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# Enhancement of the Communication Effectiveness of Interactive Robots for Autism Therapy by Using Touch and Colour Feedback

**Abstract:** Previous studies in the field of robot assisted therapy demonstrated that robots engage autistic children's attention in a better way. Therefore, the interactive robots appear to be a promising approach for improving the social interaction and communication skills of autistic children. However, most of the existing interactive robots use a very small number of communication variables which narrow their effectiveness to a few aspects of autistic childrens' social communication behaviour. In the present work, we explore the effects of touching and colours on the communication effectiveness between a robot and an autistic child and their potential for further adjustability of the robot to child's behaviour. Firstly, we investigated touching patterns of autistic and non-autistic children in three different situations and validated their responses by comparison of touching forces. Results showed that patterns of touching by non-autistic children have certain consistency, while reaction patterns in autistic children vary from person to person. Secondly, we studied the effect of colour feedback in autism therapy with the robot. Results showed that participants achieved better completion rate when colour feedback was provided. The results could support the design of more effective therapeutic robots for children with autism.

**Keywords:** Human-robot interaction, Robot-assisted therapy, Therapeutic robot, Autism therapy, Affective touch, Colour

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## 1 Introduction

The importance of communication for the development of proper behaviour in autistic children has been discussed in many studies. Children with autism who are able to communicate in a better way with others have better perspectives to integrate into society. It has been also found that such children reduce their abnormal behaviour when their communication ability is improved [1]. Autistic children's behaviour affects the social climate within their families. Several studies have revealed that some children with autism tend to have aggressive behaviour toward their families. For example, Koegel et al, found that siblings with autism often demonstrate aggressive behaviours toward younger siblings [2]. Carr and Durand stress the importance of proper communication with children with autism, before they become aggressive [3]. Moes showed that the aggressive behaviour of children with autism often causes huge amount of stress to their parents who fear that other siblings within the family could be injured by their aggressive autistic children [4]. The above studies evidence clearly the necessity of a systematic approach for development of communication abilities of children with autism.

Numerous studies demonstrated that autistic children's attention is engaged a much better way when they communicate with a robot than with a human [5, 6]. A possible reason for such behaviour could be the tendency of autistic children to prefer simple and predictable objects, such as robot, rather than complicated ones, such as humans. Robins et al. confirmed that children with autism approached very easily to a mime artist wearing plain and featureless clothing, whereas they avoided the

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same person when wearing ordinary human clothing [7]. These research findings have suggested that robots may have strong positive therapeutic effects and indicated that the interaction with a robot can be used to help autistic children to develop better human-to-human communication.

Most of the existing approaches for communication improvement are based on encouraging the child to imitate different facial expressions or behaviours of a human communicator. Such approaches often have low effectiveness because autistic children are inclined to avoid human's face and thus, they do not show engagement in such exercises [7–10]. The therapy sessions, when organised as an interaction between a robot and the child, tend to be effective because children usually demonstrate more interest in robots. Imitation of robot behaviour is a widely-used approach for development of communication skills. Experimental results from several studies have confirmed that autistic children are likely to imitate robots' behaviour, in particular, to imitate robots that move their limbs or change their facial expression. Boccanfuso and O'Kane used a simple interactive robot called CHARLIE to show that autistic children tend to imitate a robot's pose [11, 12]. Furthermore, Duquette et al. found that autistic children imitated more the facial expressions of their robot, named Tito, than the same facial expressions performed by a human [13]. Pioggia et al. used an android with highly realistic biological motion and appearance (FACE) in therapeutic sessions for helping autistic children to improve their emotion expression through imitation of robot's behaviour [14, 15] . Feil-Seifer and Mataric developed a modular interactive robot able to express different social behaviours in different situations by changing its facial expressions and gestures [16]. Robins et al. used a child-sized humanoid robot, Kaspar, with changeable facial expression, rotating head, and expressive postures and making gestures, to study the effect of the human-like appearance in therapeutic tasks for communication improvement and emotion expression of autistic children [17]. In their experiments, Duquette et al. used a wheel-based robot Tito that expressed different emotions via changing its face illumination and performing different gestures [13]. The Keepon robot was designed to express simple emotions via four actions: nodding, turning, rocking and bobbing [18]. In the majorities of those studies, researchers evaluated the therapeutic effect through direct observation or analysis of children's responses from video records of the treatment session. Such evaluation approaches contain a high level of subjectivism in recognition of child's reactions, which often leads to difficulties in assessing important communication skills, such as facial expression response.

The effectiveness of autistic treatment can be increased additionally if the interactive robot has the abilities to analyse a child's behaviour and to respond to it accordingly [19]. Figure 1 illustrates this approach. The interaction effectiveness of the robot will increase if the modalities of the robot behaviour match the communication skills of the individual child. In our previous study, for example, we found that children responded in a better way than interactive robots that had faces and moving limbs [20]. A robot can be designed to encourage positive responses of the child during the therapy session. For example, the robot may perform a suitable encouraging gesture or may change its appearance when the child demonstrates behaviour or social skills as expected. The provision of feedback from the robot has the potential to improve child's performance and stimulate their curiosity. In other words, by providing feedback to the child, the robot plays the role of an effective social mediator [19].


**Fig. 1.** The interaction concept in robot-assisted autism therapy

Various studies prove the importance of touch in the communication. "Touch is a crucial aspect of most human relationships" [21]. Touching as an approach for communication with infants has been studied by many researchers. Knapp found that new-borns receive great amount of information about the surrounding world through tactile information [21]. Barnett claims that the touch provides most fundamental means of contact with the external world [22]. Hewett emphasises that communication through touch helps children with disabilities to develop a sense of connectedness with other people around them [23]. Bardeen indicates that touch can be stronger than other means of communication and specifies that touch is a means for sharing of feelings and sending information about personality [24]. Various studies emphasise that affective touch plays a crucial role in the regulation of human emotions and psychological state [25–27].

The role of touch in the development of social skills in autistic children was explored in a few research studies, where the number of touch events was used for measurement of child's engagement [28]. A study based on assessment of the touch type, location and pressure while autistic children interacted with the small humanoid robot, Kaspar was presented in [17]. In the present study, we propose a new approach of touch training where the response of the robot is based on assessing a child's performance during the present therapeutic session and considering the total time of the previous training and the level of autism in the child.

The ultimate goal of our research is to develop an effective interactive robot for children with autism. The present study is an initial step toward the robot design. This study aims to identify effective approaches for robot interaction that engage autistic children's attention and facilitate better interaction with them. In this paper we present the results of two experimental studies, named below as Study A and Study B. The first experimental study (Study A) examined the parameters of the affective touch applied by autistic children to an interactive robot in a few different situations. Patterns of affective interaction were used as markers for evaluation of the child's communication level with the robot. Another purpose of Study A was to explore the differences in the touching practices of autistic children. With the same study we also tried to verify the effectiveness of our approach for detecting children's touching behaviours. In the same study, we also compared the touching patterns of non-autistic and autistic children. The second goal of this work was to explore the effect of colour on the interaction of the child with the robot, as described below in section 3, Study B. Based on the results of Study A, in Study B the children with autism were engaged in experimental therapeutic sessions that combined touching and colour feedback. The results from Study B provided further information on the role of colour for the level of engagement of the autistic children.

# 2 Study A

## 2.1 Purpose of the Study

It is anticipated that the abnormal touching behaviour of autistic children is due to their inability to understand social cues [29]. In this study, we explored the affective touch patterns of autistic children by comparing the way of touching between non-autistic and autistic children in different social situations and different interpersonal relations.

Many therapeutic approaches for development of correct touch behaviour in autistic children consider a human mediator who uses simple illustrations and text to teach children the proper touch they need to use in different situations. An example of such reference material is shown in Figure 2. It refers to a five point scale [30].

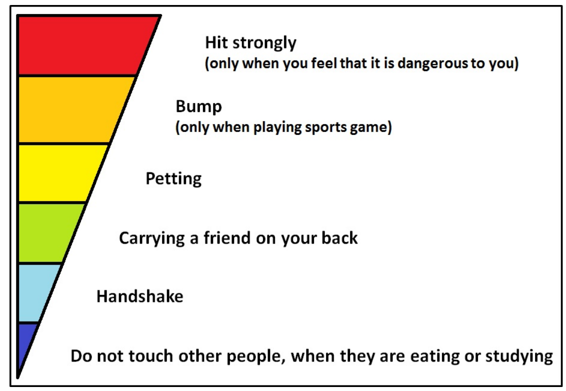


**Fig. 2.** Teaching material for touching with social situations

A disadvantage of such approach is that the force applied by the child is not measured quantitatively and the evaluation of child's response depends entirely on the skills and experience of the human-mediator. Another drawback of the same approach is that the child may exert too high force in certain situations which may injure the teacher.

In this study, our goal was to obtain quantitative information about the way of touching. For that purpose, we developed a special interface that allowed measurement of the forces of touching applied by the children.

## 2.2 Method

### 2.2.1 Participants

Six children (males) diagnosed with low-functioning autism and six non-autistic children (3 girls and 3 boys) took part in the experiments. The average ages (*M*) of the autistic children was 9.83 years and the standard deviation of their ages (*SD*) was 2.32 years. Non- autistic participants had M = 9.83 years and *SD* = 1.72 years. The level of impairment of each autistic participant was evaluated by the Social Responsiveness Scale (SRS) from information provided by the parents. The SRS is a quantitative scale for measurement of the severity and the type of autistic spectrum disorders in children and adolescents [31]. A score of 75 or more indicates significant clinical levels of autistic traits. The levels of impairment of the children who participate in the tests are shown in Figure 3.

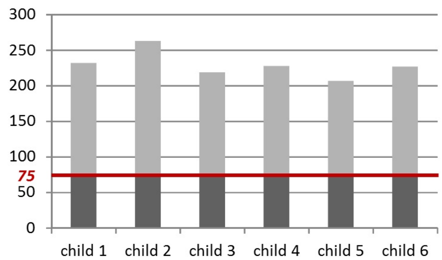


**Fig. 3.** SRS row score in each participant

### 2.2.2 Procedure

For the experiments we designed a special HMI called Touch Ball. In order to decide the shape of the interface device, we interviewed a few school teachers working with autistic children who suggested that autistic children like the shape of sphere. Also, from our previous study where we used a robot whose head was shaped as a transparent sphere, we also found that spherical shape attracts children's attentions [20]. Based on these facts, we designed the test interface shown in Fig. 4. It consists of a transparent half sphere (position 1 on Figure 4a) with a diameter of 12 cm connected to a base plate (position 2 on Figure 4b) via a a three-component force sensor (position 3 on Figure 4b).

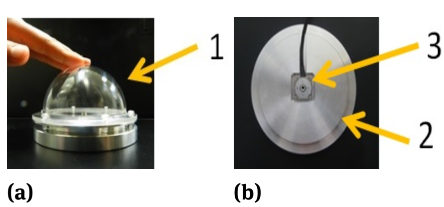


**Fig. 4.** The Touch Ball, used in the experiments; (a) The touch ball assembly; (b) The base plate and the three axis force sensor

The Touch Ball was connected to a PC computer as shown in Figure 5. On that figure, $f_x(t)$, $f_y(t)$, and $f_z(t)$ are the signals from the three-component force sensor.

During the experiments, three different figures representing a baby, a friend, and a mother were projected on the computer screen. We used figures from

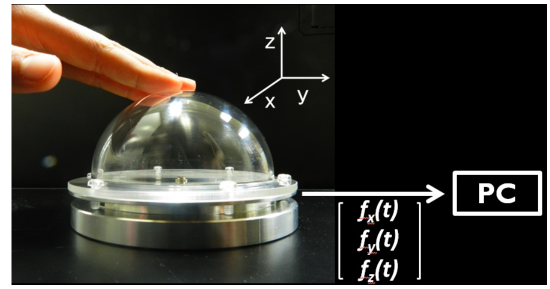


**Fig. 5.** Block diagram of the force data collection

DropTalk[1](Dynamic and Resizable Open Picture Symbols) which is vocabulary software for autistic children. Children were asked to perform physical interaction with the figure that appeared on the screen by touching the Touch Ball with adequate force. The images that we used are shown in Figure 6.

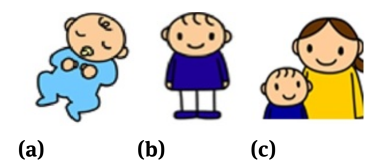


**Fig. 6.** Three different figures representing a baby (a), a friend (b), and a mother (c)

The participants took part in a total of nine virtual scenarios of social interactions. They were required to perform three different interpersonal interactions with each figure. The "social interactions" included giving a person high-five, waking a person up, and soothing a person. Each figure appeared on the laptop display together with a simple sentence that clarified expected interaction, as shown in Figure 7.

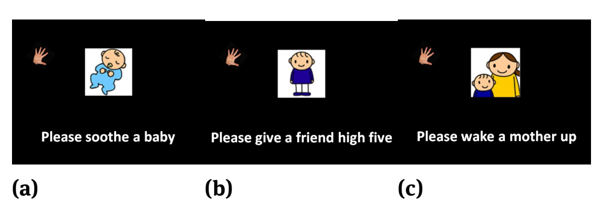


**Fig. 7.** The example of artificial social interaction, "Please wake a baby up" (a), "Please give a friend high five" (b), "Please soothe a mother" (c)

1 http://droplet.ddo.jp/

**Table 1.** Sequence of the virtual social situations (as they appear on the screen)

| Sequence | Sentence |
|---|---|
| Ba-hf | Please give a baby high five |
| Break | Thank you! |
| Ba-wu | Please wake a baby up |
| Break | Thank you! |
| Ba-st | Please soothe a baby |
| Break | Thank you! |
| Fr-hf | Please give a friend high five |
| Break | Thank you! |
| Fr-wu | Please wake a friend up |
| Break | Thank you! |
| Fr-st | Please soothe a friend |
| Break | Thank you! |
| Mo-hf | Please give a mother high five |
| Break | Thank you! |
| Mo-wu | Please wake a mother up |
| Break | Thank you! |
| Mo-st | Please soothe a mother |
| Break | Thank you! |

The sequence of the figures that appeared on the screen during the experiment and the instructions to the child about the interactions expected from him/her are summarised in Table 1. Each participant was asked to complete 3 sets of experiments. All sets contained all interactions listed in Table 1. Before starting the experiments, each participant took part in a pre-test session that included practicing of more than ten interaction situations. The pre-tests were done for avoiding eventual adaptation of the participants to the tests and evading ordering errors on the results. After the completion of the current interaction in the set, participants were given five seconds break before they started the next interaction task. Two minutes break was given to participants before they started the next set.

## 2.3 Data Analysis

To evaluate individual performances of the children and to compare the responses of both groups, we analysed two features: the touching force and the manners of touching of the Touch Ball.

### 2.3.1 Time average of the contact force

To compare the time average of the contact force used by the autistic and non-autistic children, we calculated the time average of contact force magnitude $F$, as expressed in Equation 1.

$$F = \left(\int_{T_S}^{T_F} \sqrt{f_x(t)^2 + f_y(t)^2 + f_z(t)^2}\, dT\right)/D_T \tag{1}$$

Here, $T_S$ is the time when the child starts to touch the Touch Ball and $T_F$ is the finishing time of the touch event. The duration of the touching action is $D_T = T_F - T_S$ and $f_x(t)$, $f_y(t)$, and $f_z(t)$ are the force components measured by the three-component force sensor (see Figure 5).

### 2.3.2 Assessment of the manner of touching

To evaluate the manner of touching, we analysed the tangential component of the contact force during touching. We calculated the ratio $H$ between the horizontal projection and the contact force magnitude applied to the Touch Ball, as in Equation 2.

$$H = \left(\int_{T_S}^{T_F} \frac{\sqrt{f_x(t)^2 + f_y(t)^2}}{\sqrt{f_x(t)^2 + f_y(t)^2 + f_z(t)^2}}\, dT\right)/D_T \tag{2}$$

The time interval when the child touches the sphere is $D_T = T_F - T_S$, where $T_S$ is the time when the child starts touching and $T_F$ is the time when the touching finishes.

### 2.3.3 Normalisation of *F* and *H*

In order to remove the individual bias, the data were normalised by using Equation 3. Here $\bar{F}$ is the mean of $F$, and $\sigma_F$ is standard deviation.

$$z_F = \frac{F - \bar{F}}{\sigma_F} \tag{3}$$

The ratio $H$ is also normalised in terms of all six autistic children and six non-autistic children, as in Equation 4. Here, $\bar{H}$ is the mean of $H$, and $\sigma_H$ is the standard deviation.

$$z_H = \frac{H - \bar{H}}{\sigma_H} \tag{4}$$

## 2.4 Results

The changes of the z values of the forces used by the groups of the autistic and non-autistic children in the different situations are illustrated in Figures 8, 9, 10 and 11.

The result in Figure 8 shows that the force used by non-autistic children to give a high five is stronger than the force that they use for soothing or wake-up. As shown in Figure 9, the time average of the contact forces for autistic children indicates slightly different patterns comparing with the forces used by the non-autistic children.

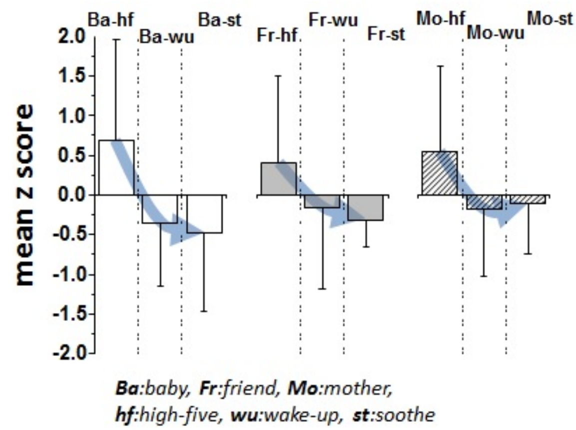


**Fig. 8.** The time average of contact force in the experiment with non-autistic children

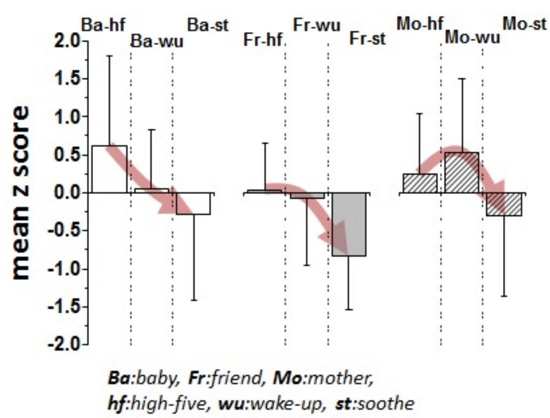


**Fig. 9.** The time average of contact force in the experiment with autistic children

The results of the estimated horizontal projection in the experiment with non-autistic children and autistic children are shown in Figures 10 and 11.

The result in figure 10 shows that the force ratio $H$ for the non-autistic children for the situation of soothing a person is stronger than $H$ for giving high-five or waking a person up. As a difference, we did not discover any patterns in the H ratios of the autistic children (Figure 11). The experimental results are presented in Tables 2 and 3.

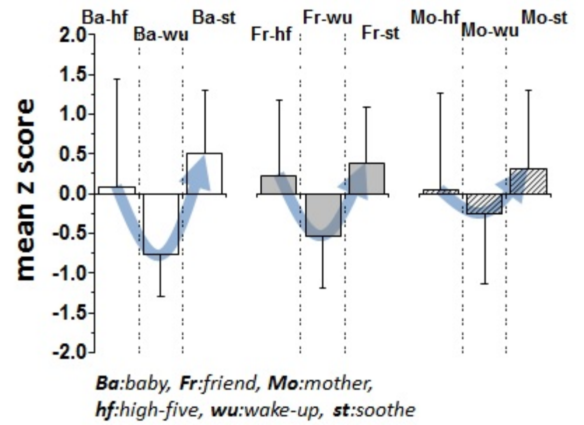


**Fig. 10.** Estimating the horizontal projection in the experiment with non-autistic children

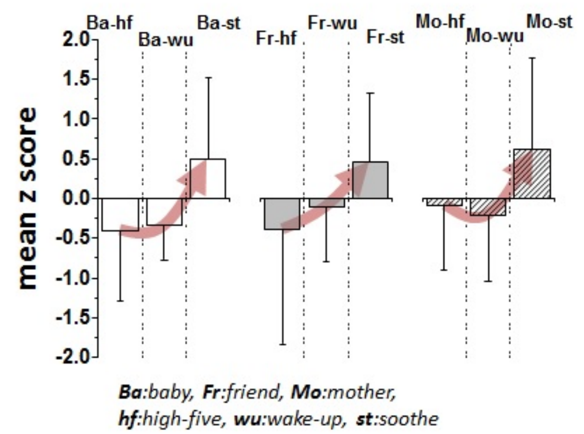


**Fig. 11.** Estimating the horizontal projection in the experiment with autistic children

For the non-autistic children, the results on the time average of the contact force show that the responses of the autistic children in the interpersonal relationship or social situations differ from the results of the non-autistic children. The results show that the manner of touching of the non-autistic children is quite consistent in all interpersonal relationships and all three social situations. Differently from that, the results of the autistic children show some irregularities, except the result for the horizontal projection in different social situations.

**Table 2.** The experimental result of the time average of contact force

| The time average of contact force | Non-autistic children | Autistic children |
|---|---|---|
| Interpersonal Relationship | Mother ≈ Friend ≈ Baby | Touched irregularly |
| Social Situation | Giving a High-five > Waking a person up, Soothing a person | Touched irregularly |

**Table 3.** The experimental result of estimating horizontal projection

| Estimating horizontal projection | Non-autistic children | Autistic children |
|---|---|---|
| Interpersonal Relationship | Mother ≈ Friend ≈ Baby | Touched irregularly |
| Social Situation | Soothing a person > Giving a High-five > Waking a person up | Soothing a person > Giving a High-five > Waking a person up |

# 3 Study B

## 3.1 Purpose of the Study

The results from Study A showed that the autistic children and the non-autistic children demonstrated different touching response in the interpersonal relationships tests. Further to that, we also explored the effect of colour-based feedback on the communication effectiveness of autistic children and investigated the colour feedback effectiveness when different colours are used. We also compared the force response of autistic and non-autistic children to colour stimuli. The results of that study are introduced below.

Many previous studies reported on the effect of colour on communication with persons with autism. For example, Moore noticed that children with autism seem obsessed by colours when they describe their parents [32]. Brian et al. observed that the usage of colours increased communication results of children with autism during experiments [33].

## 3.2 Methods

### 3.2.1 Participants

Four children diagnosed with low-functioning autism without other complications took part in the experiments. Participants were aged from 9 to 12 years ($M$ = 10.75, $SD$ = 2.06, males).

### 3.2.2 Materials

For the experiments we used the Touch Ball introduced in section 2.2. For the new experiments, we used a small projector to illuminate the surface of the half-sphere of the Touch Ball and to change its colours to red, yellow, blue, and green. In addition to the Touch Ball, we included in the test scenario a small humanoid robot, called Palro[2] which was developed by Fujisoft Inc. The same robot is shown in Figure 12. The role of the robot was to attract the child's attention toward the experiment by speaking to the child or changing randomly the direction of its head.

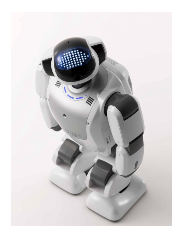

**Fig. 12.** Small humanoid robot, Palro

### 3.2.3 Procedure

Before the start of the experiment, we established the order of preference of each child to each colour. Preliminary tests aimed to identify the colour that causes negative perception to the individual participant and to exclude the same colour from the following experiments with the same participant. For that purpose, children were shown all four

**2** http://palro.jp/

colours and were asked to choose a favourite colour and a colour that they hate. Then, during the next experiments the favourite colour was used as the goal and the most disliked colour was excluded from the experiments. For example, if a child chose blue for a favourite colour and red for a hated colour, the blue colour was set as a dominant colour and yellow and green were used as signs, while the red colour was excludes from all trials in which the child was involved. This way, we defined the individual sets of three colours for each child.

The experiments included three different scenarios, as illustrated with Figure 13.

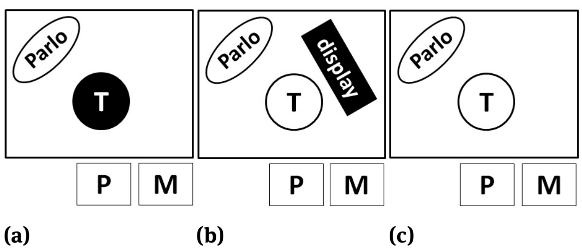


**Fig. 13.** The arrangement of experimental environment. (a) Scenario with illuminated half-sphere; (b) scenario with changing colour of the circle on the computer screen; (c) scenario with only verbal notification. T: Touch Ball, P: Participant, M: Moderator

In the first scenario (Figure 13a), the colours were introduced to the child by changing the colour of the Touch Ball. In the second scenario, the colour information was presented on a laptop display as a circle with 12 cm diameter, which was the same as the diameter of the Touch Ball (Figure 13b). In the third scenario, colours were not presented visually but instead, the participant received speech feedback about the colour by a moderator (Figure 13c).

In the first set of trials (Figure 13a), the computer algorithm was set to change the colour of the Touch Ball depending on the magnitude of the force applied to its surface. Children were asked to apply force to the half-sphere until it becomes illuminated in their favourite colour. In the second experiment (Figure 13b) children needed to change the colour of the circle on the laptop screen by pushing the half-sphere. In the third experiment (Figure 13c), the force $F_c$ applied by the child to the Touch Ball was measured and shown on the computer screen of the moderator who provided verbal information about the colour. The forces, applied to the half-sphere during the experiment and the colour responses of the system were recorded.

**Table 4.** Sequence of the virtual social situations (as they appear on the screen) and expected response by the participants

| Pre-trial | First/Second/Third scenario (Randomly) |
|---|---|
| Trial 1 | First scenario |
| | Break |
| Trial 2 | First scenario |
| | Break |
| Trial 3 | Second scenario |
| | Break |
| Trial 4 | Second scenario |
| | Break |
| Trial 5 | Third scenario |
| | Break |
| Trial 6 | Third scenario |

All participants were included in all three scenarios. Each child repeated twice each scenario. This way, each child performed six trials. Thirty seconds breaks were given between the start of the next trial. Before the trials, the children were asked to perform randomly some scenarios. That allowed them to understand the tests and the responses expected from them. During the preparatory stage, the moderator explained to the children how to use the Touch Ball and ensured that they feel comfortable during the tests. The sequence of the tests is shown in Table 4.

In all three trials children needed to set their favourite colour by touching the Touch Ball and increasing the applied force until the favourite colour appeared. Depending on the value of the force $F_c$, the colours changed in the following order: The favourite colour of the child appeared when a moderate force was applied to the sphere. The less preferred colour (the second colour in the individual list of colour preferences) appeared when low force was applied. The least preferred colour (the third in the list) appeared when maximum force was applied. The sphere remained dark when no force was applied.

The force $F_c$, applied to the half-sphere was calculated in the following way (Equation 5):

$$F_c = \sqrt{f_x(t)^2 + f_y(t)^2 + f_z(t)^2} \quad (5)$$

where $F_c$ is the magnitude of the contact force and $f_x(t)$, $f_y(t)$, and $f_z(t)$ are the force components in the axial directions. Table 5 shows an example of the relationships between the force $F_c$ and the selected colour for a child whose colour set has blue as the least preferred colour and red as the favourite colour. During the pre-trials, some children found it a bit difficult to select moderate force.

**Table 5.** An example of the relationships between force $F_c$ and colour changing

| $F_c$ | $F_c < 2[mN]$ | $2[mN] \leq F_c < 3[mN]$ | $F_c \leq 3[mN]$ |
|---|---|---|---|
| Force | Weak force | Moderate force | Strong force |
| Colour | Yellow | Red | Blue |

## 3.3 Data Analysis

We define as target keeping (TKT) the sum of the intervals when the favourite colour is kept. The TKT is defined Equation 6. In our experiments, each scenario task was executed for test time $E_T = 20[s]$. The success ratio for keeping the favourite colour can be called target keeping rate (TKR) and can be defined as the ratio between the target keeping time and the test time, as in Equation 7.

$$TKT = \sum_{i=1}^{n} t_i \tag{6}$$

$$TKR = (\frac{TKT}{E_T}) \times 100 \tag{7}$$

## 3.4 Results

During the trials, the target keeping time of each scenario was recorded. Table 6 presents the target keeping rate for each scenario.

**Table 6.** The target keeping time and target keeping rate of the task in first scenario

| | Target Keeping Rate [%] | | |
|---|---|---|---|
| Subject | First Scenario | Second Scenario | Third Scenario |
| M | 10.5 | 8.625 | 4.75 |
| Y | 4.125 | 5.25 | 2.25 |
| H | 2.5 | 3.25 | 1.5 |
| K | 9.125 | 6 | 2.375 |

The results can be presented with the graph in Figure 14. As shown in the same graph, two of the participants with autism, M (age 9) and K (age 12)achieved highest rate for the completion of the first scenario. Their target keeping ratio for the second scenario was lower than the result from the first scenario. Other two autistic children (Y (age 9) and H (age 11)) achieved slightly higher results on the second scenario comparing to their results from first scenario. All participants showed the lowest results in the third scenario.

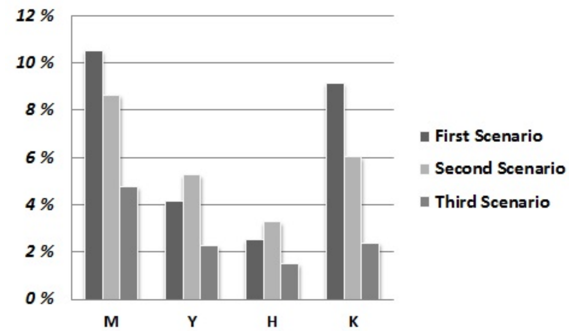


**Fig. 14.** The target keeping rate in each trials with three different scenarios

We monitored participants' behaviour during the completion of the tests. Some specifics of participants' behaviour during each trial are presented in Table 7.

# 4 Discussion

As indicated in the literature review, the touching behaviour is an essential communicative function of the autistic children and they need to be trained to develop abilities to select proper force for each interaction situation. For more accurate evaluation of the touching manners, we used a special HMI system (TouchBall) as an interactive training tool. In Study A, the analysis of participant responses in several test situations showed that the autistic children and the non-autistic children used different amount of force to respond to the same interaction scenario. The analysis of the test results showed that non-autistic children were much more consistent in their touching behaviour in all three different social situations, while the autistic children were unable to choose proper touch levels relevant to various social situations. A possible reason for the different touch response of the autistic children could be the lack of imagination ability. It has been found that often autistic children concentrate on very small details instead of seeing the whole situation[34]. The results from Study B demonstrated that the combination of touch and colour feedbacks is effective. In the first and the second scenarios, children referred to visual information (presented with the changing colours of the sphere or the circle on the screen), while the substitution of the colour feedback with a verbal message about the colour in the third scenario led to lower performance. The level of performance also depended on the method of displaying the colour information. When colours were projected directly on the Touch Ball in the first scenario, the comple-

**Table 7.** Describing the characteristics of each participant

| subject | Age | Scenario | Description of the characteristics |
|---|---|---|---|
| M | 9 | First | talked to himself, "okay, the colour changed" |
| | | Second | only looked at the computer monitor/ never talked to or looked up Palro |
| | | Third | looked up Palro many times |
| Y | 9 | First | looked at the Touch Ball and sometimes looked up the Palro |
| | | Second | only looked at the computer monitor/ never talked to Palro |
| | | Third | kept looking up Palro |
| H | 11 | First | only looked at the Touch Ball/ talked to himself, "red", "yellow"/ glanced at Palro |
| | | Second | only looked at the computer monitor/ never talked to the Palro |
| | | Third | no eye contact with moderator and only looked at the Touch Ball |
| K | 12 | First | only looked at the Touch Ball/ never talk to or looked up Palro |
| | | Second | only looked at the computer monitor/ never talk to or looked up Palro |
| | | Third | kept eye contact with moderator and sometimes looked at the Touch Ball / never talked to looked up Palro |

tion rate was higher than the results from the second scenario, when the colours were displayed on the computer screen. The results demonstrated that the colour feedback influenced touch training positively for autistic children.

## 5 Conclusion and Future work

The method of communication of a robot with autistic children should be organized on a way that not only attracts children's attention but also elicits positive perception from the children. The feedback provided by the interactive robot to the child is an important issue for effective interaction in robot-assisted therapy. The results presented in this paper show that robotic feedback based on touch and colour could increase the efficiency of interactive robots for improvement of the communication ability of autistic children. Results from this study showed that autistic children used different levels of forces and manners of touch than the non-autistic children who participated in the same experiments. The colour feedback experiments showed that the colour feedback can be understood easier by children with autism who are hyposensitive or hypersensitive. In this study, we analysed the response of a limited number of participants and that is why the present study cannot pretend to strong conclusions, but still it shows some important tendencies in the response of autistic children to visual and colour stimuli that need to be studied in further details in the future. We believe that this study can contribute to better design of robot for improvement of the communication skills of children with autism.

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## References

[1] A. J. Esbensen, M. M. Seltzer, K. S. L. Lam, and J. W. Bodfish. Age-related differences in restricted repetitive behaviors in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, 39(1):57–66, January 2009.

[2] L. K. Koegel, D. Stiebel, and R. L Koegel. Reducing aggression in children with autism toward infant or toddler siblings. *The Journal of The Association for Persons with Severe Handicaps*, 23(2):111–118, June 1998.

[3] E. G. Carr and V. M. Durand. Reducing behavior problems through functional communication training. *Journal of Applied Behavior Analysis*, 18(2):111–126, 1985.

[4] D Moes. Parent education and parenting stress. In Robert L. Koegel and Lynn Kern Koegel, editors, *Teaching children with autism: strategies for initiating positive interactions and improving learning opportunities*, pages 79–93. P.H. Brookes Pub. Co, Baltimore, 1995.

[5] B. Scassellati, Henny A., and M. Matarič. Robots for use in autism research. *Annual Review of Biomedical Engineering*, 14(1):275–294, August 2012.

[6] B. Robins, E. Ferrari, K. Dautenhahn, G. Kronreif, B. Prazak-Aram, G. Gelderblom, B. Tanja, F. Caprino, E. Laudanna, and P. Marti. Human-centred design methods: Developing scenarios for robot assisted play informed by user panels and field trials. *International Journal of Human-Computer Studies*, 68(12):873–898, December 2010.

[7] B. Robins, K. Dautenhahn, and J. Dubowski. Does appearance matter in the interaction of children with autism with a humanoid robot? *Interaction Studies*, 7(3):509–542, January 2006.

[8] A. T. Wang. Reading affect in the face and voice: Neural correlates of interpreting communicative intent in children and adolescents with autism spectrum disorders. *Archives of General Psychiatry*, 64(6):698–708, June 2007.

[9] J. Sinzig, D. Morsch, and G. Lehmkuhl. Do hyperactivity, impulsivity and inattention have an impact on the ability of facial

affect recognition in children with autism and ADHD? *European Child & Adolescent Psychiatry*, 17(2):63–72, September 2007.
[10] H. Koshino, R. K. Kana, T. A. Keller, V. L. Cherkassky, N. J. Minshew, and M. A. Just. fMRI investigation of working memory for faces in autism: Visual coding and underconnectivity with frontal areas. *Cerebral Cortex*, 18(2):289–300, May 2007.
[11] L. Boccanfuso and J. M. O'Kane. Adaptive robot design with hand and face tracking for use in autism therapy. In *Proceedings of the Second international conference on Social robotics*, pages 265–274. Springer-Verlag Berlin, Heidelberg, 2010.
[12] L. Boccanfuso and J. M. O'Kane. CHARLIE : An adaptive robot design with hand and face tracking for use in autism therapy. *International Journal of Social Robotics*, 3(4):337–347, September 2011.
[13] A. Duquette, F. Michaud, and H. Mercier. Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism. *Autonomous Robots*, 24(2):147–157, October 2007.
[14] G. Pioggia, M. L. Sica, M. Ferro, R. Igliozzi, F. Muratori, A. Ahluwalia, and D. De Rossi. Human-robot interaction in autism: FACE, an android-based social therapy. In *Proceeding of the 16th IEEE International Symposium on Robot Human Interactive Communication*, pages 605–612, Jeju, Korea, 2007. IEEE.
[15] G. Pioggia, M. Ferro, M. L. Sica, G. Dalle Mura, S. Casalini, D. De Rossi, R. Igliozzi, and F. Muratori. Imitation and learning of the emotional behaviour: Towards an android-based treatment for people with autism. In *International Workshop on Epigenetic Robotics, Modeling Cognitive D evelopment in R obotics Systems*, pages 119–125, 2006.
[16] D. Feil-Seifer and M. Matarič. B3ia: A control architecture for autonomous robot-assisted behavior intervention for children with autism spectrum disorders. In *Proceeding of 17th IEEE International Symposium on Robot and Human Interactive Communication*, pages 328–333. IEEE, August 2008.
[17] B. Robins, K. Dautenhahn, and P. Dickerson. From isolation to communication: A case study evaluation of robot assisted play for children with autism with a minimally expressive humanoid robot. In *Proceedings of the Second International Conferences on Advances in Computer-Human Interactions,*, pages 205–211. IEEE, February 2009.
[18] H. Kozima, C. Nakagawa, and Y. Yasuda. Children-robot interaction: a pilot study in autism therapy. In *Progress in Brain Research*, volume 164, pages 385–400. Elsevier, 2007.
[19] J. J. Diehl, L. M. Schmitt, M. Villano, and C. R. Crowell. The clinical use of robots for individuals with autism spectrum disorders: A critical review. *Research in Autism Spectrum Disorders*, 6(1):249–262, January 2012.
[20] J. Lee, H. Takehashi, C. Nagai, G. Obinata, and D. Stefanov. Which robot features can stimulate better responses from children with autism in robot-assisted therapy? *International Journal of Advanced Robotic Systems*, 9(72):1–6, September 2012.
[21] M. L. Knapp. *Nonverbal communication in human interaction*. Holt, Rinehart and Winston, New York, 1972.
[22] K. Barnett. A theoretical construct of the concepts of touch as they relate to nursing. *Nursing Research*, 2(21):102–109, March 1972.
[23] D. Hewett. Do touch: physical contact and people who have severe, profound and multiple learning difficulties. *Support for Learning*, 22(3):116–123, August 2007.
[24] J. P. Bardeen. *Interpersonal Perception Through the Tactile, Verbal and Visual Modes*. San Francisco State College, 1970.
[25] F. Tiffany. *Touch*. MIT Press, Cambridge, MA, 2001.
[26] Spence C. *The ICI report on the secret of the senses*. The Communication Group, London, 2002.
[27] A. Gallace and C. Spence. The science of interpersonal touch: An overview. *Neuroscience & Biobehavioral Reviews*, 34(2):246–259, February 2010.
[28] B. Robins, F. Amirabdollahian, and K. Dautenhahn. Investigating child-robot tactile interactions: A taxonomical classification of tactile behaviour of children with autism towards a humanoid robot. In *Proceeding of the Sixth International Conference on Advances in Computer-Human Interactions*, pages 89–94, Nice, France, February 2013.
[29] J. H. Foss-Feig, J. L. Heacock, and C. J. Cascio. Tactile responsiveness patterns and their association with core features in autism spectrum disorders. *Research in Autism Spectrum Disorders*, 6(1):337–344, January 2012.
[30] K. D. Buron and M. Curtis. *The incredible 5-point scale: assisting students in understanding social interactions and controlling their emotional responses*. AAPC Pub, Shawnee Mission, Kan, significantly improved and expanded 2nd ed edition, 2012.
[31] J. N. Constantino. *Social Responsiveness Scale*. Western Psychological Service, Los Angeles, 2002.
[32] C. Moore. *George and Sam*. Viking, London, 2004.
[33] J. A. Brian, S. P. Tipper, B. Weaver, and S. E. Bryson. Inhibitory mechanisms in autism spectrum disorders: typical selective inhibition of location versus facilitated perceptual processing. *Journal of Child Psychology and Psychiatry*, 44(4):552–560, May 2003.
[34] F. J. Scott and S. Baron-Cohen. Imagining real and unreal things: Evidence of a dissociation in autism. *Journal of Cognitive Neuroscience*, 8(4):371–382, October 1996.