

# Detecting and Analysing Children's Play Styles with Autonomous Mobile Robots: A Case Study Comparing Observational Data with Sensor Readings

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**Abstract.** In this paper<sup>1</sup> we demonstrate that infrared sensors located on robots can be easily used to detect and distinguish human contact, in this case with children. We point out how to use the sensors and how the recorded data can be analysed to yield patterns of interaction from the individual child interacting with the robot. The application of infrared sensors to detect and distinguish human contact or behaviour potentially has many uses, not only in adaptation, entertainment (toys) and service robots but also in areas such as rehabilitation or therapy where the recording of movement and interactions is important.

## 1. Introduction

One day robots that serve as personal aids to humans might be abundant. Robots are already increasingly used in assistive technology (which encompasses prosthetic limbs, wheel-chairs etc), surgery and therapy (e.g. [1], [2]) and developing methods that enable easy and effective communication between robots and humans is crucial in this area.

Although robot-human interaction is a growing and intensely studied research area, robot-human interfaces in current systems are still limited. At present most interfaces involve vision or speech recognition (e.g. [3], [4], [5]), or make use of buttons to register touch or communication from people, e.g. *RoboX* [3], *Robota* [6], or Sony's *Aibo* [7]. Touch seems particularly important in work with young children, as recognised in [8] "in the case of very young children, non-verbal communication is more important than verbal communication. Especially, tactile communication is very important." However, most touch sensors used in robotics are based on microswitches which are very different from biological touch or surface sensors (e.g. the skin) that facilitate a variety of more natural touch interactions including stroking, gentle touching etc. A move away from the typical use of microswitches for detecting touch is realized e.g. in the seal robot *Paro* developed for robot assisted activity in hospital or homes for the elderly. In this instance touch to the robot is recognized by air-bag type tactile sensors [9].

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Our work further addresses the question of how robot-human interfaces can be improved using inexpensive, reliable and robust *infrared* (IR) sensors. Infrared sensors do not require heavy sensor processing; they can provide a very natural form of touch without the need to exert force or to press down in a specific area.

Our specific research interest is to use IR sensors to detect individual differences in play and interaction styles of children. Individuality is a distinct feature of humans that also needs to be acknowledged in robot-human interfaces. It has been argued previously that in the context of human-agent interface design “Humans are individuals and they want to be treated as such” [10, p. 609]. Similarly, it was suggested that “socially interactive robots will eventually need to support a wide range of users: different genders, different cultural and social backgrounds, different ages, etc. In many current applications, social robots engage only in short-term interaction (e.g. in museum tours) and can afford to treat all humans in the same manner. But as soon as a robot becomes part of a person’s life, that robot will need to be able to treat him as a distinct individual” [11, p. 146]. A related view has also been expressed in [5].

Obtaining reliable data from the robot’s infrared sensors that enables human contact to be identified and distinguished can lead to the development of a method that will not only assist in developing human-robot methods but also a method to help quantify and study human behavioural characteristics. A similar approach has been pursued in the context of using stationary sensors located in the environment of elderly people’s houses to investigate patterns of human behaviour that could be useful in monitoring the normal routine of the occupants [12].

The infrared sensors in our work are located on a simple, autonomously moving robot in interaction with single children. The robot functions as a toy and registers the child’s proximity and physical handling. We apply cluster analysis on the sensor input data to recognize patterns in the way children interact with the robot and compare the results with an ethological analysis of the play behaviour of the children. In the discussion we outline the limitations of this technique and suggest possible extensions of the application of IR sensors as a valuable channel in human-robot interaction.

## **2. Working Hypothesis**

We argued above that if we are to develop useful believable, socially intelligent autonomous robots that can interact with people more ‘naturally’, then an essential property will be the ability to adapt to individual differences in interaction styles. In this work we hope to produce a robot that can adapt to the highly variable behaviours of children. To design such a robot we first need to know *what features* of human behaviour the robot should adapt to. To approach this matter, we investigate how different types of children play with the same robot. Our working hypothesis for the current work is that characteristic patterns in the behaviour of the different children will be revealed as ‘fingerprints’ of the child-robot interaction in the registration of the IR sensor data. Once we can identify certain patterns of interaction coming from corresponding groups of children then this information could be used to adapt the behaviour of the robot.

## **3. The Robot**

We use a medium sized mobile robot; Pekee (see figure 1), [13]. The robot has an attractive plastic chassis covering a built-in micro controller, equipped with various sensors. It has

two front wheels, each with its own motor, and a castor wheel at the back. Pekee is 400mm long, 255mm wide and 210mm high and weighs approximately 2.9kg. It has a maximum speed of 6km/h although during the experiments the speed did not exceed 3km/h. The mobility of the robot gives the children a variety of ways and positions to interact with it. The robot has a ring of 15 infrared sensors located around its rim, six of these are located to the front, three to each side and three to the rear.

The environment that the robot is exposed to is highly dynamic and unpredictable: ‘anything can happen’ while children interact with the robot (children often treat the robot quite roughly). The software cannot rely on any precise measurements due to the pushing, pulling, picking up etc. This in itself is not a problem, as the robot does not have a traditional goal such as path planning to achieve during interaction with the children. Instead, its sole purpose is to engage the children and encourage interaction.

The robot measures distances to objects in the environment by means of its infrared sensors and changes the wheel direction and speed accordingly so as to clearly avoid them. This allows the robot free movement in uncluttered environments whilst avoiding static, inanimate objects. At the same time, close contact or interaction with moving people is recorded. The robot’s micro-controller updates the distance measurements from each of the infrared sensors approximately 8 times per second.

#### **4. The Experimental Set up**

To carry out the experiment we invited six children to the University of Hertfordshire and tested interactions with the mobile robot under laboratory conditions. Each child was exposed to the robot once. The children were initially asked to sit in a meeting room with their parents whilst doing some drawing and colouring while the experiment was prepared in an adjacent room. The children were then taken to the experimental room one at a time, without their parents (figure 1). This room contains an arena, the ‘pen’ of the robot, of approximately 2m<sup>2</sup> and is enclosed by four shallow wooden walls. For the experiments, the robot was connected to the network with a long flexible lead<sup>2</sup>. The children were asked to step inside the arena, to play with Pekee, or to do whatever they liked. The experiment lasted between 1 and 1½ minutes. Some initial trials were carried out for longer periods but it was found that shy children grew uncomfortable in the unfriendly environment of the robotics laboratory and wanted to leave; for the experiments proper we accordingly shortened the time to around one minute. During the experiment they had complete freedom to do as they pleased, playing with the robot or watching as it moved about; no child completely ignored the robot or pursued an activity that had no regard to it.

#### **5. The Children**

The children were typically developing boys between 5 and 7 years of age. Their general character or personality types ranged from boisterous to shy. We categorised the children prior to conducting the experiment according to three broad psychological groupings. After discussion with the children’s parents and acquiring information from them about the child’s behaviour at school and at home, each child was placed within one of these categories. A child was categorised as type A if i) he was considered naughty at home and

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<sup>2</sup> The lead did not seem to interfere with the children’s play, but the onboard computer has since been updated to no longer require this connection.

school, and ii) he seemed confident, unafraid and active. Children were placed in the type C category if i) they usually did as they were told both at school and at home, ii) they seemed to require the security of being with a familiar adult, and iii) they did not readily explore on their own. A child not falling into either of these categories was classified as type B, Table 1 (below) shows our classification.

**Table 1:** Classification of children into three categories. All names have been changed.

<u>Name</u>	<u>Age</u>	<u>Character</u>	<u>Name</u>	<u>Age</u>	<u>Character</u>	<u>Name</u>	<u>Age</u>	<u>Character</u>
Thomas	6	Type A	Bill	6	Type B	Len	7	Type C
Victor	6	Type A	Chris	6	Type B	Colin	5	Type C

## 6. Data

The data was obtained from two sources: 1) Sensor readings, and 2) direct observation from video footage taken of the children.

### 6.1 Sensor Readings

Sensor readings are stored and eight times per second the current cumulative number of touches or interactions (i.e. close proximity) for each sensor is recorded. Such data ‘profiles’ characterise the interaction pattern of that particular child with the robot for that particular run. Sometimes events were misclassified as interactions when the children forced the robot against the wall. However, even in these cases (which could be detected by matching the video data with the sensor data) the information is still valuable and will be exploited in our future work. *Prima facie* it shows high levels of interaction, and possibly a child that behaved more proactively towards the robot than other children. We are also now studying the different patterns these misclassifications yield and how these can be analysed to gain information about such events as ‘the robot got stuck in a corner’.

### 6.2 Observational Data

From the tapes, the following 21 types of behaviour (i.e. behavioural elements, activities) were identified:

**Table 2:** Behaviours scored from the video tapes.

Crawl	Child is on his hands and knees whilst moving	CR
Knees	Child is on his knees	KN
Stand up	Child is in upright position	STAN
Lie on floor	Child’s back or stomach is in contact with the floor	LFL
Manipulate	Child uses hands to control the robot via its sensors	MAN
Follow	Child appears to move so as to keep themselves at the same distance from the robot	FOL
Step around	Child moves himself (whilst standing) around the robot keeping the same proximity	St_AR
Move/Back Away	Child moves away from the robot	MV
Approach	Child moves towards the robot in a deliberate manner	APP
Touch Robot	Child makes contact with robot using hand	TCHRO
Stroke/Pat	Child uses hand to stroke or pat the robot	PAT
Touch Tail	Child uses hand to touch the robot’s tail	TCHTA
Pickup	Child lifts the robot	PUP
Jump/Stamp	Child is in upright position, using feet to either Jump or (using one foot) to Stamp	JUM
Look at Person	Child’s eye gaze is directed towards another person	LPER
Talk to Robot	Child uses speech to make reference to the robot	TKRO

Talk to Person	Child uses speech to make reference to another person	TKPER
Watch/look at Robot	Child looks at robot as a whole and is not engaged in any other behaviour	WTCHRO
Show interest in Front	Child's attention is focused on the front of the robot	INFR
Show interest in Back	Child's attention is focused on the back of the robot	INBK
Walking in Front	Child walks in front of the robot so as make the front sensors react	WKIN_FRT

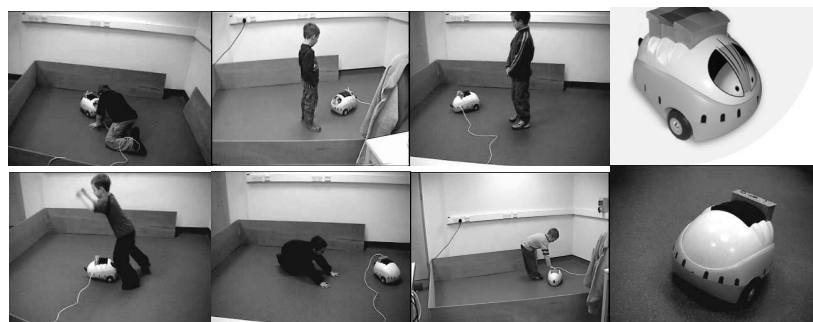
The data collection technique was based on an established methodology e.g. used in [14], [15], [16]. While viewing the videotapes, the behavioural elements (defined above) were recorded on a protocol sheet in the sequence in which they occurred. A statistical analysis was performed on the accumulative count of the activities (i.e. on how many times each child performed each of the 21 defined behaviours).

## 7. Data Analysis

Using the sensor data, we investigated two questions: 1) Can information from the sensor readings be used to classify the children into the same broad psychological groups that they had previously been assigned to? and 2) Can the sensors be grouped based on their stimulation by the subjects (i.e. are certain sensors similar to others because they are activated more often by the same children)? These questions were addressed by performing a cluster analysis on a matrix containing the children's profiles, using Euclidian distance as a measure for the degree of similarity among the profiles. In cluster analysis, nearest neighbours (the pairs of profiles with the smallest Euclidean distance) are brought together in initial clusters. In turn, these are fused into larger ones by a linkage algorithm. We chose Ward's Average as the linkage algorithm: it combines clusters into a super cluster with minimal variance. All cluster analyses were performed in Statistica (v6) [17]. As we wanted to investigate how the children played with the robot regardless of their overall activity frequency (certain children were much more active than others), we logarithmically transformed the data prior to the analysis. Firstly, the children (rows) were clustered over the sensors (columns). This showed which children were similar in terms of sensor activation patterns. Secondly, using the transpose (columns and rows exchanged) matrix, we clustered sensors over children: this showed which sensors on the robot were similarly activated by the children.

## 8. Results

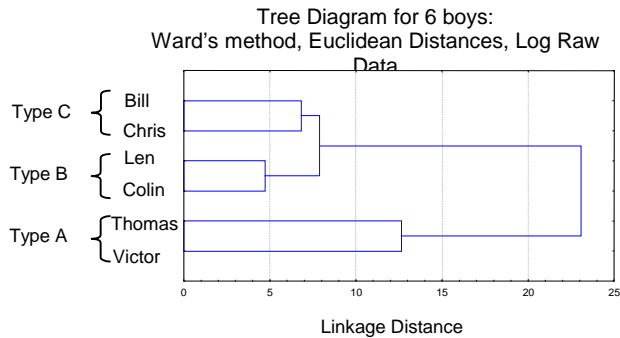
Overall the children showed a variety of different behaviours when playing with Pekee, and all appeared to enjoy the experience. Behaviour ranged from cautious and wary, to very confident or rough. Below we can see some examples of different styles of play.



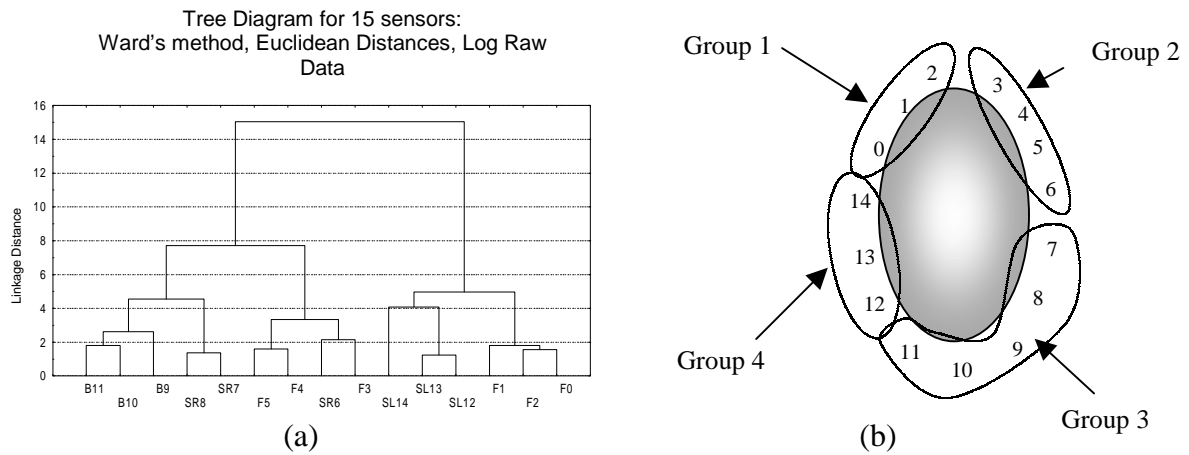
**Figure 1:** Pictures showing the arena and different styles of play.

### 8.1 Sensor Readings

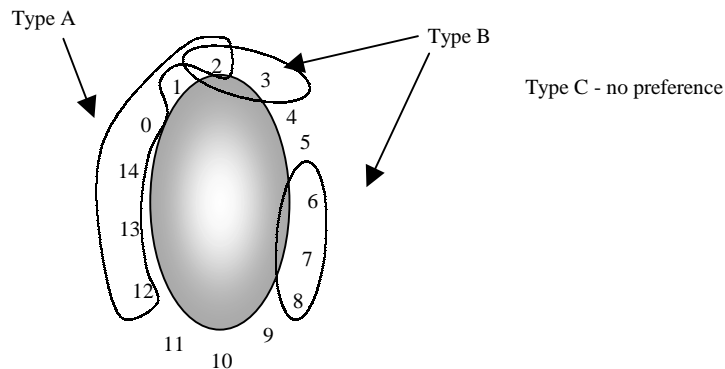
The cluster analysis of the sensor data showed some interesting results. There were indeed patterns in the activation of the sensors: the children were grouped into clusters that corresponded to the prior psychological classification (figure 2). This indicates that children can be classified into personality types on the basis of the sensor regions they activate.



**Figure 2:** Dendrogram showing result of clustering of children over sensors. Boys that have similar profiles i.e. similar frequencies by which they activated certain sensors are grouped together.



**Figure 3:** Results of clustering sensors over children. (a) Tree diagram illustrating the clustering of sensors into regions on the robot. (b) Location of the groups of sensors, as identified by the cluster analysis.

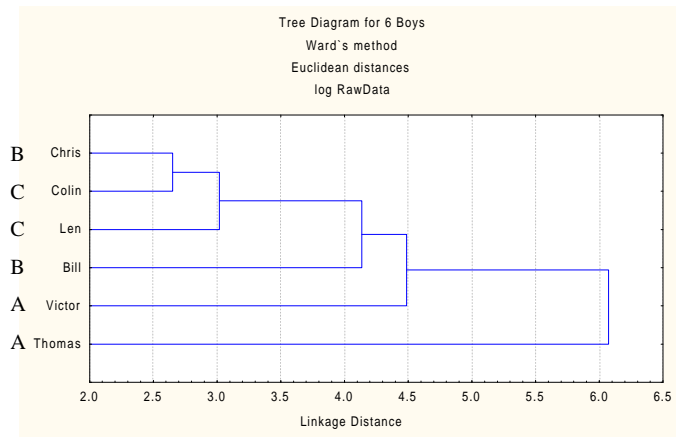


**Figure 4:** The areas activated by the different classes of children are shown. Here, the classification of the children based on the sensor readings is combined with the categorisation of sensors.

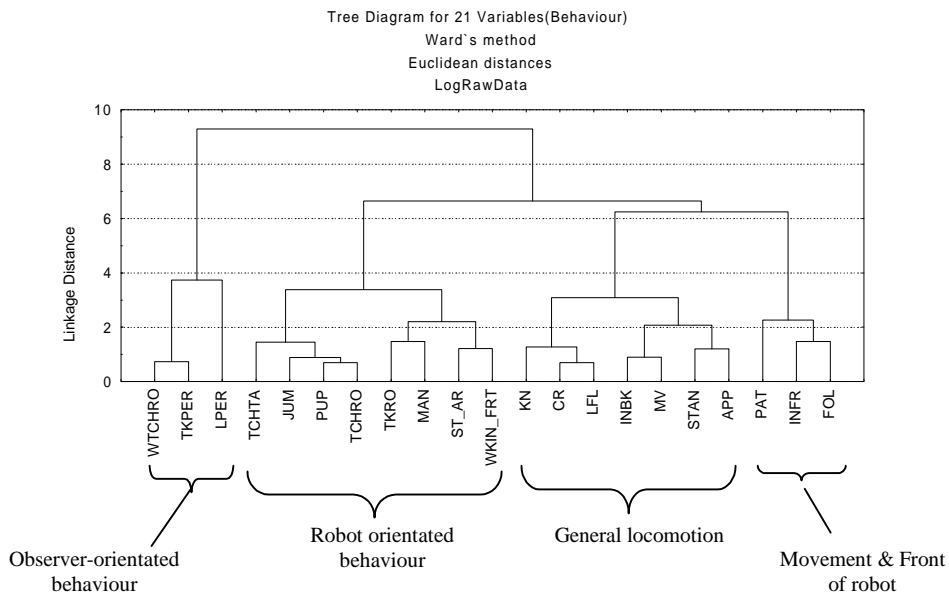
Furthermore, by performing cluster analysis on the transposed matrix, we found that sensors can be divided in groups that correspond to particular physical regions on the robot (figure 3). Finally, we investigated what type of children stimulated which sensor regions of the robot by applying a two-way joining procedure that simultaneously clusters children and sensors. The results of this analysis are shown diagrammatically in figure 4, and can be summarised as follows: Type A children were attracted to the left side of the robot, type C children showed no preference for specific areas of the robots to interact with, and type B children preferred the front and right side of the robot.

### 8.2 Behavioural Observations

It was much harder to recognise clearly distinguished groups within the observational data, i.e. the children did not seem to cluster into clear groups. However, closer analysis does reveal one similarity between the classification of the children and the observations taken from the video: as can be seen from figure 5, type A boys are typically split off from the rest of the children.



**Figure 5:** The figure shows results from clustering boys based on observational data.

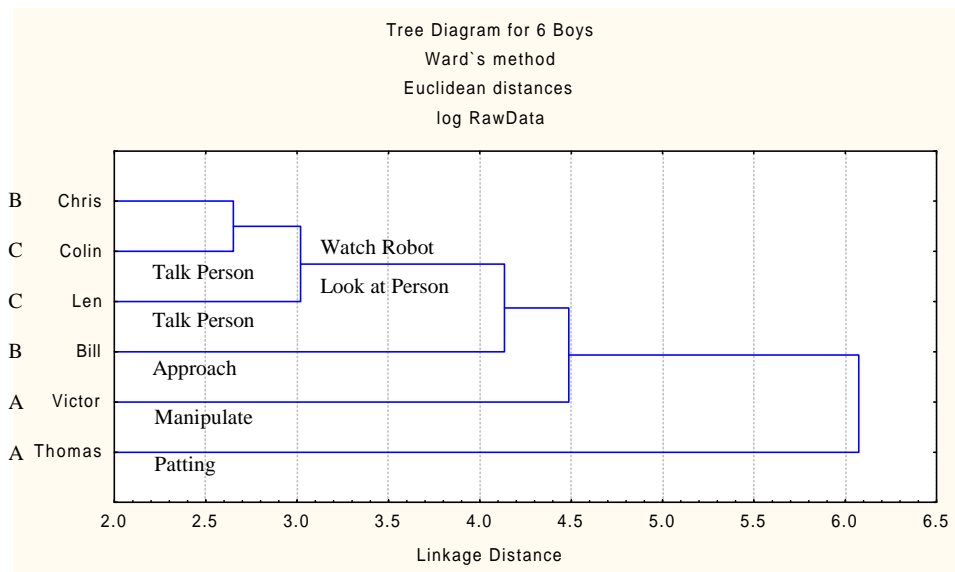


**Figure 6:** Cluster analysis of activities (over subjects). For abbreviations, see Table 2.

When investigating which activities are clustered together based on similar distributions over children, we find the following classes of behaviour (figure 6):

1. A class of observer-oriented behaviour, including the elements TKPER (Talk to Person) and LPER (Look at person). Interestingly, boys that frequently performed these activities, also often looked at the robot. This cluster is split off from the main body of the dendrogram, which can be further divided into:
  2. A class of robot-oriented behaviour (e.g. picking up, touching the robot).
  3. A class of general locomotion activities to which a subset of robot-oriented activities is attached (e.g. kneeling, crawling, approach).

A two-way joining analysis identified the activities that characterise the cluster of children (figure 7). It can be seen that passive children are grouped together on the basis of especially observer orientated behaviours (i.e. talking to the experimenter, looking at the experimenter), whereas the boisterous ones stand out by manipulating and patting.



**Figure 7:** Two-analysis results identifying the activities that cluster children.

## 9. Summary of Results

All the children enjoyed playing with Pekee and were actively engaged with the robot. Our initial working hypothesis was confirmed: we did find that the children had different styles of playing with the robot. This allowed categorisation of the children through information from the robot's sensor readings. Specifically, our findings are:

- The analysis based on the robot's sensor readings supports the prior psychological classification of the children. The analysis of observational data gives less clear results.
- Irrespective of widely differing interaction levels, different types of children exhibited patterns of behaviour which showed similarities within the type group and differences between the groups
- Type A children preferred to interact with the front left side of the robot, type C children had no preference for any one area on the robot, type B children preferred the front right side.

## 10. Discussion and Future Work

Future studies with larger sample sizes will be designed to confirm our findings. However the results presented in this paper show the feasibility to develop a method by which children's behaviour can be categorised based on the robot's infrared sensor readings. The importance of this is threefold. First, it shows that personality type is reflected in a child's behaviour while playing with a robot. Second, in an educational or therapeutic application context, it potentially gives a teacher, parent, or therapist an extra tool to quantify children's behaviour<sup>3</sup>. Third, it is a prerequisite for building robots that adapt to human behaviour. We should emphasise however that the quantitative approach we pursue will be able to point out only certain aspects of a child's behaviour, cf. [16].

A number of issues raised in this study need to be investigated further in future work. Why, for example, did children classified as type A prefer to stay to the front left side of the robot? We should point out that the robot had a bias to turn to the right (due to the implemented obstacle avoidance strategy). A possible explanation might therefore be that these children chased the robot as it moved away to the right, whereas type B children (more passive than type A) stood and waited for the robot to approach them (the right hand side of the robot thus recording a higher incidence of interactions in this case).

Another open question is the importance of the robot's 'eyes', and whether they are on or off during the trials (see figure 1). Four of the children interacted with Pekee with its sticker eyes on, for the other two children the eyes had been taken off. We could not identify any significant effect of this when a statistical analysis was performed. However it is possible that there may have been a greater tendency for the children to stay to the front of the robot when the eyes were on. This again requires further experiments and analysis.

Since submitting this paper we have conducted a new set of trials, with larger sample sizes, and repeated exposure of the children to the robot. The new trials were held at the children's schools in order to provide a more familiar environment. Our detailed findings will be published in a separate publication, but first results seem to confirm that typically developing children quickly get bored by robots, i.e. the novelty effects wears out over time, as shown in [5]. These results support our argument for developing robots that can adapt to different interaction levels, based on personality styles (as described in this paper), and also based on long-term effects. For example, a robot interacting with a shy child could react by slowing down, stopping at times and thus being non-threatening; similarly it could speed up, spin and beep so as to hold the interest of the confident child, or a child that has lost interest in the robot. In this paper we have established a technique that could be a stepping stone towards robots that can, in this way, adapt to human behaviour.

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<sup>3</sup> Compare related work on assistive technology for children, e.g. [18], [19], [20].

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