Investigating Child-Robot Tactile Interactions:
A taxonomical classification of tactile behaviour of children with autism towards a humanoid robot.

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Abstract—**The work presented in this paper is part of our investigation in the ROBOSKIN project. One key research activity in the project was to explore tactile interactions of children with autism with the humanoid robot KASPAR in order to develop methods and mechanism to support robot-assisted therapy for children with autism. This article presents a detailed taxonomical classification of tactile interactions of 14 children with autism with the humanoid robot KASPAR. Our quantitative analysis confirms results from the literature highlighting the great variety of autistic children's interaction capabilities.**

Keywords-assistive technology; human-robot interaction; autism therapy; robot assisted therapy.

I. INTRODUCTION

Physical touch is one of the most basic, but at the same time very important forms of communication. Tactile sensing can help to provide awareness of one's own self and each other. On the playground, touch and physical contact are used by children to give and receive support and encouragement, to build trust, to communicate and to develop their social relationship. In therapy, the tactile sense can be used individually to increase self knowledge, body image, to achieve sense of stability, and build confidence. Touch of another person, when it happened, is seen also as a way of breaking through isolation [1, 2].

However, for people with autism, in addition to their inabilities to relate to other people, show little use of eye contact, and have difficulty in verbal and non-verbal communication, impairments in tactile interaction prevent them even further from social interaction with other people. Some people with autism might be hyposensitive and seem not to feel pain. They may not sense their touch of other people or objects appropriately, which could lead them to unintentionally hurt other people, or break objects. Other people with autism might have a hyper-tactility condition which is very common and results in overwhelming sensation. As touch can be excruciating to people with this condition it leads to fear of being touched. This fear could be so great, that it may cause a panic attack [3, 4].

On the other hand, tactile interaction (if tolerated) might be an important means of communication for children with autism, as some do not have verbal skills and others use their verbal skills inadequately. Caldwell [5] suggests that problems with verbal skills and eye gaze in children with autism create the need for touch to replace these detrimental ways of communicating.

We argue that a 'tactile' robot can be used as a 'buffer' that mediates between a person with autism and another person, by providing indirect rather than direct human-human contact, until such time that the person builds enough strength and confidence to tolerate direct human contact. A robot with tactile applications could allow a person with autism to feel safe and build their confidence in tactile interaction where they can explore touch in a playful way that could be completely under their control. Also, while inappropriate tactile interaction with another person will automatically lead to negative feedback (e.g., when hitting another person), interaction with a robot can provide a non-judgemental environment where the child can safely explore tactile interaction, in a long-term process that involves reflection and feedback given to the child about his or her actions.

Several observational systems and taxonomies can be found in the literature that were created to help clinicians and researchers making inferences about play, based on the observation of behaviours, e.g., Knox play scale [6], or Bundy's Test of Playfulness [7]. Taxonomies of children's behaviour during play provide criteria to guide observation of behaviours in narrower categories that may be easier to observe, describe and explain.

However, play behaviours at their core are thought to involve experiential characteristics that are typically difficult to observe directly, such as intrinsic motivation, enjoyment and active engagement, and it is important to remember that taxonomies often rely on observable behaviours which often cannot capture fully the person's subjective experience [8]. This becomes an even more important factor to consider when working with a population for whom communication skills are one of the main areas of impairment (such as the case of children with autism - many have limited or no language skills at all) and it is very difficult, if not impossible, to interview the person about their experience. In addition to impaired communication, atypical sensory processing, motor difficulties, and cognitive impairment are other very common characteristics of autism. As children with autism may manifest these symptoms to varying degrees, this results in an extremely heterogeneous population [8], which in turn, makes the task of developing a taxonomy and classification of typical tactile behaviour of children with autism very difficult. Although children with

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autism share the same core difficulties, each child displays these in an individual way [9]. A series of 14 interaction sessions that were conducted in a recent study with autistic children and the robot KASPAR were used as a basis for our taxonomical classification. The following sections describe the robotic platform used and the trials set up and procedures and continue with the taxonomical classification of tactile interaction followed by discussion and future plans.

II. THE ROBOTIC PLATFORM - KASPAR

KASPAR is a child-sized minimally expressive robot which acts as a platform for HRI studies, using mainly bodily expressions (movements of the hand, arms and facial expressions) and gestures to interact with a human (Figure 1). The robot has a static body (torso, legs and hands were taken from a child-sized commercially available mannequin doll) with an 8 DOF head and two 3 DOF arms.

The face is made from a silicon rubber mask that covers an aluminum frame. It has 2 DOF eyes fitted with video cameras; eye lids that can open and shut and a mouth capable of opening and smiling. These features enable KASPAR to show minimally expressive emotional states such as *happiness*, *neutral*, *sadness* and *surprise* (Figure ***2***). It has several pre-programmed behaviours that include various facial expressions, hand waving and drumming on a toy tambourine that is placed on its legs. KASPAR's movements are either controlled remotely through a remote control device, or it can operate autonomously.

For a complete description of KASPAR's design rationale, hardware, and application examples see [10].

III. TRAILS SET-UP AND PROCEDURES

The study, which involved 14 children with autism, was designed to provide essential observational data on children's behaviour during child-robot interaction including spontaneous tactile interaction.

The trials took place in a special needs school for children with moderate learning difficulties in the UK. With the objective to provide a reassuring environment, the trials were designed to allow the children to have free and unconstrained interaction with the robot and with the present adult (i.e., teacher, experimenter) should they wish to. The trials were conducted in a familiar room often used by the children for various activities. Before the trials, the humanoid robot was placed on a table, connected to a laptop. The investigator was seated next to the table. The robot was operated remotely via a wireless remote control (a specially programmed keypad), either by the investigator or by the child (depending on the child's ability). The children were brought to the room by their carer and the trials stopped when the child indicated that they wanted to leave the room or if they became bored. Two stationary video cameras were used to record the trials.

Figure 1. The robotic platform KASPAR.

Figure 2. Some of KASPAR's facial expressions and expressive gestures.

IV. TAXONOMICAL CLASSIFICATION OF TACTILE INTERACTION

All interaction sessions of the children and the robot were video recorded from different angles. 14 sessions (one for each child) were used in building the taxonomical classification reported here. The resulting videos were analysed in a coding process that included watching the videos and manually identifying touch types, locations, durations and estimated pressure by observing video sequences and coding start, end or onset of events. This entailed complete coding of all 14 videos using the Observer software (Noldus). Table 1 shows the tactile features that were observed during the interaction. In addition, the duration of these features were detected and calculated.

A. *Preliminary visual inspection of the coded events*

In order to provide a more detailed classification and taxonomical breakdown, events coded in these videos were further analysed. Figure ***3*** shows a visual representation of the events detected in 4 of these videos. As can be seen, these four cases present a very different result in terms of type, duration, and frequency of the tactile events observed.

In order to gain a fuller picture of these variations, number and duration of these touch events were plotted versus one-another (Figure 4 & Figure 5). As different participants interacted with the robot for different lengths of time, the number of tactile events are normalized based on the durations. Thus a further plot is included presenting the rate of occurrence for these tactile events (Figure 6).

TABLE 1
TACTILE FEATURES: TOUCH TYPES, PRESSURES AND LOCATIONS

Touch type
Grasp
Touch
Stroke
Poke
Pinch

Touch Pressure
Light
Medium
Tight

Touch Location
Left arm
Left leg
Right arm
Right leg
Both arms
Both legs
Head
Torso

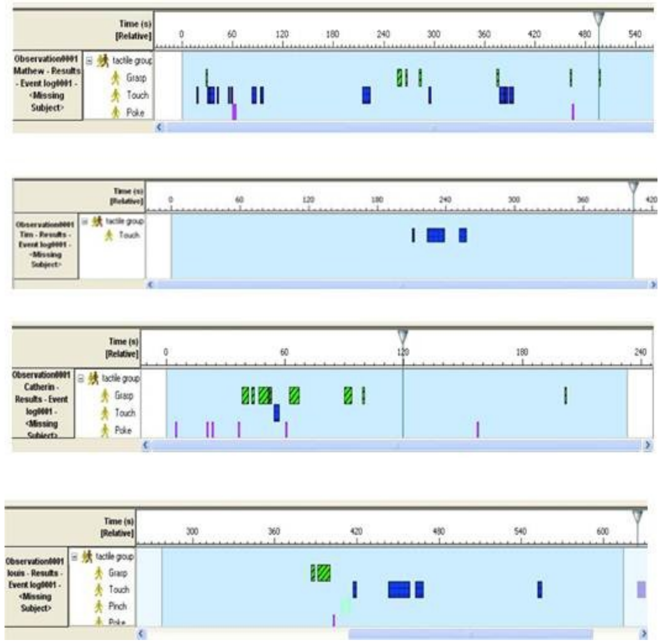

Figure 3. Four examples of tactile events detected.

In order to further investigate the extent of these observed differences, coded events were analysed statistically.

A. Statistical analysis of the coded events

Comparing the number of touch events as shown in Figure 3 can be misleading as longer sessions can include a larger number of tactile events. The occurrence rate of tactile events is a compound variable that consists of the number of specific tactile events and the total duration of each session thus allowing for comparison based on rate (number/duration). This parameter was analysed statistically in order to highlight differences in between touch types and individual participants.

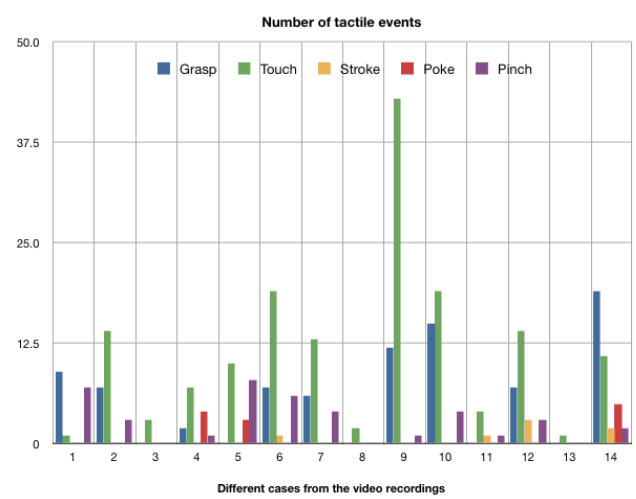

Figure 4. Comparison between number of tactile events detected for different cases.

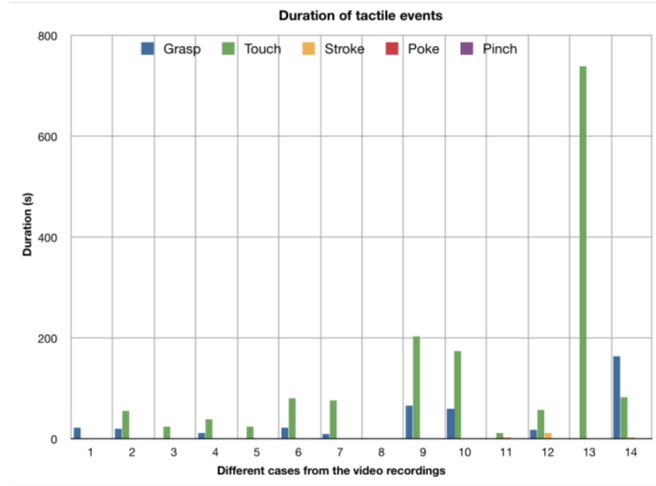

Figure 5. Comparison between the duration of the tactile events detected from different cases. Please note that poke and pinch were point events and did not have a duration attribute.

At a first glance, the boxplot presented in Figure 7 shows the extent of these observed variations as presented by the 'rate per minute' variable. As can be seen, the grasp and touch events present higher rates of touch and also higher variability while pinch, stroke and poke present lower rates, and less variability.

1) General linear model (two-way ANOVA)

In order to identify the extent of inter-event variations, as well as variations between each touch type, a two-way ANOVA model was constructed using the PASW statistical analysis package. This package uses the general linear model for multivariate analysis including the two-way ANOVA. Model variable was the 'Rate per minute', while factors were 'touch type' and 'participant'. This allows for identifying differences between different touch types and

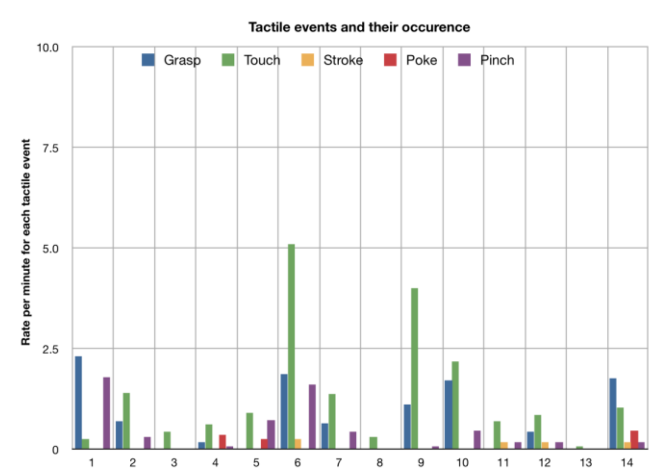

Figure 6. Occurrence rate per minute for each tactile event for different cases. These include normalised number of events over the duration of each session in minute.

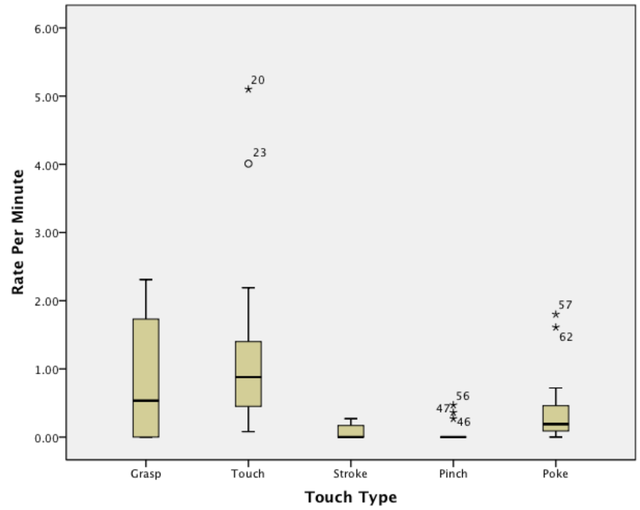

Figure 7. Boxplot comparing rate per minute for different tactile events.

also how participants performed under each type of tactile event.

Table 2 highlights that in addition to significant variations between the touch events identified, there were significant variations between different participants and their rate and type of touch.

Table 3 presents the parameter estimates and their influences on the general linear model. It shows that different parameters (intercept, participant 6 and touch type 2) had most influenced the linear model. Such a model is a type of linear best-fit line for the data points and here the model tries to fit a line to those data points presented by touch type and for different participants. Significant and influential parameters are shaded rows while close to significant values are shown by shading the cell only.

It is interesting to note that participant 6 and touch type 2 are presented as the most dominant features seen in Figure ***5***, while participants 8 and 13 present the least visible features in this figure, highlighted by the negative slope value (column B in Table 3).

TABLE 2
TOUCH TYPE AND PARTICIPANT VARIATIONS SHOWN BY A GENERAL LINEAR MODEL

Tests of Model Effects

Source	Type III Wald Chi-Square	df	Sig.
(Intercept)	53.819	1	.000
Participant	39.104	13	.000
TouchType	44.198	4	.000

Dependent Variable: Rate Per Minute
Model: (Intercept), Participant, TouchType

TABLE 3
PARAMETER ESTIMATION AND IDENTIFICATION OF SIGNIFICANT PARAMETERS

Parameter Estimates

			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	.621	.3144	.004	1.237	3.897	1	.048
[Subject=1]	.142	.3921	-.626	.910	.131	1	.717
[Subject=2]	-.252	.3921	-1.020	.516	.413	1	.520
[Subject=3]	-.642	.3921	-1.410	.126	2.681	1	.102
[Subject=4]	-.482	.3921	-1.250	.286	1.511	1	.219
[Subject=5]	-.354	.3921	-1.122	.414	.815	1	.367
[Subject=6]	1.040	.3921	.272	1.808	7.036	1	.008
[Subject=7]	-.240	.3921	-1.008	.528	.375	1	.540
[Subject=8]	-.668	.3921	-1.436	.100	2.903	1	.088
[Subject=9]	.312	.3921	-.456	1.080	.633	1	.426
[Subject=10]	.144	.3921	-.624	.912	.135	1	.713
[Subject=11]	-.524	.3921	-1.292	.244	1.786	1	.181
[Subject=12]	-.398	.3921	-1.166	.370	1.030	1	.310
[Subject=13]	-.716	.3921	-1.484	.052	3.335	1	.068
[Subject=14]	0[a]	.	.	.	.	.	.
[TouchT=1]	.337	.2343	-.122	.796	2.070	1	.150
[TouchT=2]	.947	.2343	.488	1.406	16.340	1	.000
[TouchT=3]	-.374	.2343	-.833	.086	2.542	1	.111
[TouchT=4]	-.354	.2343	-.813	.106	2.277	1	.131
[TouchT=5]	0[a]	.	.	.	.	.	.
(Scale)	.384[b]	.0650	.276	.535			

Dependent Variable: Rate Per Minute
Model: (Intercept), Participant, TouchType
a. Set to zero because this parameter is redundant.
b. Maximum likelihood estimate.

2) General linear model for tactile location and touch intensity

We further extended the analysis by considering variations of touch across different body parts of the robot
shown by TABLE 1. This is a more complex statistical model, which would allow investigating if there were similarities for touch event rates for a specific body part and specific touch intensities. Such a model requires a more detailed coding and calculation of rates per body location, as well as data structuring to allow for a two-way ANOVA, done under the PASW general linear model. The model constructed here uses the 'rate per minute' as its variable while factorising 'participant', and 'body part; intensity'. The last parameter identifies the body part touched and observed intensity of the touch type. The box plot presented by Figure ***8*** highlights these results.

The general linear model once more identified significant differences in rate per minute between participants and 'touch event; intensity', which is evident in the above boxplot (Table 4). These differences are highlighted by Figure 9 and TABLE 5.

Further results are provided by the parameter estimates (TABLE 5). This table shows that when modeling based on observed variations, participant 6 still presents a strong positive influence while participant 8 continues to provide a negative contribution towards a common fitted line. Other participants, participant 9 and 10, also provide significant contributions towards the trend. Touch events 'ba; 1' and 'head; 1' both present significant influences. The 'ba; 1'

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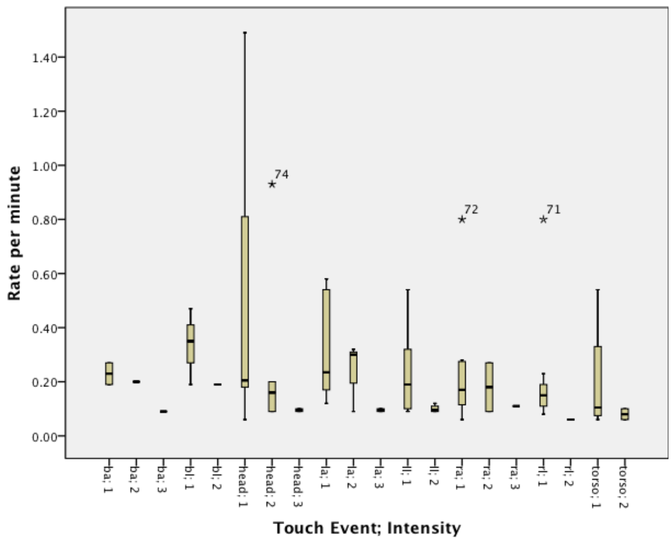

Figure 8. Rate of tactile events based on touch location and intensity.

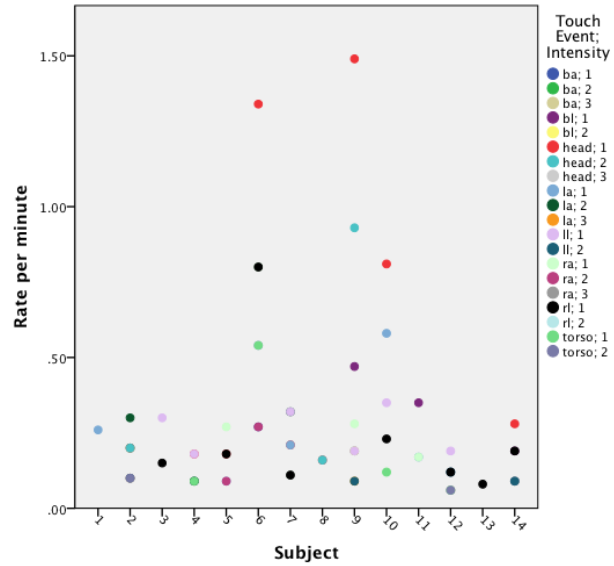

Figure 9. Rate per minute for participant and tactile event; intensity.

indicates slight touch on both robot arms and can be seen on the boxplot to present small variations in rate per minute, while the light head touch identified by 'head; 1' shows stronger variations, thus contributing to the positive slope as reflected by column B.

A. Discussion of results

The visual inspection and statistical analysis of different observed touch types for different participants present a Versatile picture varying across touch types, intensities and different participants. This was predicted prior to the start of this study as touch events are shown to be different in their features, locations and for different participants. This is evident in the statistical results showing significant differences of touch type and participant levels. This poses a potential challenge to taxonomical classification as interactive scenarios with low functioning children with autism often feature free or less-structured interactions. For example, often it is difficult to enforce a certain type of touch for a certain duration and thus studies of the results from such interaction are bound to have large inter/intra

TABLE 4
TOUCH LOCATION AND PARTICIPANT VARIATIONS PRESENTED BY THE GENERAL LINEAR MODEL

Tests of Model Effects

	Type III		
Source	Wald Chi-Square	df	Sig.
(Intercept)	18.887	1	.000
Participant	104.189	13	.000
TouchEvent	60.008	19	.000

Dependent Variable: Rate per minute
Model: (Intercept), Participant, TouchEvent; intensity

TABLE 5
PARAMETER ESTIMATES FOR THE TOUCH PER MINUTE BASED ON PARTICIPANT AND TOUCH-TYPE; INTENSITY

Parameter Estimates

			95% Wald Confidence Interval		Hypothesis Test		
Parameter	B	Std. Error	Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	.065	.1347	-.199	.329	.231	1	.631
[Subject=1.00]	.135	.1877	-.232	.503	.521	1	.470
[Subject=2.00]	.034	.0864	-.135	.203	.156	1	.693
[Subject=3.00]	.124	.1333	-.137	.386	.868	1	.351
[Subject=4.00]	-.038	.1005	-.235	.159	.144	1	.705
[Subject=5.00]	.026	.0971	-.164	.217	.073	1	.786
[Subject=6.00]	.592	.0924	.411	.773	41.008	1	.000
[Subject=7.00]	.053	.0931	-.130	.235	.319	1	.572
[Subject=8.00]	-.147	.1375	-.417	.122	1.145	1	.285
[Subject=9.00]	.400	.0887	.226	.574	20.340	1	.000
[Subject=10.00]	.241	.0962	.053	.430	6.295	1	.012
[Subject=11.00]	.115	.1200	-.120	.350	.919	1	.338
[Subject=12.00]	-.004	.0890	-.178	.171	.002	1	.968
[Subject=13.00]	-.029	.1786	-.379	.321	.027	1	.869
[Subject=14.00]	0[a]	.	.	.	.	.	.
[TouchEvent=ba; 1]	-.330	.1689	-.661	.000	3.830	1	.050
[TouchEvent=ba; 2]	.101	.1971	-.285	.487	.264	1	.608
[TouchEvent=ba; 3]	-.375	.2062	-.779	.030	3.300	1	.069
[TouchEvent=bl; 1]	.100	.1567	-.207	.407	.410	1	.522
[TouchEvent=bl; 2]	-.275	.2062	-.679	.130	1.773	1	.183
[TouchEvent=head; 1]	.311	.1285	.059	.562	5.844	1	.016
[TouchEvent=head; 2]	.174	.1407	-.101	.450	1.535	1	.215
[TouchEvent=head; 3]	.013	.1632	-.307	.333	.007	1	.935
[TouchEvent=la; 1]	.060	.1408	-.216	.336	.180	1	.671
[TouchEvent=la; 2]	.143	.1500	-.151	.437	.909	1	.340
[TouchEvent=la; 3]	-.187	.1628	-.506	.132	1.314	1	.252
[TouchEvent=ll; 1]	.027	.1285	-.225	.279	.045	1	.831
[TouchEvent=ll; 2]	-.072	.1394	-.345	.201	.269	1	.604
[TouchEvent=ra; 1]	-.010	.1348	-.274	.255	.005	1	.944
[TouchEvent=ra; 2]	-.194	.1706	-.528	.141	1.290	1	.256
[TouchEvent=ra; 3]	-.007	.2085	-.416	.401	.001	1	.972
[TouchEvent=rl; 1]	.045	.1331	-.216	.306	.113	1	.737
[TouchEvent=rl; 2]	-.001	.1971	-.387	.385	.000	1	.995
[TouchEvent=torso; 1]	-.060	.1444	-.343	.223	.173	1	.677
[TouchEvent=torso; 2]	0[a]	.	.	.	.	.	.
(Scale)	.025[b]	.0040	.018	.034			

Dependable Variable: Rate per Minute;
Model: (Intercept), Participant, TouchType
a. Set to zero because this parameter is redundant
b. Maximum Likelihood estimate

participant variations. As shown by statistical results as well as plots presented, the touch rate per minute varies at all factor levels (participant, touch type or touch intensity).

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This is a true reflection of the captured behaviour and it is in-line with what is confirmed by the literature, i.e., that children with autism are an extremely heterogeneous population and although they share the same core difficulties, each child displays these in an individual way.

This conclusion is also supported by observation analysis of trials where children with autism interacted with the robot in free play context. Figure 10 shows examples of the variety of interaction styles from forceful poking and grabbing (two images on the left) to gentle stroking (image on the right).

In addition, literature suggests that children with autism may demonstrate more interest in parts of objects rather than the object itself as a whole (e.g., wheels on a toy car rather than the car itself) [11]. Sometimes object manipulation is focused on self-stimulatory use of toys rather than exploration of the properties of the object [12].
These behaviours present additional challenges and must be considered when building autonomous robots for cognitive social interaction with children with autism.

V. Conclusion And Future Work

The paper presented a taxonomical classification of tactile interactions of 14 children with autism with the humanoid robot KASPAR. It described the experiments which were designed to observe the tactile interaction of the children with the robot and record the location and type of these interactions. It than presented the statistical analysis results comparing the observed interaction in term of rate per minutes between different users and different type of tactile interaction. The statistical results presented in the paper showed significant differences across touch type intensities and participants. These results support the literature suggesting that children with autism are an extremely heterogeneous population and although they share the same core difficulties, each child displays these in individual ways. The case study examples discussed in the paper highlight the need and possible benefit for future modular play scenarios and adaptive robots that can be flexible in their operation, i.e., capable of autonomous operation and response to interaction but at the same time allow operation via a remote control where a teacher/therapist could work with the child alongside the robot, triggering additional robot behaviors adapted to the individual needs of the children.

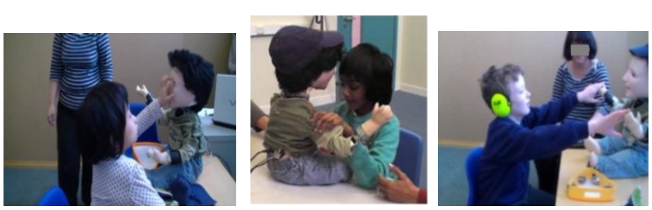

Figure 10. Forceful and gentle interaction of children with KASPAR.

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