PALADYN Journal of Behavioral Robotics

VERSITA

Research Article · DOI: 10.2478/pjbr-2013-0010 JBR · 4(2) · 2013 · 73-82

A Preliminary Study on the Response of Autistic Persons to a Robot Feedback based on Visual Stimuli

Jaeryoung Lee[1]*, Goro Obinata[2]†, Dimitar Stefanov[3]‡, Chikara Nagai[4]§

1 Graduate School of Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-0807, Japan

2 EcoTopia Science Institute, Nagoya University, Nagoya, Japan

3 Faculty of Engineering & Computing, Coventry University, Priory Street, CV1 5FB, Coventry, United Kingdom

4 Green Mobility Collaborative Research Center, Nagoya University, Nagoya, Japan

Received 14-05-2013

Accepted 15-09-2013

Abstract

Interactive robots are seen as an efficient tool for the improvement of the social communication skills of autistic children. Recent studies show that the effectiveness of the human-robot interaction can be improved further if the robot can provide positive feedback to the child when he/she demonstrates behaviour or social skills as expected. However, there is no clear answer to which visual stimuli and which combination of visual stimuli could attract better attention. In this paper we present initial results from our study of the response of participants with autism traits to four visual stimuli. We conducted a series of experiments where the experimental system provided a visual response to the user's actions and monitored the user's performance for each visual stimulus. The experiments were organised as a game and included four groups of participants with different levels of autism. The results showed that a colour tended to be the most effective way for robot interaction with autistic people. The results could help the design of very effective assistive robots for supporting people with autism.

Keywords

Human-robot interaction · robot-assisted therapy · assistive robot · autism therapy · affective touch · visual feedback

1. Introduction

Various research studies have shown that autistic children's attention can be engaged better when they communicate with a robot rather than with a human [1, 2]. These findings led to the development of new therapeutic approaches where robots are used as mediators. Currently, the research efforts are focused on the improvement of the efficiency of these methods. A number of studies have argued that the performance of children with autism during the training session can be increased if the robot could give feedback as a reward of a desirable behavior. Duquette et al. [3] noted that the interaction of the robot with the child was improved when the robot provided positive feedback for correct responses. Diehl et al. [4] suggested that the feedback efficiency of the robot can be enhanced if it is based on many factors and recommended further studies on the aspects that augment the feedback communication efficiency.

It has been found that autistic children tend to understand visual information more easily than verbal information [5–7]. As stated, "one of the most profound mysteries of autism has been the remarkable ability of most autistic people to excel at visual spatial skills while performing so poorly at verbal skills" p.19 [8]. Carr et al. [9] compared the response of autistic children to information presented to them via different stimuli. In their experiment, five objects were introduced to a group of children by the use of three types of cues: visual, vocal, and lip-reading. The percentage of correct responses to the visual stimuli was significantly higher than the results from the other ways of presentation. The evaluation of training approaches for the improvement of the communication skills of people with autism also showed that training strategies based on visual stimuli have better efficiency [10, 11]. In most studies, the visual stimuli are represented with changes of colour, changes of facial expression, changes of number, or changes of arrow direction.

The response of the children with autism to information introduced to them as colour sequences has been tested in many studies. Frith [12, 13] conducted experiments to explore how accurate the autistic children refer to colours when they describe previous events. The colour obsession of two autistic children in various situations was noticed by their parent [14].

Many studies proved that children with autism have difficulties in perceiving human facial expressions. For helping the autistic children to read the facial expressions of others and to make their own facial expressions, a range of training programs have been developed [15–17]. The response of autistic children to human faces has been studied in experiments where two sets of images of humans with simple facial expressions have been shown to a group of autistic children. It has been found that the images where the human's head was presented as a spot with a plain colour have attracted more attention than the images with human-like appearance [18].

Furthermore, it has been found in several studies that children with autism have obsessive interests in information presented to them by

*E-mail: lee.jaeryoung@ a.mbox.nagoya-u.ac.jp; Tel.: 052-789-5583; Fax: 052-789-5589

†E-mail: obinata@mech.nagoya-u.ac.jp

‡E-mail: d.stefanov@coventry.ac.uk

§E-mail: nagai@coe.mech.nagoya-u.ac.jp

numbers. Bemporad described that an autistic child liked numbers and was also found to have a lifelong fascination with arithmetic [19]. Smits also presented a case study of an autistic child with a strong interest in numbers [20]. The same result was confirmed by Wire whose findings showed that many children with Asperger's syndrome have the potential to respond better to information introduced to them by numbers [21].

An arrow is a symbolic cue that people often use inside the social environment. The evaluation of the eye gaze response of autistic children to arrow cues showed that the arrow image is accepted as a prompt for orienting or attention. It has also been addressed that the response to arrow cues is an automatic phenomenon [22–24].

Touch is an essential communication aspect and occurs rather frequently in social interaction [25]. Numerous studies on the behaviour of autistic children during communication tasks with interactive robots have shown that the participants demonstrated engagement with the experiment by changing the way of touching the robot (or robot interface device) when they respond to different situations [26, 27]. Although some autistic children show great fear of touching objects and avoid touching [28], tactile interaction is a much more common reaction of autistic children than verbal communication [29, 30]. While the importance of touch for the development of communication skill in social interactions has been well recognised, the practical training of autistic children for development of touching, which is a specific social behaviour, often remains a quite difficult task due to the absence of objective approaches for evaluation of children's touching response and teaching efficiency, respectively [31]. In some cases, children with autism demonstrate hyper or hypo tactile sensitivity to touching that might result in dangerous situations for both the trainers and the children [32]. Buron and Curtis [33] have developed multiple materials for helping autistic children to develop and improve their interaction behaviour and to control their touch force by using five touch levels and assigning a number or colour to each force level.

2. Motivation

As explained in the previous section, the interactive robots for autism therapy engage children's attention better if they provide positive feedback to the child when he/she demonstrates behaviour or social skills as expected. The feedback encourages children to communicate, increases therapeutic effectiveness, and stimulates children's curiosity. Previous studies showed that visual feedback is very effective. Such visual feedback can be organised by different visual cues and with different communication scenarios. However, there is no clear answer to which visual stimuli or combination of them could attract children's attention in the best way.

The long-term goal of our study is the development of robot design strategies for visual feedback stimulation according to the level of the individual's autism tendencies. As an initial step, in this paper we explore the responses of a small group of young adult participants with a tendency to autism to a few visual cues used for providing feedback information. The results of this study gave initial information about the general tendencies in the response of individuals to each stimulus which will be used further in the design of much more thorough and wider experiments with larger groups of autistic children.

As found in the previous works reviewed in Section 1, visual information is effective for autistic children understanding and we expected that visual stimuli are more likely to elicit a positive response in the autistic participants. With the experiment we wanted to verify the following two hypotheses:

H1: The task success rate will depend on the type of feedback stimulus used and on the AQ score of the participant.

H2: The initial success time will depend on the type of visual feedback and on the AQ score of the participant.

In this study, we conducted an experiment to explore the effectiveness of the following several types of visual feedback stimuli: colour, facial expression, numbers, and arrows with the aim to produce quantitative experimental results that can help the improvement of the assistive robots' effectiveness. The rest of this paper is organised as follows. Section 3 introduces the method used in this experiment and comments on the experimental settings and procedure; Section 4 discusses the experimental results; Section 5 concludes the work in this paper.

3. Method

3.1. Participants

Our end goal is to investigate how autistic children respond to different stimuli and which stimuli result in a better response. Experiments with children with autism need to be designed very carefully due to the specifics of their impairments. That is why, before we conduct experiments with autistic children, as a first step, we decided to investigate how adults with a tendency of autism respond to the same stimuli. We expect that such an approach will allow us to tune the research method and to clarify the exact set of stimuli that will be used in the second stage of our research project when we will conduct tests with autistic children.

In this preliminary study, university students who have autism tendencies were tested instead of children. Ten volunteers (age average M = 23.3, SD = 1.6) took part in the experiments. The extent of the autistic traits of each participant was evaluated by using the Autism Spectrum Quotient (AQ) test, Adult version [34].

The AQ test contains 50 questions that cover 5 different domains: social skill, attention switching, attention to details, communication abilities, and imagination. Each question allows the subject to indicate ”definitely agree”, ”slightly agree”, ”slightly disagree” or ”definitely disagree”. Each area is assessed with 10 questions. The Cronbach's (alpha) coefficient of internal consistency and reliability of the AQ test is 0.79 [34].

Depending on their AQ test score, the participants were divided into four groups. GROUP 1 included two participants who scored 32 or higher, indicating a strong likelihood of autism (M = 35.5). GROUP 2 included two participants who scored between 26 and 31, a borderline indication of an autism spectrum disorder and it is also possible to have autism within this range (M = 29.0). GROUP 3 was formed by the participants who scored between 22 and 25, which shows autistic tendencies slightly above the population average (M = 24.0), and the participants who obtained scores of less than 21 were included in GROUP 4 (M = 18.25). The information about the participant groups is summarised in Table 1.

By using adults with different AQ we also investigate how the response of people changes depending on their AQ. With the tests with adults we find the stimuli and the situations that attract the highest attention of people. If we know that in advance, we will be able to design our experiments with autistic children in a much more efficient way, and that will reduce stress from the experiments on autistic children.

Table 1. Four groups of participants

Group	Diagnosis	AQ	No. of participants in the group
G1	Autism	35.5	2
G2	Borderline	29.0	2
G3	Slightly higher than average autistic traits	24.0	2
G4	Average for most of the population	18.25	4

G1= group 1, G2= group 2, G3= group 3, G4= group 4, AQ= the average AQ test score among participants in each group

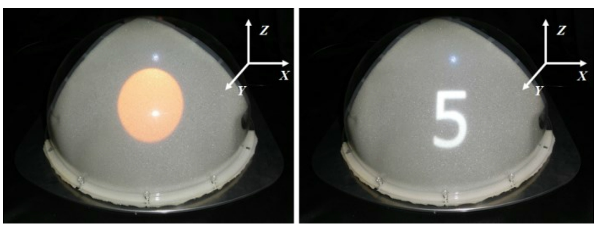

Figure 1. Touch Ball, examples in cases of colour and number feedback.

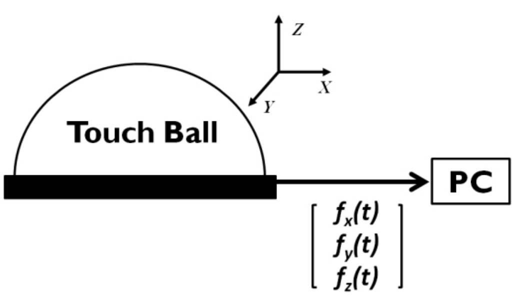

Figure 2. Block diagram of the force data collection.

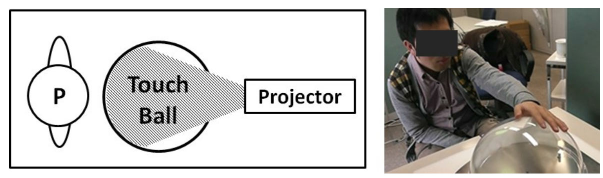

Figure 3. The test settings – the participants sit in front of the Touch Ball and apply force onto it; P = Participant.

3.2. Test interface

For the experiments, we used a special human machine interface (HMI) called Touch Ball. The Touch Ball was developed for studying the touching behaviour of children with autism in social situations. Touch behaviour in social situations is used for expressing emotions, delivers the feeling of affinity toward another person and forms trust between each other [35].

It is shaped as a half sphere with a 30 centimetre diameter that is linked to the base via a three axial force sensor. The shape of the Touch Ball was decided in our previous studies when it was found that a spherical image attracts children's attention [36]. The Touch Ball sensor was connected to a computer. A small projector was used to illuminate the surface of the half-sphere and to display visual information on it [27]. The block diagram and examples of the experimental Device are shown in Fig. 1 and Fig. 2. The force sensor measures the components $f_x(t)$, $f_y(t)$, and $f_z(t)$ of the force F applied to the half-sphere. F was calculated in the following way, as in Eq. 1.

$$F = \sqrt{f_x(t)^2 + f_y(t)^2 + f_z(t)^2} \quad (1)$$

Depending on magnitude of the force F, the visual stimuli projected on the Touch Ball were changed by using a special algorithm, as explained below.

3.3. Procedure

3.3.1. Experiment setup

Initially, each participant was invited to sit on a chair in front of Touch Ball as shown in Fig. 3. Some time for relaxation and adaptation to the new environment was given before the start of the session. The experimenter explained to the participant how to play the Touch Game (see Section 3.3.2) and how to apply force to the Touch Ball. Next, the participant was asked to set a target figure by applying force to the Touch Ball, for example, to set the yellow colour while getting help and additional instructions from the experimenter. After that, the participant was asked to practice changing images by controlling the force on the Touch Ball for various force ranges that were selected randomly. After the pre-test stage, the Touch Game started.

3.3.2. Touch Game

The experiment was organised as a game that the participants were asked to play. It was introduced to them as the "Touch Game". The experimental device allowed the participants to change the images projected on the Touch Ball by changing the force applied to it. Participants were asked to set on the Touch Ball a preliminary defined figure or colour by applying the correct amount of force to the HMI. Each test continued for 20 seconds. It was explained to the participants that after the start of the test they needed to try to set the goal colour (or the goal image) as quickly as they could and to continue to apply the same force to keep the goal until the end of the test.

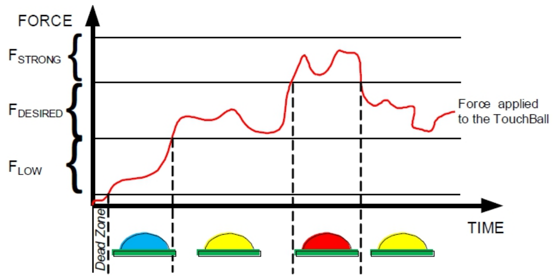

Figure 4. An example of the colour changing algorithm.

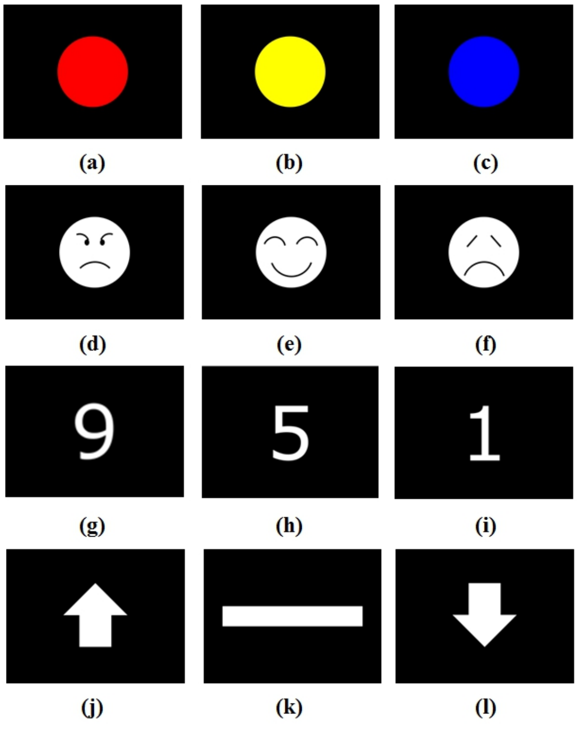

Figure 5. The visual stimuli projected on the Touch Ball: (a), (b) and (c) as Colour; (d), (e) and (f) as Facial expression; (g), (h) and (i) as Numbers; (j), (k) and (l) as Arrows.

Fig. 4 shows an example of the relationship between the forces applied by the user and the colour of the Touch Ball during the colour tests. As shown in the figure, the target colour (yellow) can be set if the force lies within the preliminary defined goal force range, denoted on the same figure as $F_{DESIRED}$. When the force is below a certain threshold value, no colour is projected on the Touch Ball (denoted on the figure as "Dead Zone"). The visual stimuli projected on Touch Ball are presented in Fig. 5. Red, yellow and blue colours were used in the experiments for measurement of the responses of the participants to colours, and yellow was selected as the goal colour (Fig. 5, (a), (b), and (c)). During the facial expression experiment, images of an angry face, a smiling face, and a sad face were used (Fig. 5, (d), (e), and (f)) and the participants were asked to set on the sphere the image of a smiling face by changing the force on the Touch Ball. Numbers one, five and nine were projected on the sphere in the experiment for studying participant's response to numbers (Fig. 5, (g), (h), and (i)) and number five was the goal. For exploring the acceptance of information presented as arrows, we used images of an arrow pointing upward, a bar, and an arrow directed downward (Fig. 5, (j), (k), and (l)) and the bar image was selected as the target. The relationships between the force applied to the Touch Ball and the images are shown in Table 2.

Table 2. Relationships between user's force and the figure/colour on the Touch Ball.

Force range	Colour	Face	Number	Arrow
F_{STRONG}	Red	Anger	Nine	Upward
$F_{DESIRABLE}$	Yellow	Smile	Five	Bar
F_{WEAK}	Blue	Sad	One	Downward

F_{STRONG} = strong force, $F_{DESIRABLE}$ = desirable force, F_{WEAK} = weak force

Table 3. Arrangement of the trials.

Set	Force range [N]	Trial No.	Visual stimulus
	Pre-test		colours/numbers/face expressions/arrows
S1	1< F <2	Trial 1	numbers
		Trial 2	colours
		Trial 3	arrows
		Trial 4	facial expressions
S2	0.5< F< 1.5	Trial 5	colours
		Trial 6	arrows
		Trial 7	numbers
		Trial 8	facial expressions
S3	1< F< 1.5	Trial 9	colours
		Trial 10	facial expressions
		Trial 11	numbers
		Trial 12	arrows
S4	0.5< F <1	Trial 13	facial expressions
		Trial 14	arrows
		Trial 15	colours
		Trial 16	numbers
S5	2< F <3	Trial 17	facial expressions
		Trial 18	colours
		Trial 19	arrows
		Trial 20	numbers
S6	1.5< F< 2.0	Trial 21	colours
		Trial 22	numbers
		Trial 23	arrows
		Trial 24	facial expressions

The Touch Game consisted of six sets. Each set included four trials. Four different ways of visual feedback (colour, facial expression, numbers, and arrows) were used in each trial. The order of the feedback

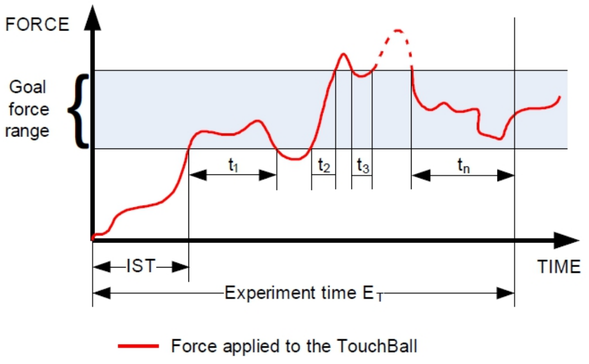

Figure 6. Changing force applied by the participant to the Touch Ball during the experiment. IST = Initial success time.

stimuli was selected randomly. The goal figure (or the goal colour) appeared on the Touch Ball sphere when the force that the participant applied to the Touch Ball was within a preliminary defined force range. For each set of the Touch Game, the range of the forces for selecting the goal figures or goal colours was different. This was implemented to avoid a the learning effect. Table 3 presents the force ranges for setting the target image for each set and the order of the visual stimuli tests during the experiment.

4. Results

To evaluate the effect of the visual feedback stimuli, we compared the initial success times (IST) and the target keeping rate (TKR) for each task of the Touch Game.

4.0.1. Initial Success Times (IST)

The initial success time (IST) is the time from the start of the test to the moment when the participant succeeds in setting the goal colour or goal image for the first time (see Fig. 6).

4.0.2. Target Keeping Rate (TKR)

As explained in the previous section, the goal image or goal colour appeared on the Touch Ball surface only at the moments when the force exercised by the participant to the Touch Ball was within the goal force range that was defined in advance for each set of the Touch Game. We define the target keeping time (TKT), as in Eq. 2, as the time for which the target image or the target colour is kept:

$$TKT = \sum_{i=1}^{n} t_i \tag{2}$$

The experiments consisted of six sets with four trials and we allowed 20 seconds in each trial for the completion of the task, i.e. the experiment time E_T = 20 [s]. The success ratio also can be judged from the target keeping rate (TKR) that is the ratio between the target keeping time and the test time, as in Eq. 3.

$$TKR = \left(\frac{TKT}{E_T}\right) \times 100[\%] \tag{3}$$

4.1. Relationships between the target keeping rate (TKR) and the visual stimuli

The results are listed as follows: Group 1 (2 participants), Group 2 (2 participants), Group 3 (2 participants), and Group 4 (4 participants).

4.1.1. Group 1: a strong likelihood of autism (AQ score = 32 or higher)

The participants from Group 1 (Participant 1(G1): AQ=39; Participant 2(G1): AQ=32; both males) demonstrated the highest TKR in the colour feedback tasks. Their individual scores are shown in Fig. 7 (a) and Fig. 7 (b) respectively.

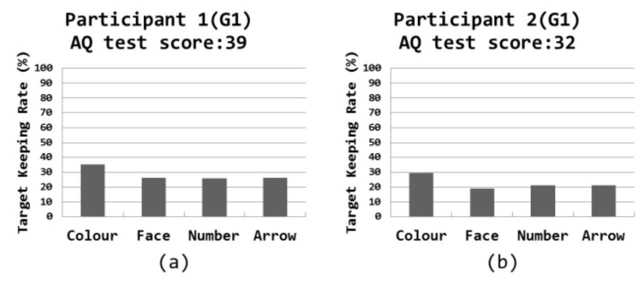

Figure 7. TKR of the participants in Group 1 (Autism). (a) Participant 1(G1): Male, AQ score: 39, (b) Participant 2(G1): Male, AQ score: 32.

4.1.2. Group 2: a borderline of autism (AQ score = 26 – 31)

The participants from Group 2 (Participant 1(G2), female and Participant 2(G2), male; both with AQ score 29) demonstrated a sustainable TKR for all tasks while achieving a TKR that was a little higher for the task with numbers. The individual results of the participants are presented in Fig. 8 (a) and Fig. 8 (b) respectively.

Figure 8. TKR of the participants in Group 2 (Borderline). (a) Participant 1(G2), female, AQ score: 29; (b) Participant 2(G2), Male, AQ score: 29.

4.1.3. Group 3: Slightly higher than average autistic traits (AQ score = 22 – 25)

Group 3 consisted of Participant 1(G3) (male, AQ score 25) and Participant 2(G3) (female, AQ score 23). Both of them indicated a good target keeping rate (TKR) in the trials with face expression feedback.

Table 4. The summary for the visual stimuli tests.

Group	Average of AQ score	Visual stimuli that indicated better results
Group 1	35.5	Colour
Group 2	29.0	Number
Group 3	24.0	Face or Arrow
Group 4	18.25	Arrow

The individual scores of Participant 1(G3) and Participant 2(G3) are presented in Fig. 9 (a) and Fig. 9 (b), respectively. Participant 2(G3) also achieved a high TKR on the arrow test.

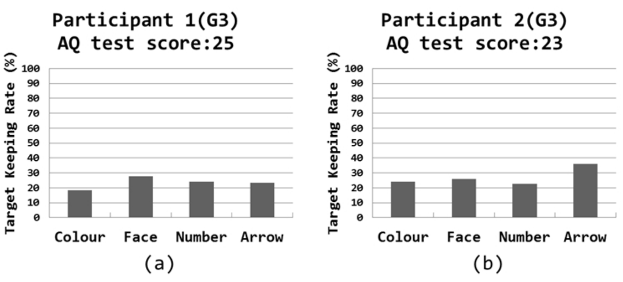

Figure 9. TKR of the participants in Group 3 (Slightly higher than average autistic traits), (a) Participant 1(G3), male, AQ score: 25; (b) Participant 2(G3), female, AQ score: 23.

4.1.4. Group 4: Average for most of the population (AQ score = less than 21)

Group 4 (control group) included four participants (two females and two males). Participant 1(G4) (female, AQ score 20), Participant 2(G4) (male, AQ score 19), Participant 3(G4) (female, AQ score 19) and Participant 4(G4) (male, AQ score 15) achieved a better target keeping rate (TKR) in the trials with arrow feedback. Participant 2(G4) also demonstrated a higher TKR in the colour feedback task. The individual results of all participants are shown in Fig. 10. The results, as shown in Fig. 7, Fig. 8, Fig. 9 and Fig. 10 indicate that the Target keeping rates (TKRs) in Touch Game were significantly different for each group and depended on the type of visual stimuli. Group 1 (participants with a strong likelihood of autism) showed higher TKRs in colour feedback, Group 2 (participants with a borderline of autism) had higher TKRs in number, Group 3 (participants with slightly higher than average autistic traits) showed good results in the tasks with arrow or face expression and Group 4 (control group; average for most of the population) played the Touch Game more effectively with arrow feedback. The same result is shown in Table 4.

4.2. Relationships between the initial success times (IST) and the visual stimuli

In these tests, Group 4 was considered as the control group (G_C) and their results were compared with the results of the other groups (G_T); Group 1, Group 2 and Group 3. IST were used as indicators for the

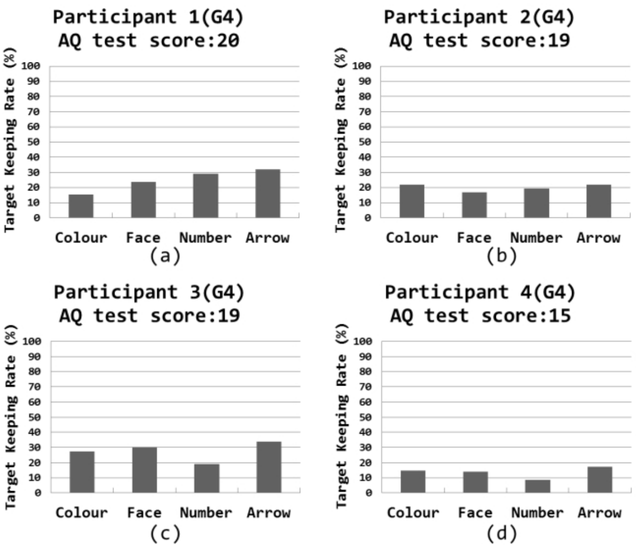

Figure 10. TKR of the participants in Group 4 (Average for most of the population; a control group). (a) Participant 1(G4), female, AQ score: 20; (b) Participant 2(G4), male, AQ score: 19; (c) Participant 3(G4), female, AQ score: 19; (d) Participant 4(4), male, AQ score: 15.

Table 5. Initial success times for the visual stimuli tests.

Groups		P	AQ	C	F	N	A
G_T	G1	1(G1)	39	2.07ˇ	**1.57***	1.99	1.83
		2(G1)	32	**1.36***	1.91ˇ	1.77	1.88
	G2	1(G2)	29	**1.38***	1.58	3.09ˇ	1.47
		2(G2)	29	1.97ˇ	1.66	1.68	**1.59***
	G3	1(G3)	25	**1.93***	2.33ˇ	2.16	2.00
		2(G3)	23	1.53	**1.42***	1.62	1.64ˇ
G_C	G4	1(G4)	20	2.06ˇ	**1.91***	1.93	1.98
		2(G4)	19	2.30ˇ	2.28	**1.96***	**1.96***
		3(G4)	19	**1.90***	1.94	3.18ˇ	2.20
		4(G4)	15	1.80ˇ	1.64	**1.50***	1.56

G_T = test group, G_C = control group, G_1= group 1, G_2= group 2, G_3= group 3, G_4= group 4, P = participant, AQ = AQ rate, C = color test, F = facial expressions test, N= test with numbers, A = arrows test, * = shortest initial success time, ˇ = longest initial success time

acceptance of each visual stimulus by the participant. Table 5 shows the ISTs for each participant for each task. The times in Table 5 are calculated as the average of the IST for the same task in all sets.
For comparison of the response of each group to each visual stimulus, we identified in Table 5 the shortest initial success time (SIST) and the longest initial success time (LIST) for each participant. In Table 5, the SIST is denoted with (*) and the LIST is indicated with (ˇ). We calculated the highest success ratio (SHSR) for each visual stimulus as the ratio between the number of participants who have a shortest initial time for the same stimulus and the total number of participants in the same test,

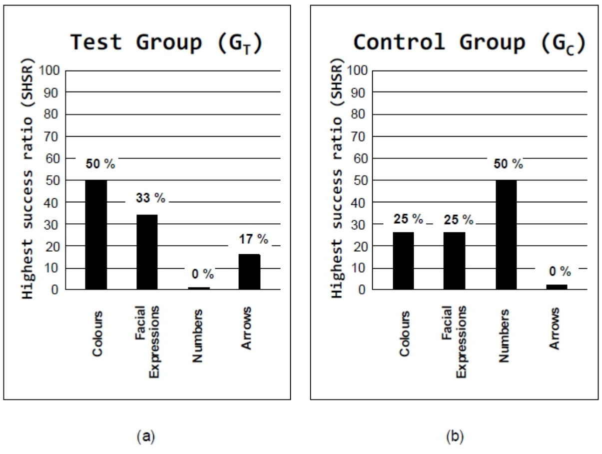

Figure 11. Highest success ratio (SHSR) for each visual stimulus.

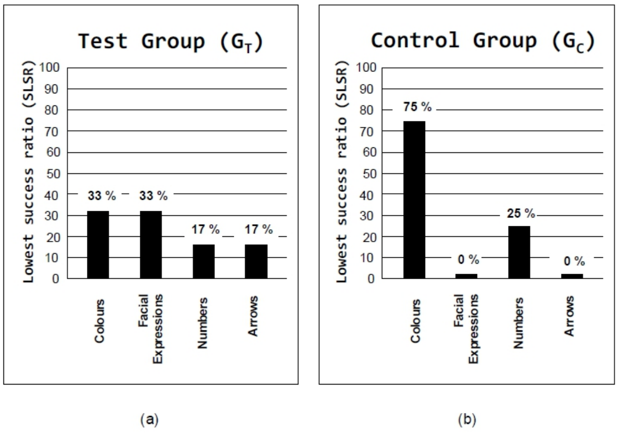

Figure 12. Lowest success ratio (SLSR) for each visual stimulus.

as in Eq. 4.

$$SHSR = \left(\frac{PH}{GP}\right) \times 100[\%] \tag{4}$$

where:
SHSR – highest success ratio of the stimulus
PH – number of participants whose shortest initial success time is for the same stimulus
GP – number of participants in the group.

We calculated the stimulus lowest success ratio (SLSR) in a similar way, as in Eq. 5:

$$SLSR = \left(\frac{PL}{GP}\right) \times 100[\%] \tag{5}$$

where:
SLSR – lowest success ratio of the stimulus
PL – number of the participants whose longest initial success time is for the same stimulus
GP – number of participants in the group.

For example, SHSR in G_T, 50%, was calculated as the following: number of participants in the test group (groups 1, 2 and 3) is 6 (GP). Number of participants whose shortest initial success time is for the colour stimulus is 3 (PH). Then we can calculate SHSR, using Eq. 4, to be 50%.
SLSR in G_C, 75%, was calculated in a similar way : number of participants in the control group (group 4) is 4 (GP). Number of participants whose longest initial success time is for the colour stimulus is 3 (PL). Then we can calculate SLSR, using Eq. 5, to be 75%.
The SHSRs and the SLSRs for the test group (G_T) and for the control group (G_C) for each visual stimulus are presented in Fig. 11 and Fig. 12 respectively. As shown in Fig. 11 (a), 50% of all participants from the test group (G_T) demonstrated a shortest initial success time for the task with colour feedback. In contrast, the participants from the control group demonstrated best performance on the task with numbers (Fig. 11 (b)). The test groups demonstrated a lower SHSR result for the task with face expressions (33%). Their SHSR for the arrow task was 17%. Their SHSR for the task with numbers was 0% (no single participant achieved their best score on the task with numbers).
As presented in Fig. 12 (a), the participants from the test group G_T have demonstrated a lowest success ratio (33%) for the tasks with colour and face expression. In contrast, 75% of the participants from the control group G_C have demonstrated their lowest performance on the task with colours.
The results, as shown in Fig. 11 and Fig. 12, demonstrated that the participants who have autistic traits were likely to accept the colour feedback rather than facial expression, number or arrow feedback, while it took quite a long time to adapt to the colour feedback for the participants without autism traits during the Touch Game.

4.3. Relationship between the target keeping rate (TKR) and the target force ranges

As explained in Table 3, the experiment was conducted in six sets including four trials in each set. In each set, the force range for triggering the target colour (or target image) was different. Target keeping rates (TKR) of each participant for each force range are shown in Fig. 13 and Fig. 14. As shown in Fig. 13, the results showed that 7 participants (1(G1), 2(G2), 1(G3), 2(G3), 1(G4), 2(G4) and 4(G4)) demonstrated the highest TKR in set 5 (force range from 2.0 N to 3.0 N). In contrast, as shown in Fig. 14, participants 2(G1), 1(G2), and 3(G4) who did not achieve their highest TKR for set 5, had relatively higher TKR for set 1 ($1.0<F<2.0$) and set 2 ($0.5<F<1.5$).

4.4. Relationship between the initial success times (IST) and the target force ranges

The IST of each participant and each group for each target force range are shown in Table 6. Results showed that the ISTs of Group 1 and Group 2 for the completion of Set 4 (force range: $0.5 < F < 1.0$) were shorter than the ISTs of the same groups for the completion of the other sets. Groups 3 and 4 completed Set 2 ($0.5 < F < 1.5$) much faster than the other sets. However, the longest initial time did not indicate a group dependence .

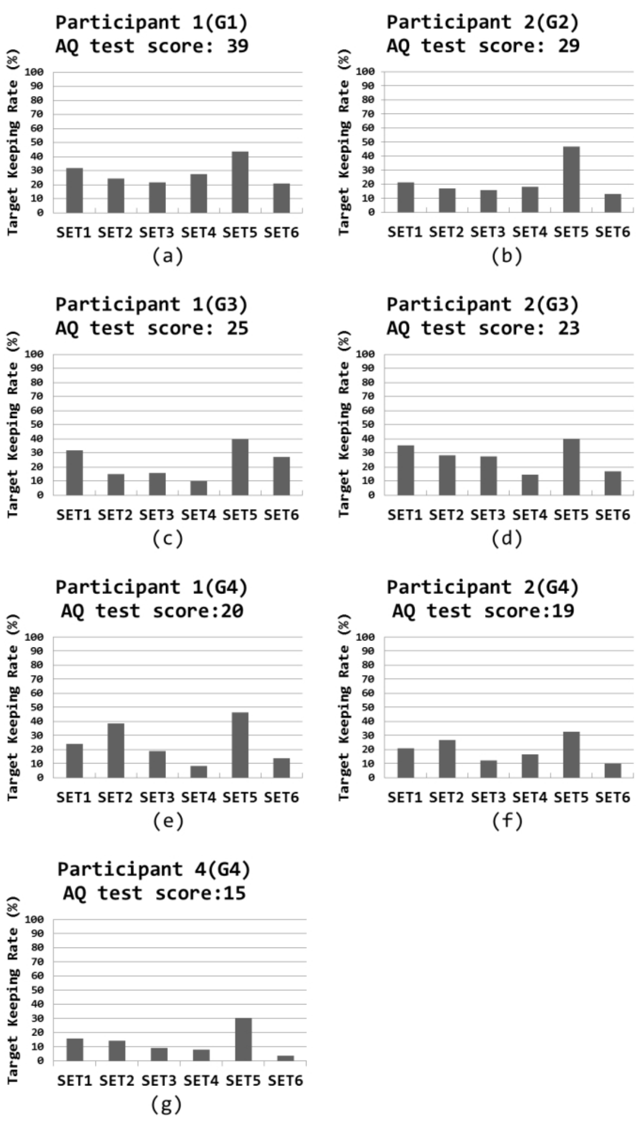

Figure 13. Target keeping rate (TKR) of each participant who showed highest TKR in set 5.

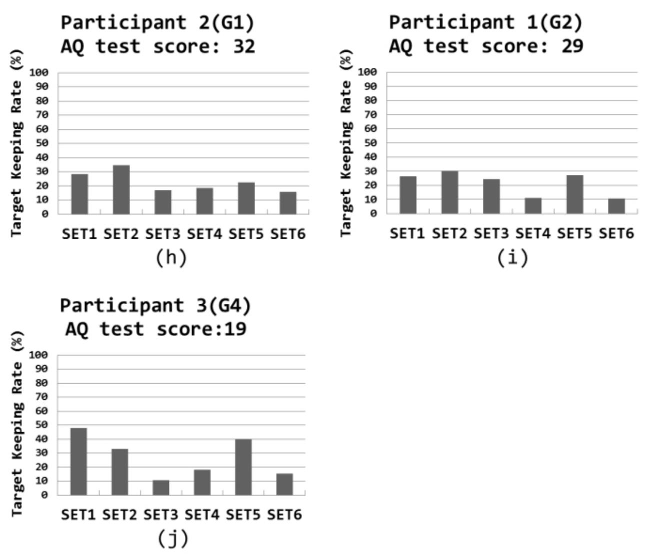

Figure 14. Target keeping rate (TKR) of each participant who didn't show the-highest TKR in set 5.

Table 6. Initial success time for each force range.

	AQ	SET1	SET2	SET3	SET4	SET5	SET6
G1	39	1.79	1.40	2.26	**1.38***	2.01	2.34ˇ
	32	2.45ˇ	1.06	1.55	**1.06***	2.36	1.88
G2	29	1.63	1.06	1.19	**1.01***	1.86	4.53ˇ
	29	1.60	1.34	1.83	**1.13***	2.13	2.33ˇ
G3	25	1.75	**1.35***	1.93	1.46	3.58ˇ	2.58
	23	1.94ˇ	**0.96***	1.38	1.09	2.10	1.85
G4	20	1.89	**1.29***	2.56ˇ	1.64	2.53	1.93
	19	2.54	**1.05***	2.70	1.31	2.19	2.95ˇ
	19	1.51	**1.34***	2.33	1.38	2.90	4.39ˇ
	15	1.96	**0.96***	1.61	1.00	2.24ˇ	1.98

G1= group 1, G2= group 2, G3= group 3, G4= group 4, * = shortest initial success time, ˇ longest initial success time

This is an unexpected result, as shown in Table 6, the force ranges that participants were able to reach easily were divided depending on the extent of autism.

5. Discussion and conclusion

In this study, as the initial step for developing assistive robots for autistic children, we conducted experiments with young adults who have autism tendencies to investigate the effectiveness of the following four types of visual feedback stimuli: colour, facial expression, numbers, and arrows. Moreover, we assumed that there is a different response depending on the extent of autism. The results indicated that these visual stimuli have different efficiency for the test group and for the control group. The result for the target keeping rate (TKR) and for the initial success times (IST) showed that the colour feedback can be considered as the most effective way of feedback for the participants with autism tendencies. The highest efficiency of the colour stimuli may be explained by the fact that the colour feedback is simpler than the other figures (face expression, numbers, or arrows). Numerous studies have already revealed that autistic children prefer objects that are simple in functioning and appearance [18].

Moreover, we hypothesized that the efficiency of the visual feedback methods will depend on the extent of autistic traits of each participant. It means that there is a relationship between the autistic degree of the participant and the form of visual stimuli. The results confirmed the initial assumption. The results of target keeping rate (TKR) showed that the participants with different extent of autism respond differently to the visual stimuli. For example, participants with a high AQ test score demonstrated good result in the experiments with colour feedback. The participants whose AQ score is on the borderline for autistic traits performed better in the tasks with number feedback. The participants whose AQ score was slightly higher than the average autistic traits showed a better response to the face feedback than the feedback with arrows. On the other hand, the control group tended to like the Touch Ball game with arrow feedback.

We also hypothesized that the initial success times (IST) of the different methods of visual feedback will depend on the degree of autistic behaviour. Results supported our hypothesis. The participants who have autism tendencies showed the best initial success time when they received colour feedback rather than the other three visual stimuli, while the control group participants without autism tendencies reached the goal with the best time during number feedback.

One unanticipated finding was that a particular target force range let the participants apply their force easier than others. The results of target keeping rate (TKR) indicated that seven participants demonstrated a good result in SET 5. Also, the results of the initial success times (IST) showed that the participants who have a high AQ test score and on the borderline for autistic traits reached the target force faster in SET 4, while the rest of the participants did so in SET 2. This finding should also be considered as important when an assistive robot is designed for improving autistic children's touching behaviour. These results demonstrate that the effective feedback method is different for each group and depends on the individual's extent of autism.

These preliminary results need to be confirmed with further studies with wider groups of autistic children. Depending on the autistic degree, the interaction scenario may be different. For example, an autistic child whose impairment affects the perception of human facial expressions might prefer a simpler figure such as numbers or signs.

As mentioned in section I, it is crucial that children learn to touch other people properly and the training doesn't materialise as a school support program. This study provides further support for the hypothesis that it is effective to use an assistive robot for training touching behaviour in autism therapy when the robot can change the type of feedback provided depending on the extent of autistic traits.

6. Acknowledgment

We would like to thank for their assistance Toru Yoshikawa M.D in Nagoya University Hospital and Hiroki Takehashi in Tokyo Future University

References

[1] 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", *Int. J. Hum.-Comput. Stud.*, vol. 68, no. 12, pp. 873–898, Dec. 2010.

[2] B. Scassellati, Henny Admoni and M. Mataric, "Robots for Use in Autism Research", *Annu. Rev. Biomed. Eng.*, vol. 14, no. 1, pp. 275–294, Aug. 2012.

[3] A. Duquette, F. Michaud and H. Mercier, "Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism", *Auton. Robots*, vol. 24, no. 2, pp. 147–157, Oct. 2007.

[4] 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", *Res. Autism Spectr. Disord.*, vol. 6, no. 1, pp. 249–262, Jan. 2012.

[5] V. K. Tubbs, "Types of linguistic disability in psychotic children", *J. Intellect. Disabil. Res.*, vol. 10, no. 3, pp. 230–240, 1966.

[6] K. A. Quill, *Teaching children with autism: strategies to enhance communication and socialization*. New York: Delmar Publishers, 1995.

[7] K. A. Quill, "Instructional considerations for young children with autism: The rationale for visually cued instruction.", *J. Autism Dev. Disord. J. Autism Dev. Disord.*, vol. 21, pp. 697–714, 1997.

[8] T. Grandin, *Thinking in pictures: and other reports from my life with autism*. London: Bloomsbury, 2006.

[9] E. G. Carr, J. A. Binkoff, E. Kologinsky and M. Eddy, "Acquisition of sign language by autistic children. I: Expressive labelling.", *J. Appl. Behav. Anal.*, vol. 11, no. 4, pp. 489–501, 1978.

[10] L. A. Hodgdon, *Solving Behaviour Problems in Autism: Improving Communication with Visual Strategies*. Troy, Mich: QuirkRoberts Pub, 1999.

[11] J. E. Janzen, *Understanding the nature of autism: a guide to the autism spectrum disorders*, 2nd ed. San Antonio, TX: Therapy Skill Builders, 2003.

[12] U. Frith, "Studies in pattern detection in normal and autistic children", *J. Exp. Child Psychol.*, vol. 10, no. 1, pp. 120–135, Aug. 1970.

[13] U. Frith, "Cognitive mechanisms in autism: Experiments with color and tone sequence production", *J. Autism Child. Schizophr.*, vol. 2, no. 2, pp. 160–173, Jun. 1972.

[14] C. Moore, *George and Sam*. London: Viking, 2004.

[15] 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", *Cereb. Cortex*, vol. 18, no. 2, pp. 289–300, May 2007.

[16] R. Wilson, O. Pascalis, and M. Blades, "Familiar Face Recognition in Children with Autism: The Differential use of Inner and Outer Face Parts", *J. Autism Dev. Disord.*, vol. 37, no. 2, pp. 314–320, Jul. 2006.

[17] 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?", *Eur. Child Adolesc. Psychiatry*, vol. 17, no. 2, pp. 63–72, Sep. 2007.

[18] B. Robins, K. Dautenhahn and J. Dubowski, "Does appearance matter in the interaction of children with autism with a humanoid robot?", *Interact. Stud.*, vol. 7, no. 3, pp. 509–542, Jan. 2006.

[19] J. R. Bemporad, "Adult recollections of a formerly autistic child", *J. Autism Dev. Disord.*, vol. 9, no. 2, pp. 179–197, Jun. 1979.

[20] T. Smits, *Autism: beyond despair*. Emryss Publishers, 2010.

[21] V. Wire, "Autistic Spectrum Disorders and learning foreign languages", *Support Learn.*, vol. 20, no. 3, pp. 123–128, Aug. 2005.

[22] J. Tipples, "Eye gaze is not unique: Automatic orienting in response to uninformative arrows", *Psychon. Bull. Rev.*, vol. 9, no. 2, pp. 314–318, Jun. 2002.

[23] A. Senju, Y. Tojo, H. Dairoku and T. Hasegawa, "Reflexive orienting in response to eye gaze and an arrow in children with and without autism", *J. Child Psychol. Psychiatry*, vol. 45, no. 3, pp. 445–458, Mar. 2004.

[24] G. Kuhn, V. Benson, S. Fletcher-Watson, H. Kovshoff, C. A. McCormick, J. Kirkby and S. R. Leekam, "Eye movements affirm: automatic overt gaze and arrow cueing for typical adults and adults

with autism spectrum disorder", *Exp. Brain Res.*, vol. 201, no. 2, pp. 155–165, Oct. 2009.

[25] M. L. Knapp, *Nonverbal communication in human interaction*. New York: Holt, Rinehart and Winston, 1972.

[26] 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 Proceeding of the 2nd International Conferences on Advances in Computer-Human Interactions, 2009, pp. 205– 211.

[27] J. Lee, H. Takehashi, C. Nagai and G. Obinata, "Design of a therapeutic robot for interacting with autistic children through interpersonal touch", in Proceeding of the 21st IEEE International Symposium on Robot and Human Interactive Communication, 2012, pp. 712–717.

[28] O. Bogdashina, *Sensory perceptual issues in autism and Asperger Syndrome different sensory experiences, different perceptual worlds*. London; New York: Jessica Kingsley, 2003.

[29] P. Caldwell, *Getting in touch: ways of working with people with severe learning disabilities and extensive support needs*. Brighton: Pavilion Publishing: Joseph Rowntree Foundation, 1996.

[30] B. Robins, K. Dautenhahn and P. Dickerson, "Embodiment and Cognitive Learning – Can a Humanoid Robot Help Children with Autism to Learn about Tactile Social Behaviour?", *Social Robotics*, vol. 7621, S. S. Ge, O. Khatib, J.-J. Cabibihan, R. Simmons, and M.-A. Williams, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012, pp. 66–75.

[31] G. B. Mesibov, *The TEACCH approach to autism spectrum disorders*. New York: Kluwer Academic/Plenum Publishers, 2005, pp. 96.

[32] J. H. Foss-Feig, J. L. Heacock and C. J. Cascio, "Tactile responsiveness patterns and their association with core features in autism spectrum disorders", *Res. Autism Spectr. Disord.*, vol. 6, no. 1, pp. 337–344, Jan. 2012.

[33] K. D. Buron and M. Curtis, *The incredible 5-point scale: assisting students in understanding social interactions and controlling their emotional responses*, Significantly improved and expanded 2nd ed. Shawnee Mission, Kan: AAPC Pub, 2012.

[34] Simon Baron-Cohen, Sally Wheelwright, Richard Skinner, Joanne Martin, and Emma Clubley, "The Autism-Spectrum Quotient (AQ): Evidence from Asperger Syndrome/High-Functioning Autism, Malesand Females, Scientists and Mathematicians", *J. Autism Dev. Disord.*, vol. 31, no. 1, pp. 5–17, Feb. 2001.

[35] Jeremy N. Bailenson, Nick Yee, Scott Brave, Dan Merget, and David Koslow, "Virtual interpersonal touch: expressing and recognizing emotions through haptic devices", *Hum.-Comput. Interact.*, vol. 22, no. 3, pp. 325–353, Aug. 2007.

[36] 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?, *Int. J. Adv. Robot. Syst.*, pp. 1–6, 2012.