stress 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 8 to 11 show children's success while performing activities A, B, and C. Regarding Activity A, successful responses overtook significantly unsuccessful ones, $\chi 2$ (6, N = 979) = 18.14, p <.05, varying from 61.79% to 80.95% (Fig. 8).

Concerning Activity B - 2 body parts, successful responses also exceeded unsuccessful ones significantly,

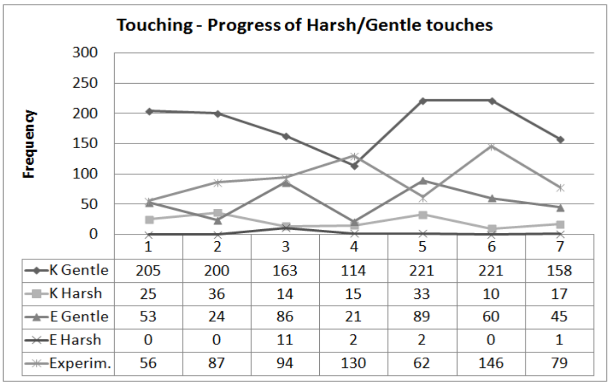


Fig. 6 Touching performance comparing the sum of harsh and gentle touches. Gentle overtook harsh touches.

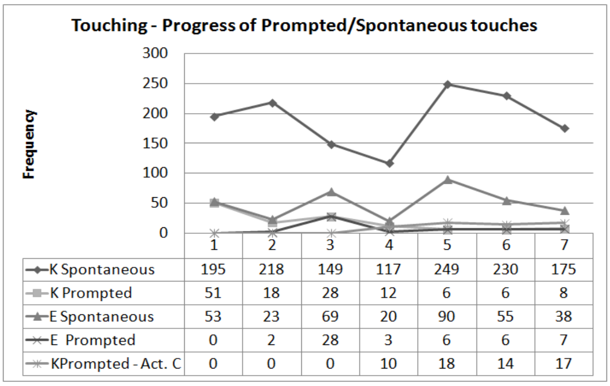


Fig. 7 Touching performance comparing the sum of prompted and spontaneous touches. There are more prompted touches in the first session, because the experimenter encouraged that behaviour, but after the first session, children touched KASPAR spontaneously.

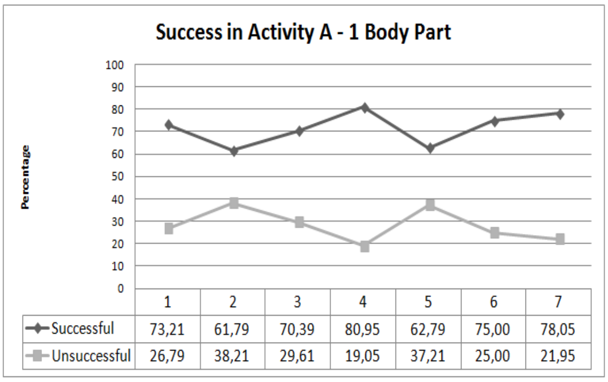


Fig. 8 Percentages of correct and incorrect responses in Activity A. Successful responses overtook unsuccessful ones.

$\chi 2$ (6, N = 233) = 13.325, $p < .05$, varying from 72.88% to 95.24% (Fig. 9).

Identifying successfully sequences of 3 body parts in Activity B varied between 54.84% and 73.68%, but it was not found statistically significant, $\chi 2$ (5, N = 233) = 3.516, $p > .05$. This activity was not performed in the first session (Fig. 10).

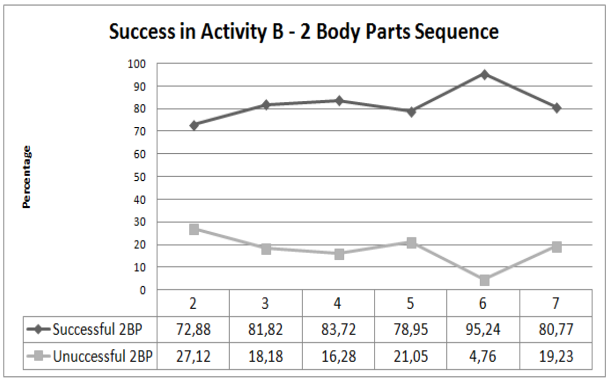


Fig. 9 Percentages of correct and incorrect response in Activity B - 2 body parts. Successful responses overtook unsuccessful ones.

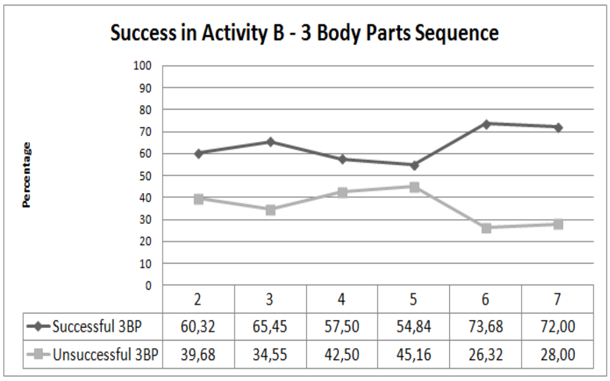


Fig. 10 Percentages of correct and incorrect response in Activity B - 3 body part. Successful responses overtook unsuccessful ones.

Fig. 11 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 children sang along. There is only data from the fourth session since Activity C was only performed from this session onwards. We can identify a general increase in these two behaviours reaching the highest values in the last session.

Fig. 12 refer to the number of times children switched their eye gaze between the other two elements in the room, KASPAR and the experimenter. A two-second time limit between switching from one element to the other was established, because we did not want to consider events when the child looked at KASPAR, looked elsewhere for a longer period, and then looked at the experimenter for some reason not related to the one that made him look at KASPAR earlier. 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, alter-

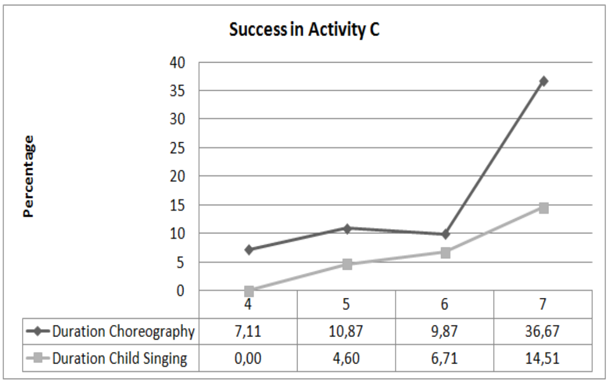


Fig. 11 Percentages of correct and incorrect response in Activity C. Some child with verbal communication were able to sing along with KASPAR, and also to imitate KASPAR performing the song's choreography.

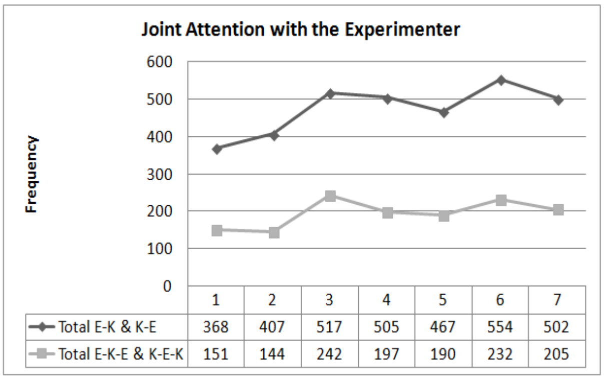


Fig. 12 Frequency of eye gaze exchanges between KASPAR and the experimenter in less than two seconds. On average 40% of the total exchanges were of KASPAR-Experimenter-KASPAR and Experimenter-KASPAR-Experimenter type

nating 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 (M = 474.29; SD = 65.53). 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 (M = 194.429; SD = 37.062).

Figures 13 and 14 illustrates 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%. Only 8% of the eye gaze was directed to the experimenter. When we analysed each session (Fig. 13), 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% of the time towards KASPAR, and 14% of the time they looked at the experimenter. When KASPAR was singing in activity C (Fig. 14), most of the time children looked at KASPAR. An exception occurred during the fifth 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.

Besides the number of times children looked at KASPAR and the experimenter, we were also interested in knowing how the duration in these two behaviours evolved. On average, time intervals while looking at

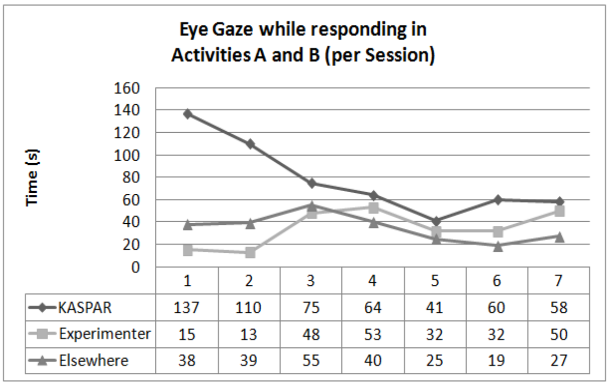


Fig. 13 Eye Gaze Time during Activities A and B per session. Eye gaze towards KASPAR decreased and towards the experimenter increased.

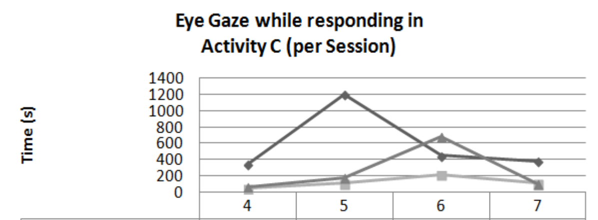
KASPAR decreased, except for the last session, and in general time intervals while looking at the experimenter increased. These values varied between 25.54 and 57.22 seconds and between 3.39 and 12.57 seconds, respectively.

On average, children took between 5.7 and 8.68 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 7.38 to 12.81 seconds. The lowest value occurred in the first session, these measures varied greatly between sessions.

As reported in [6], in the pre- and post-test there were no significant differences in the time children took to complete the performance task (p = .365). The average time children took was 156 seconds in the pre-test and 124 seconds in the post-test. 75% 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 = 5.425), and 17.25 in the post-test (SD = 1.753). We found no significant difference, comparing these scores in the pre- and post-tests (p = .0135).



	4	5	6	7
Singing & Looking at Kaspar	338,4	1198,14	449,4	375,79
Singing & Looking at the Experimenter	43,4	106,6	212,4	110,4
Singing & Looking Elsewhere	65,28	172,64	675,48	104,37

Fig. 14 Eye gaze time during Activity C per session. On average, eye gaze towards KASPAR was higher than towards the experimenter.

5 Discussion

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

Pointing to a specific object, and following the index finger of another person are behaviours that indicate social engagement [32]. 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 increase.

Besides eye gaze towards KASPAR and the experimenter, we were interested in observing, 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 [33].

Our results suggest in general that the interaction and games performed with KASPAR were useful for the children's learning, however no significant differences between the results of the pre- and post-tests were found. This is most likely due to the fact that five of the eight children were already able to perform the task in the pre-test. For the other children, it is reasonable to assume that KASPAR was a tool to promote this learning. The differences between the data in figures 8 and 11 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. Our expectations regarding research question (b) were fulfilled.

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 remainder of the 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. Due to the nature of the experiment the values between the sessions are not linear, sometimes the children are less motivated 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 comparatively a significant trend emerges. For details please refer to the text of the result section.

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 a prompted and an 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.

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 ASC.

According to the skill to be promoted, and the corresponding tasks, we would advise 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, where they might have to perform the same task repeatedly. Specifically with this target group, it seems to us that a cooperative spatial placement of the actors in the room facilitates 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 to this study (Section 3.3), we would like to highlight the familiarization phase, 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 feedback from teachers, outcomes of specific tasks, behavioural analysis, among others allowed us to draw our conclusions more easily. An important fact is that since the children are not able to express themselves directly most of the times, the teachers as the people who work with them closely should be carefully heard and included in the design of the experiments.

Regarding data analysis a precise definition of the behaviours we would like to identify in the videos was essential. This was important to deal with instances of e.g. 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.

5.1 Limitations of the Study

This study presents encouraging results indicating that the use of a robot as a tool to interact with autistic children, 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.

5.2 Summary of Hypotheses and Implications

This study investigated if and how KASPAR could promote interactions between an autistic child 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.

(a): Expectations regarding this research question were supported, with the children showing significantly more gaze directed towards KASPAR, and increasing joint attention over sessions.

(b): The comparison of the scores in the pre- and the post-test do not allow us to conclude that all the children managed to acquire new knowledge regarding body parts. However, the results from the performance during the activities in the practise phase gives a clue that KASPAR contributed to this knowledge acquisition for the children not able of fulfilling the task during the pre-test. In conclusion, expectations regarding this research question were partially met.

(c): 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 autism to perform appropriate physical social engagement.

The goals of this research was to understand if and how the robot could promote interactions between an autistic child and another person, and whether it could facilitate the ability to acquire knowledge about human body parts. The results of this study largely 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 verified, 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 therapies.

6 Conclusion and Future Work

This article presents a study in which a humanoid robot was used to interact with children with ASC. 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. We wanted 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 that 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.

The authors believe that a triadic relationship was promoted between the child, the robot and the experimenter. The robot represents an alternative tool to already existing interventions with children with ASC, 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 and tactile interaction with children with autism spectrum disorders. Further research with more children should be conducted to identify the differences between high and low functioning children. In addition, it would be interesting to test the relative improvements gained from a robot-assisted intervention compared to more traditional interventions that do not include robots, adding a control group to the procedure. The dependent factor is the robot, and the same methodology should be applied.

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