Exploring the design space of robots: Children’s perspectives

Sarah Woods *

Psychology Department, University of Hertfordshire, College Lane, AL10 9AB Hatfield, Herts, UK

Received 3 March 2005; received in revised form 29 November 2005; accepted 8 May 2006

Available online 27 June 2006

Abstract

Children’s perceptions and evaluations of different robot designs are an important unexplored area within robotics research considering that many robots are specifically designed for children. To examine children’s feelings and attitudes towards robots, a large sample of children (N = 159) evaluated 40 robot images by completing a questionnaire for each image, which enquired about robot appearance, robot personality dimensions and robot emotions. Results showed that depending on a robot’s appearance children clearly distinguished robots in terms of their intentions (i.e. friendly vs. unfriendly), their capability to understand, and their emotional expression. Results of a principal components analysis of the children’s ratings of the robots’ personality attributes revealed two dimensions labelled ‘Behavioural Intention’ and ‘Emotional Expression’. Robots were classified according to their scores on these two dimensions and a content analysis of their appearance was conducted in an attempt to identify salient features of different robot personalities. Children judged human-like robots as aggressive, but human–machine robots as friendly. Results on children’s perceptions of the robots’ behavioural intentions provided tentative empirical support for the Uncanny Valley, hypothesized by (Mori, M., 1970), reflecting a situation where robots are very human-like, but still distinguishable from humans, evoking a feeling of discomfort or repulsion. The paper concludes with a discussion of design implications for robots, and the use of robots in educational contexts.

© 2006 Elsevier B.V. All rights reserved.

Keywords: Robots; Child evaluations; Attitudes; Personality; Emotions; Uncanny valley

* Tel.: + 44 1707 285057; fax: + 44 1707 285073.
E-mail address: s.n.woods@herts.ac.uk

0953-5438/ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.intcom.2006.05.001
1. Introduction

1.1. Overview

Different robot designs are currently studied in the research community, ranging from mechanically looking (e.g. Pioneer\(^1\) robots) to zoomorphic robots (e.g. the AIBO, discussed below), to humanoids such as Asimov\(^2\) or QRIO\(^3\). Moreover, robot design kits are available (e.g. LEGO Mindstorms\(^4\), cf. Druin and Hendler, 2000) that allow researchers to create different robot designs for specific purposes. This paper discusses design considerations for robots with a particular emphasis on child users. How should robots be designed for application areas involving child users, e.g. in educational contexts? To address this question, we conducted a study investigating children’s attitudes and feeling towards different robot designs. We considered children as our ‘experts’ to evaluate different robot designs against a set of criteria such as appearance and liking, and robot behaviour and how this relates to different appearances. Our study considers children’s perceptions and evaluation of robots in terms of physical attributes and personality features, namely behavioural intentions and feelings. To examine children’s attitudes towards robots, a set of 40 robot pictures was generated and a large sample of school children was used to evaluate the robot pictures with a questionnaire that was specially designed for this purpose. The implications of this type of research for the process of designing robots are then discussed followed by a consideration of the possible role of robots in educational settings. An important motivation for this study are the possible implications of this study in relation to the idea of using robots as a novel technique for primary school children to understand, and explore the complexities of aggressive and bullying behaviour in a safe non-threatening environment within schools.\(^5\) In this context, different robots are required to represent different roles, such as ‘bully’, ‘victim’, ‘bystander’, etc. (Wolke et al., 2001). Thus, the robots’ roles within the bullying context will have to be perceived by the children based on the robots’ appearances and behaviour. Results from the present study into children’s attitudes and feelings towards robots might provide some hints towards this goal, and could possibly also inform other applications of robots as well as robot research projects involving child users.

1.2. The diverse use of robots

Robots have been used in a variety of service, educational, entertainment or therapeutic applications, some projects focussing on the robot’s functionalities, others on the social aspects using human–robot interaction studies to evaluate human

---

\(^1\) http://www.activrobots.com/
\(^2\) http://world.honda.com/ASIMO/
\(^3\) http://www.sony.net/SonyInfo/QRIO/
\(^4\) http://mindstorms.lego.com/eng/default.asp
\(^5\) This paper is an extensively revised and expanded version of: S. Woods, K. Dautenhahn, J. Schulz, The design space of social robots: investigating children’s views, in Proceedings of IEEE Int. Workshop on Robots and Human Interactive Communication; RoMan, Japan, 2004.
responses to the appearance and behaviour of robots for different contexts (e.g. Thrun et al., 2000; Falcone et al., 2003; Severinson-Eklundh et al., 2003; Goetz et al., 2003; Kahn et al., 2003). LEGO Mindstorms, for example, provides an educational platform for robots where children use an iconic programming interface, which allows the child to guide the behaviour of robots (Mikhak et al., 2000). Studies have considered the therapeutic use of robots such as aids for the elderly at home performing tasks they are unable to carry out, and providing socialising opportunities for the elderly who may be lonely and unable to leave the house (Monk and Baxter, 2002). Minerva designed by Thrun et al. (2000) has a specialised niche by providing an interactive tour-guide service in a Smithsonian museum. Falcone et al. (2003) considered a broader range of robotic capabilities within the Personal Rover Project that designed a domestic personal robot that could enter a user relationship without the need of a facilitator, or a specially prepared environment. A primary goal of the project was to ensure that the robot became a member of the household rather than a forgotten entity stored away in a cupboard.

Increasingly, research supports the design process by identifying the needs and expectations of the end user-group, be it adults, children, experts, or therapeutic client groups. Although, there are numerous commercialised products including robot characters (e.g. ‘Toy Story’), which appear to be accepted for entertainment purposes, it is still not clear to what extent the physical appearance of a robot and the associated psychological impression it may evoke determine whether it will be accepted by the user. Furthermore, it may be necessary to change the appearance of robots depending on their main function, for example, entertainment or educational purposes. Design considerations need to take a wide range of physical and behavioural features into account, as well as the psychological impact a robot may have on its users.

1.3. Design considerations for robots

Design specifications for robots encompass a wide range of facets including firstly physical aspects such as overall appearance, robot mode of locomotion, gender, facial features, and functionality, and secondly, psychological aspects such as perceived personality attributes and emotions.

1.3.1. Robot appearance

The overall appearance of robots is important as it influences the expectations that humans might have when interacting with a robot. For example, a robot that has an overall animal appearance will be perceived differently to a robot, which has a human-like appearance, and thus may be perceived more as a person rather than a machine. This has important implications for the accompanying behaviour a human user would expect for a machine-like robot compared to a human-like robot. For instance, a human user might expect a human-like robot to have language capabilities and personality characteristics, but might not expect a machine-like robot to have any language communication abilities at all. Robotic appearance will no doubt impact on

---

6 See http://www.pixar.com/featurefilms/ts/
people’s overall perceptions in terms of likeability, whether they would approach the robot and feel comfortable with it, trust, and overall willingness to engage with the robot (Fong and Nourbakhsh, 2003). There is limited research that has directly considered the impact of the design of robot appearance on human–robot interaction. However, the categorisations proposed by Fong and Nourbakhsh (2003) provide a useful starting point for understanding the different dimensions of robot appearance such as anthropomorphism, zoomorphism, and caricatured robots.

Anthropomorphism is the tendency to attribute human characteristics to objects in order to facilitate understanding and interpretation of their actions. Whether robots should be structurally and functionally similar to a human (i.e. android vs. cartoon-like) is still an open research question, although some believe that a robot should not resemble humans too closely cf. (Breazeal, 2002). Minato et al. (2004) developed an android robot that closely resembled human motion and appearance in an attempt to purely study the effects of behaviour in human–robot interactions. They hypothesised that robot appearance and behaviour independently influence human–robot interaction (i.e. an identical behaviour can differently influence human perceptions if the appearances are different). To evaluate their hypothesis, a study of gaze behaviour was carried out, where the eye motion of people during a conversation with an android and human girl were compared and recorded. Results revealed that subject’s gaze at the android, especially its eyes were different from how they gazed at the human girl. Rather than using android robots to evaluate human–robot interactions, an anthropomorphic robot KISMET has been used to explore human–robot interactions in terms of expressive, pre-linguistic and face to face social interactions. However, although Kismet is described as being anthropomorphic, it is different to the android robots as it has cartoon-like exaggerated features such as the eyes, mouth, big articulated ears and large furry eyebrows (Breazeal, 2002), which would not be described as closely human-like. Further, the exaggerated features are still quite mechanistic in appearance (e.g. wires for the mouth). The tendency to attribute human-like characteristics to robots with a human appearance is an important design consideration as this facilitates human–robot interaction (Friedman et al., 2003). Zoomorphic robots are designed to imitate living non-human creatures to allow owner–pet relationships, (e.g. Sony, 2004), and caricatured robots primarily focus on developing exaggerated features such as the eyes or mouth (e.g. Canamero, 2002).

1.3.2. Robot mode of locomotion

Little consideration has been given to robot mode of locomotion and how this is related to its overall appearance. For example, do children perceive robots differently depending on the mode of locomotion, be it wheels, two legs, four or more legs, or tracks?7 It is, however, difficult to isolate the relationship between robot mode of locomotion and overall appearance as they are both closely interlinked. For example, a robot that has two legs is more likely to be perceived by children as having

---

7 The current study did not consider a robot’s quality of movement (e.g. whether it moved smoothly or in a jerky way) as images of robots were used. However, we were able to assess children’s perceptions of a robot’s mode of locomotion.
anthropomorphic qualities compared to a robot, which moves using tracks. A robot using tracks for locomotion would usually be considered as being machine-like and therefore having industrious functions.

1.3.3. Robot gender

Do humans and in particular children assign gender to robots, and does this have an impact on perceptions of robot personality, believability and engagement? Few conclusive results have been published, however, Bumby and Dautenhahn (1999) found that children tended not to attribute gender to robots although they did tend to give the robot human facial features and a humanoid shape, when they were asked to draw pictures of a robot. Some studies have considered adult perceptions of gender relations in HRI trials (Kiesler, 2005), but little is known about whether, or how children attribute gender to robots, and how this may lead to some kind of gender stereotype for robots.

1.3.4. Robot personality

There is no universally accepted definition of ‘personality’ in psychology. However, it is generally agreed that personality comprises a set of characteristics in terms of abilities, beliefs, preferences, dispositions and temperamental features that have consistency across situations and time (Dryer, 1999). The tendency for humans to assign personality qualities to robots may facilitate the user to understand its behaviour, and help to engage with the robot; this may be particularly important for children, cf. (Norman, 1994). Experiments have shown that robot personality should match its design purpose (Druin, 1999). For example, Goetz and Kiesler (2002) carried out two different trials that examined people’s preferences for human-like robots in different job roles, and compliance with a playful or serious robot for different tasks. The matching hypothesis was supported in both trials, as human-like robots were preferred for jobs that require more social skills, and subjects preferred a playful robot for fun tasks, but followed the instructions more closely if the robot behaved in a serious manner. Dryer (1999) and Fong and Nourbakhsh (2003) have provided classification systems, which may assist in the design of agent and robot personality. However, few studies have yet considered whether children’s perceptions of robot personality are related to specific features of the robot’s appearance, for example, having a face.

1.3.5. The design space of robots and the Uncanny Valley

An interesting concept regarding the nature of people’s perceptions of and attitudes towards robots is the ‘Uncanny Valley’, first proposed by the Japanese roboticist Masahiro Mori (1970). Mori’s Uncanny Valley hypothesis postulates that people’s familiarity with robots increases the more human-like the machines become, up to a certain point indicated by a sharp drop (the Uncanny Valley) where the robots evoke a repulsive reaction or unpleasant feeling. Robots at this stage appear very human-like, but due to subtle effects will still be clearly distinguishable from humans. This is also called the ‘Zombie effect’, reflecting our attitude towards moving corpses that very much behave and look like humans, but are distinctively non-human. Similar effects can be observed with how people react to very life-like appearing prostheses: they invoke discomfort if they appear ‘almost’ natural, but
only in certain distinct ways suddenly are identified as artificial. In such cases, the appearance of life-likeness does not necessarily add to the acceptability (Dautenhahn et al., 2002). MacDorman et al. (2005) provide experimental evidence suggesting that robots that fall in the Uncanny Valley elicit in subjects’ an innate fear of death and mortality, which might explain why people often experience discomfort in the company of androids. The Uncanny Valley, however, can be overcome: as Mori suggests, once robots become more and more realistic and similar to humans, approaching a situation where they appear and behave like humans, familiarity is likely to increase again, up to a point where they are indistinguishable from humans. As discussed in MacDorman et al. (2005) and MacDorman (2005) research into how androids, human-like robots, can escape the Uncanny Valley is a scientifically interesting area of research. Fig. 1 shows the Uncanny Valley as proposed by Mori (1970) using different examples for illustrative purposes. Note, that Mori distinguished between robot appearance and behaviour/movement, and hypothesized that movement would have a stronger impact on the robot’s perceived familiarity.

1.4. A psychological approach towards evaluating children’s robot attitudes

The studies by Khan (1998) and Scopelliti et al. (2004) are among the first to have used questionnaires to explore adults’ attitudes towards the design of a domestic robot. Khan (1998) examined adults’ views, preferences and expectations towards an intelligent service robot in a survey, which included questions regarding what people thought robots should look like, how robots could be used for service purposes in the household, and how the robots should behave. The survey results revealed that most participants were positive towards the idea of an intelligent service robot (ISR). The majority of views demonstrated that people want an ISR to be ‘controllable’, and be able to clean the house, wash dishes, do the laundry and other tedious time consuming jobs. In terms
of the preferred appearance for an ISR, subjects did not necessarily want it to be human-like, but wanted a personal, individual design with rounded, colourful body shapes. These findings are also reflected in a study that investigated people’s views towards a robot companion in the home (Dauntenhahn et al., 2005), where a large proportion of participants were in favour of a robot companion and saw the potential role as being an assistant, machine or servant. Few people wanted a robot companion to be a friend and household tasks were preferred to child/animal care tasks. Human-like communication was most desirable for a robot companion, whereas human-like behaviour and appearance were considered important, but less essential. Similarly, Scopelliti et al. (2004) investigated people’s representation of domestic robots across three different generations taking into account gender and educational level, as well as technological capabilities and user expectations. Their results demonstrated that young people scored higher on ‘positive feelings’ (e.g. amusing, dynamic, pleasant, relaxing) towards a domestic robot compared to adults and elderly people. Younger subjects also expressed different representations for a domestic robot compared to elderly subjects, wanting the robot to have humanoid attributes to interact with in leisure situations, rather than as useful devices. Young people did not express any anxiety towards the idea of a domestic robot and would want it to be adaptable and able to learn new tasks. Conversely, elderly people were frightened of the prospect of a robot in the home, and expressed distrust towards the idea. They would not want the robot to be autonomous and wanted it to be pre-programmed in a fixed way that was not able to improve and learn new behaviours. An interesting study by Friedman et al. (2003) and Kahn et al. (2004) was conducted using unstructured play sessions for children and online discussion forums for adults, which demonstrated that the Sony AIBO robotic dog8 was psychologically engaging for both adults and children. For example, children engaged more frequently in exploratory play behaviour, apprehensive behaviour and attempts at reciprocity with the AIBO robot compared to a stuffed toy dog. However, both adults and children rarely attributed moral standing (e.g. responses to the question ‘is it OK to hit AIBO, or leave AIBO alone for a week?’). Another recent research programme has examined people’s negative attitudes toward robot interaction with a humanoid robot called ‘Robovie’9, by using the ‘Negative Attitude for Robots Scale (NARS)’, comprised of a series of 15 statements that subjects are asked to rated using a 5-point Likert scale ranging from disagreement to agreement. (Example items include; ‘I feel anxiety if robots really have their own emotions’, ‘I will feel nervous if I interact with robots’). Results demonstrated that negative attitudes toward human–robot interaction affects communication with the robot, suggesting that people with highly negative attitudes toward robots mentally tend to avoid human–robot interactions (Nomura et al., 2004).

The use of psychological approaches to explore people’s perceptions of robots is beginning to emerge in the literature. However, there are no existing studies to our knowledge that have considered evaluating children’s perceptions and attitudes towards the appearance of different robots in terms of personality and emotion.

---

8 Please refer to http://www.aibo-europe.com/ for full details of the AIBO robotic dog capabilities.
9 Please refer to http://www.irc.atr.jp/~m-shiomi/Robovie/ for full details about the capabilities of Robovie.
characteristics. If engaging and believable robots are to be designed and used within, for example, educational curriculum activities, we believe it is important that children’s views should be assessed in order to allow their input for the future design of robots.

In this particular study, we are examining children’s perceptions and attitudes towards three different types of robots in terms of robot appearance, physical attributes, personality features and emotional characteristics. The three types of robots were generated to represent zoomorphic, anthropomorphic and machine-like robots, and these groups constitute the independent variable of this study. The independent variable robot category groups were motivated by previous reviews that have documented the main robot appearance distinctions (Fong and Nourbakhsh, 2003). The study is exploratory in the sense that we did not have concrete hypotheses or predictions for the direction of the results, as children’s views and attitudes towards robots have been rarely researched. We therefore developed a new questionnaire to evaluate children’s attitudes towards robots within a classroom setting.

Our research questions for the current study are: (1) how do children evaluate different types of robot designs? (2) Depending on the physical characteristics of the robot, how do children evaluate the personality and emotional attributes of the robots? (3) What are the design implications for robots based on children’s perceptions of robots? (4) Do we find empirical support for the Uncanny Valley as proposed by Masahiro Mori?

2. Method

2.1. Design

This study used children as expert judges to evaluate altogether 40 robot images differing distinctly in their physical appearance (i.e. facial expression, mode of locomotion, colour, shape). The 40 robot pictures were generated as variations of three design prototypes of appearance: human–machine, animal–machine and machine-like. To check the reliability of this categorization, three researchers were asked to independently allocate each of the 40 robot pictures into one of the three prototypes. The inter-rater agreement was assessed using Cohen’s kappa resulting in high values for any of the three pairs of raters ($kappa_{12} = 81, p < 0.001, kappa_{13} = 89, p < 0.001, kappa_{23} = 76, p < 0.001$). Consequentially, the three robot prototypes were used as the independent variable in our study, and the dependent variables to be evaluated by the children were the robots’ personality and emotion traits (friendly, aggressive, angry, shy, bossy, happy, sad, frightened).

2.2. Participants

One hundred and fifty nine children [(male: $N$: 82 (52%) and girls: $N$: 77 (48%)] aged 9–11 (years 5 and 6) participated in the study ($M$ age = 10.19 years, SD: 0.55). Four schools based in Hertfordshire, UK, participated in the research with an equal spread of low, middle and upper socioeconomic status. Each child’s reading ability was verified before they participated in the study. There was 100% consent from parents for their child to take part in the research.
2.3. Instruments

2.3.1. Robot pictures and generation of the independent variables (IVs)

A number of different internet sources were consulted to compile the robot images portfolio resulting in a total of 85 different robot images being identified for possible inclusion in the study. The majority of the images sourced from the Internet were edited to ensure that the images were presented to the children in a standardised format. Adobe Photoshop version 7.0 was used to edit the robot images in terms of removing confounding variables such as background colour and other objects in the image. The images were edited to provide a neutral background as we did not want them to refer to specific contexts as this would have clouded children’s judgements when rating the robots. Each image was also re-scaled to guarantee that differences in size did not influence children’s perceptions of the different images. Context is an important issue, but for the purposes of this part of the study, it was essential that the context was neutral to ensure that the perceptions were based solely on the robots. Three researchers in collaboration devised a coding schedule to categorise the robots according to the following design categories: (a) mode of locomotion, (b) shape, (c) overall appearance (e.g. car, human, machine, animal), (d) facial features, (e) gender, (f) functionality (e.g. toy, friend, machine). Once the coding scheme had been designed the robots were sorted by the lead investigator into the three groups representing the independent variable. Of the 85 pictures 35 robot images were excluded from the study due to unclear images, and incomplete pictures (e.g. robot leg missing from image). The remaining 40 pictures were then divided into eight sets containing five robot images. Each set contained at least one example of a human–machine, animal–machine and machine–robot \(^{10}\). It was also important to include different robot characteristics in this study (different types of locomotion, shapes, overall robot appearance, facial features and gender) that were identified during phase one of the study.

2.3.2. Robot pictures questionnaire and dependent variables: ‘What do you think?’\(^{11}\)

A questionnaire was designed to enquire about children’s perceptions of different robot attributes. Section one contained eight questions about robot appearance (e.g. what does this robot use to move around? What shape is the robot’s body?). Section two asked four questions about robot personality, rated according to a 5-point Likert scale and included questions about friendliness, aggressiveness, whether the robot appeared shy, and whether the robot appeared bossy. An example question was: do you think this robot is (or could be) aggressive? Section three of the questionnaire concerned five questions about robot feelings and emotions where children had to indicate levels of happiness, sadness, anger and fright for each robot along the 5-point Likert scale. Before beginning the study, the questionnaire was sent to two teachers from different schools to check that the language and style format was suitable for children aged 9–11 years. The questionnaire was approved by the teachers and a few minor changes in the language were made.

\(^{10}\) The complete set of photos is available from the first author on request.

\(^{11}\) The robot pictures questionnaire is available from the first author on request.
Results from Pearson correlations revealed children had good comprehension of the robot picture questionnaire. For example, a significant negative correlation was found between child ratings of robot friendliness and robot aggressiveness ($r = -0.83$, $p = 0.01$) indicating that children understood that these two feature are more or less mutually exclusive.

2.4. Procedure

Twenty four groups of between 4 and 8 children were seated in such a way that they would be able to answer the questionnaires confidentially without distraction from other children. A complete set of all five robot images (1 of 8 categories A–E) were distributed to each child simultaneously. This decision was taken to allow the child to make comparative decisions based on the different robot images for their questionnaire responses. Each child completed five copies of the robot pictures questionnaire for each of the images. The robot images were counterbalanced within each robot group, to ensure that children did not complete the first questionnaire for the same robot image each time, etc. The presentation of the robot categories (categories A–E) were also counterbalanced as depending on the size of the group of children, not all robot categories were used (i.e. only robot categories A–D were used for a group of four children). Each of the forty robot images were rated by the children between 19 and 23 times. Children took between 5 and 7 min to complete each questionnaire, resulting in a time of approximately 25–30 min to complete all five questionnaires.

2.5. Statistical analysis

Statistical data analysis was conducted using two different data sets. One contained the total number of children’s questionnaires to the 40 robot pictures ($N = 795$). The other data set ($N = 40$) contained aggregated data of children’s answers (i.e. means and proportions) for each of the 40 robot pictures as a result of aggregating the individual questionnaires pertaining to each robot ($n$: 19–23). ANOVA was conducted on the aggregated data set to examine possible mean differences between the three robot prototypes as independent variables and the proportion of children who thought a robot had feelings and could understand them as dependent variables. Cross-tabulation analysis involving all 40 robots and the frequencies of yes/no answers in relation to the questions on robots ‘feelings’ and ‘understanding’ were also carried out to identify specific robots deviating from the overall percentage. A principal component analysis (PCA) involving the 40 robots was carried out to investigate the underlying dimensions of the correlations of the eight personality characteristics, on which the robots were rated by the children. Each variable in this analysis represented mean scores resulting from aggregation across the group of children who rated the robots (Stevens, 2002). The two dimensions that were found were translated into two new scales (i.e. behavioural intention (BI) and emotional expression (EE)), which were used to classify the robots in terms of their appearance.
3. Results

3.1. Children’s evaluations of robot feelings

Children were asked to indicate for each of the robot images they rated if they believed that the robot was capable of having feelings or not (yes/no), and these evaluations were aggregated into average percentages for each of the robots.

A one-way ANOVA was calculated between the three researcher prototypes of the overall robot appearance (human–machine, animal–machine, machine-like), and children’s evaluations of whether particular robots were more likely to have feelings or not. Significant mean differences were found between the three robot prototypes ($F(2,39) = 43.44, p < 0.001$), explaining 69% of the variance (adjusted $R^2 = 0.685$) in the proportion of having feelings. Games–Howell post-hoc comparisons revealed significant differences between each of the three robot appearance prototypes (human–machine $M = 78.95$ vs. animal machine $M = 69.77$, $p < 0.03$, human–machine vs. machine $M = 46.52$, $p < 0.001$ and animal–machine vs. machine, $p < 0.001$). Mean differences indicated that children evaluated machine-like robots as being significantly less likely to have feelings compared to animal–machine, and in particular human–machine robots.

A deeper exploration of the children’s evaluations was then carried out to determine the characteristics of those robots that children rated as having emotions vs. those less likely to have emotions. A cross-tabulation analysis between children’s evaluations of whether the robots had feelings or not, and the 40 robot images revealed a highly significant association ($X^2(39,795) = 96.72, p < 0.001$) (contingency coefficient = 0.42, $p < 0.001$), indicating that children’s opinions of whether a particular robot had feelings or not was associated with the overall appearance of the robot. To identify robots that deviated significantly from the overall percentage, a residual analysis was conducted on the basis of those robots that had an adjusted residual of $\pm 2.0$ or more. Table 1 illustrates that 25% of robots (10/40) were rated by children at a proportion more or less than expected for having robot feelings, compared to all other robots. The two robots that were rated by children at a higher proportion for having robot feelings both had exaggerated, large eyes, and a humanoid body shape. In contrast, those robots that were evaluated by the children at a lower proportion for having robot feelings, were predominantly characterised as being machine-like, had wheels or tracks, and did not have facial features. This suggests that children perceived the appearance of those robots they thought were capable of having feelings as more human-like whereas those robots they thought had no feelings were perceived as more machine-like.

3.2. Children’s evaluations of whether a robot would understand them

Children were asked to indicate for each of the robot images they rated if they believed that the robot would understand them if they spoke to it (yes/no), and these evaluations were aggregated into average percentages for each of the robots. Children’s evaluations of whether they believed a robot would understand them if they spoke to it in relation to the researcher robot appearance prototypes (human–machine, animal–machine and machine-like) were analysed using a one-way
### Table 1
Children's evaluations of robot feelings

<table>
<thead>
<tr>
<th>Robots evaluated by children as having feelings at a proportion more than expected</th>
<th>Percent of children stating that robot had feelings and adjusted residual value (values ≥ 2.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>85.7 (2.2)</td>
</tr>
<tr>
<td></td>
<td>85.0 (2.0)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Robots evaluated by children as not having feelings at a proportion more than expected</th>
<th>Percent of children stating that robot had feelings and adjusted residual value (values = &lt; −2.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>33.3 (−2.9)</td>
</tr>
<tr>
<td></td>
<td>35.0 (−2.7)</td>
</tr>
<tr>
<td></td>
<td>39.1 (−2.4)</td>
</tr>
<tr>
<td></td>
<td>39.1 (−2.4)</td>
</tr>
<tr>
<td></td>
<td>36.8 (−2.4)</td>
</tr>
<tr>
<td></td>
<td>36.8 (−2.4)</td>
</tr>
<tr>
<td></td>
<td>38.1 (−2.4)</td>
</tr>
<tr>
<td></td>
<td>38.9 (−2.2)</td>
</tr>
</tbody>
</table>
ANOVA. Significant mean differences between the three robot prototypes were found ($F(2,39) = 44.76, p < 0.001$), explaining 69% of the variance (adjusted $R^2 = 0.692$) in the proportion of being able to understand human communication. This suggests that children evaluated the ability of a robot to understand them if they spoke to it depending on its appearance. Games–Howell post-hoc comparisons revealed significant differences between human–machine and animal–machine robots, human–machine and machine-like robots, and animal–machine and machine-like robots (human–machine $M = 78.11$ vs. animal–machine $M = 45.90$, $p < 0.001$; human–machine vs. machine-like $M = 31.23$, $p < 0.001$; animal–machine vs. machine-like, $p = 0.06$). A slightly different pattern of findings emerged compared to children’s evaluations of whether a robot had feelings or not. For robot understandability, children clearly distinguished that human–machine robots would be more likely to be able to understand them if they spoke to it compared to animal–machine, and pure machine-like robots.

A further exploration of the robots that children evaluated as being able/unable to understand them if they spoke to it, was carried out to determine distinguishing design aspects. The association between children’s evaluations of whether a robot would understand them if they spoke to it (i.e. yes vs. no), and the 40 robot images was investigated by a cross-table analysis and revealed a significant result ($X^2(39,795) = 169.75$, $p < 0.001$) (contingency coefficient $= 0.42$, $p < 0.001$). This indicated that the percentages for the answer ‘yes’, the robot was able to understand them, differed considerably between the robot images. To identify robots that deviated significantly from the overall percentage, a residual analysis was conducted on the basis of those robots that had an adjusted residual of ±2.5 or more. Table 2 illustrates that 30% (12/40) of the robots were evaluated by children at a proportion higher than expected for being able/unable to understand them if they spoke to the robot. Two groups were clearly discernable; the robots that were rated as being able to understand the children, all had humanoid features in terms of legs, arms and facial features, with the exception of one of the robots. The robot that did not fall within this classification was the Sony AIBO dog robot, which children may have come into previous contact with, and does have some language communication abilities. In contrast, the robots evaluated by children as not being able to understand them were all machine-like in appearance, and in the majority of cases did not have legs or arms, or facial features.

Children in the current study clearly distinguished between those robots that they believed had feelings vs. those that did not have feelings, and those that would be able to understand them vs. those that would not be able to understand them. Therefore, we expected that there would be a significant association between the percentage of children who believed that a robot would understand them and the percentage that believed a robot had feelings. Results of a Pearson correlation confirmed this, as a strong correlation between these two mental attributes was revealed ($r(40) = .78$, $p < 0.001$).

3.3. Robot personality dimensions

Each robot was rated by a group of children ($n$: 19–23) in terms of friendliness, aggressiveness, shyness, bossiness, happiness, sadness, anger and fright on a 5-point
Table 2
Children’s evaluations of whether a robot would understand the child (N: 795)

<table>
<thead>
<tr>
<th>Robots evaluated by children as being able to understand them if they spoke to the robot at a proportion more than expected</th>
<th>% children stating that robot would be able to understand them and adjusted residual value (values ≥ 2.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>89.5 (3.5)</td>
</tr>
<tr>
<td></td>
<td>85.7 (3.3)</td>
</tr>
<tr>
<td></td>
<td>85.0 (3.2)</td>
</tr>
<tr>
<td></td>
<td>81.0 (2.9)</td>
</tr>
<tr>
<td></td>
<td>78.9 (2.6)</td>
</tr>
<tr>
<td></td>
<td>77.3 (2.6)</td>
</tr>
</tbody>
</table>

Robots evaluated by children as being able to understand them if they spoke to the robot at a proportion less than expected % children stating that robot would be able to understand them and adjusted residual value (values ≥ −2.5) (% children stating that robot would be able to understand them and adjusted residual value (values ≥ −2.5))

| | 10.5 (−3.5) |
| | 15.0 (−3.2) |
Likert scale, and these ratings were then aggregated across the groups resulting in eight mean scores for each robot.

The correlations between the mean scores were analysed by a Principal Components Analysis (PCA) to reveal the underlying dimensions of these personality attributes. Two factors emerged, which accounted for 83% of the total variance. A varimax rotation was carried out to facilitate the interpretation of the factor structure, and the resulting factor loadings are shown in Table 3. Factor I was bipolar and accounted for 62% of the variance with six high loadings in excess of 0.80.

The positive pole was defined by friendliness, shyness, and fright, and the negative pole by bossiness, aggressiveness and anger. This factor seems to represent perceived positive or negative robotic behaviour with intent and was therefore labelled ‘Behavioural Intention’ (BI). Factor II was also bipolar and accounted for 20% of the variance.

Table 3
Factor loadings after varimax rotation (N: 40)

<table>
<thead>
<tr>
<th>Item</th>
<th>Factor 1 (behavioural intention)</th>
<th>Factor 2 (emotional expression)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friendly</td>
<td>0.85</td>
<td>−0.24</td>
</tr>
<tr>
<td>Aggressive</td>
<td>−0.93</td>
<td>0.15</td>
</tr>
<tr>
<td>Shy</td>
<td>0.84</td>
<td>−0.14</td>
</tr>
<tr>
<td>Bossy</td>
<td>−0.88</td>
<td>0.00</td>
</tr>
<tr>
<td>Happy</td>
<td>0.49</td>
<td>−0.80</td>
</tr>
<tr>
<td>Sad</td>
<td>0.13</td>
<td>0.95</td>
</tr>
<tr>
<td>Anger</td>
<td>−0.95</td>
<td>0.16</td>
</tr>
<tr>
<td>Fright</td>
<td>0.80</td>
<td>0.31</td>
</tr>
</tbody>
</table>

Eigenvalue = 4.99  
Variance explained = 62.41%

Eigenvalue = 1.63  
Variance explained = 20.43%
It opposed an Roboti physica r hap (beyond having as being c of had cut-o the 90 c appearance, (see was roboti Scatterplo loading cut-o The behavioura in and (EE) exp apareara 6, defined associ e charact (see wa the of no for loading EE, children with 18 illustration and behavioural intention for each robot id (N: 40).


Two factor based scales were then computed for ‘Behavioural Intention’ and ‘Emotional Expression’ taking only the salient loadings (≥ 0.80) into account. Both scales were then z-standardized to allow direct comparisons.

3.4. Robot appearance and personality traits

To identify potential distinguishing physical robotic characteristics in relation to BI and EE, a scatterplot of the Z-scores (Fig. 2) for the 40 robots was produced. A cut-off point (indicated by dashed line) of ±0.5 standard deviations was used for BI and a slightly less stringent cut-off point of ±0.4 was used for EE to examine the most extreme robots.

Fig. 2 illustrates those robots that fell beyond the defined cut-off points. The majority of robot images rated by children had similar mean Z-scores for emotional expression (EE) resulting in indistinguishable physical robot characteristics. However, robots 6, 102 and 90 were rated by the children as being the happiest, whilst robots 25, 36, 97, and 96, were rated as the saddest robots, (see Table 4 for robot images). In contrast, for behavioural intention (BI) there were more robots that fell within the defined cut-off areas, (see Table 5 for images).

Table 6 illustrates the robots that fell within the cut-off points (±0.4/0.5) for EE and BI and distinguishable physical characteristics. Robotic physical characteristics associated with sadness were having two legs, a rectangular/square body shape, having a human-like appearance, facial features and male gender. Physical robotic attributes for happiness were harder to distinguish. However, children’s ratings of happiness were associated with an animal or human-like appearance, facial features, and male or female gender as opposed to having no gender. Robots rated as having

![Fig. 2. Scatterplot of the mean Z-scores for emotional expression and behavioural intention for each robot id (N: 40).](image-url)
negative BI were associated with having legs or wheels, having a rectangular body shape, having a machine-like appearance and a male gender. Facial features were indistinguishable for negative BI. Robots rated as having positive BI were distinguished as having legs, facial features and a male or female gender. Robot appearance was indistinguishable for positive BI. Robot images that fell within the specified cut-off points revealed that those robots with positive BI had a cartoon-like appearance, exaggerated facial features in particular the eyes, used legs or wheels as the form of locomotion and were brightly coloured.

In contrast, robots with negative BI had a realistic-like appearance, used legs or wheels, had less exaggerated facial features or faces, which were partially camouflaged, and had dull colours such as grey, brown and black. Robots rated as being happy (positive emotion) had a cartoon-like appearance, had legs, and had exaggerated facial features (such as large round eyes, large smiley mouth). Conversely, robots rated as being sad (negative emotion), with the exception of one robot had humanoid features such as legs and arms, a head and facial features (eyes, nose, mouth). The overall appearance was also quite realistic, some had enclosed heads

<table>
<thead>
<tr>
<th>Table 4</th>
<th>The happiest and saddest robots as rated by children</th>
</tr>
</thead>
<tbody>
<tr>
<td>Happy robots</td>
<td><img src="image1" alt="Happy robots" /> <img src="image2" alt="Happy robots" /> <img src="image3" alt="Happy robots" /> <img src="image4" alt="Happy robots" /></td>
</tr>
<tr>
<td>Sad robots</td>
<td><img src="image5" alt="Sad robots" /> <img src="image6" alt="Sad robots" /> <img src="image7" alt="Sad robots" /> <img src="image8" alt="Sad robots" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Robots with highest levels of positive and negative behavioural intention according to child ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive behavioural intention</td>
<td><img src="image9" alt="Positive behavioural intention" /> <img src="image10" alt="Positive behavioural intention" /> <img src="image11" alt="Positive behavioural intention" /> <img src="image12" alt="Positive behavioural intention" /></td>
</tr>
<tr>
<td>Negative behavioural intention</td>
<td><img src="image13" alt="Negative behavioural intention" /> <img src="image14" alt="Negative behavioural intention" /> <img src="image15" alt="Negative behavioural intention" /> <img src="image16" alt="Negative behavioural intention" /></td>
</tr>
</tbody>
</table>
Table 6
An overview of the physical robot characteristics associated with positive and negative emotions and positive and negative behaviours

<table>
<thead>
<tr>
<th>Mode of locomotion</th>
<th>Emotion sadness</th>
<th>Emotion happy</th>
<th>−ive B.I (e.g. aggression)</th>
<th>+ive B.I (e.g. friendly)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two legs</td>
<td>▲</td>
<td>Indistinguishable</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Wheels</td>
<td>–</td>
<td>▲</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Tracks</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Four legs</td>
<td>–</td>
<td>–</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Body shape</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circ/oval</td>
<td>–</td>
<td>Indistinguishable</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Rect/sq</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Looks like</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animal</td>
<td>–</td>
<td>▲</td>
<td>–</td>
<td>▲</td>
</tr>
<tr>
<td>Human</td>
<td>▲</td>
<td>▲</td>
<td>–</td>
<td>▲</td>
</tr>
<tr>
<td>Machine</td>
<td>–</td>
<td>–</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Facial features</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Face</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>No face</td>
<td>–</td>
<td>–</td>
<td>▲</td>
<td>–</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Female</td>
<td>–</td>
<td>▲</td>
<td>–</td>
<td>▲</td>
</tr>
<tr>
<td>No gender</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

▲. Tendency for children to rate robots as having this physical attribute for this particular emotional or behavioural category. ‘−’, robot does not have this physical attribute. ‘Indistinguishable’ signifies that there was no identifiable trend for particular robot characteristics in terms of emotions and behaviours. For example, for happy emotion, there was no pattern in data for mode of location.

(i.e. head concealed behind a capsule or helmet), and in some cases the eyes and mouth were down-turned and not exaggerated. Table 7 summarises these observations, in that positive BI and EE was associated with more cartoon-like appearances with exaggerated features, whereas negative BI and EE were associated with more realistic features.

3.5. A contribution to the evaluation of Mori’s ‘Uncanny Valley’

Mori speculated that the emotional evaluation of a robot is systematically related to how its appearance is perceived in terms of its degree of resemblance with humans. If there was such a systematic relation between similarity and familiarity it is important to know whether it would hold universally, for example, across different age groups. We therefore investigated to what extent children agreed with the classification of adult researchers who grouped the robots into the three classes (i.e. human–machine, animal–machine, machine-like) used in this study as the independent variable. Table 8 shows the mean percentages of children’s ratings for each type
of robot appearance. It is obvious from Table 8 that there is a considerable degree of agreement between the researchers and the children’s views as the highest percentage for each prototype falls on the main diagonal. Overall children distinguished very clearly between human-like and animal-like robots as indicated by the very small off-diagonal percentages for these two robot prototypes. They also agreed largely (i.e. 92%) with the researcher classification as to machine-like robots. They deviated, however, somewhat from the researchers view regarding human–machine and animal–machine robots; children rated some of those as machines. This could suggest that when children classify, they do so on the basis of more prototypical cognitive categories (i.e. pure animal features). Adults, on the other hand, might accept some degree of fuzziness in the cognitive representation of prototypes they use for classification.

Table 8 illustrates that there was high mean percentage agreement among children’s evaluations of the overall robot appearance, and the researcher robot appearance prototypes. As high agreement was demonstrated between the researcher robot appearance prototypes and children’s evaluations of the overall robot appearance (Table 8), three new variables were calculated based on the percentage agreement between children’s responses for robot appearance (animal, machine, human). A 3D scatterplot (Fig. 3) was then produced to explore the systematic association between robot appearance by plotting the variables human-like, machine-like and animal-like.

Fig. 3 illustrates, for example, that children rated robot id number 3 as having 100% animal-like features, robot id 28 had 100% pure machine-like features, robot id number 102 had 80% human-like and 20% machine-like and robot id 97 had 50% human-like features and 50% machine-like features (see Table 9 for images). It is also notable from Fig. 3 that there were a number of robots that fell in between the variables human-like, machine-like and animal-like. This suggests that for children a five category classification system of the robots might be more appropriate

Table 7
Robot appearance and the association with positive or negative behavioural intention and emotions

<table>
<thead>
<tr>
<th>Behavioural intention (BI)</th>
<th>Cartoon robot appearance</th>
<th>Realistic robot appearance&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emotion (EE)</td>
<td>Positive features (e.g. friendliness)</td>
<td>Negative (e.g. aggressiveness)</td>
</tr>
<tr>
<td></td>
<td>Positive (e.g. happiness)</td>
<td>Negative (e.g. sadness)</td>
</tr>
</tbody>
</table>

<sup>a</sup> In Table 7, we have used the term ‘realistic’ appearance. Realistic in this instance does not mean that the robot looked exactly human-like (i.e. may not have had full set of facial features), but had a clear human-like/animal-like shape, or overall appearance.

Table 8
Mean percentage agreement between children’s evaluations of overall robot appearance and the researcher robot appearance prototypes

<table>
<thead>
<tr>
<th>Researcher robot appearance prototypes</th>
<th>Children’s evaluations of the overall robot appearance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Human-like</td>
<td>Animal-like</td>
</tr>
<tr>
<td>Human–machine</td>
<td>72.54</td>
<td>2.16</td>
</tr>
<tr>
<td>Animal–machine</td>
<td>4.52</td>
<td>60.77</td>
</tr>
<tr>
<td>Machine-like</td>
<td>1.58</td>
<td>6.79</td>
</tr>
</tbody>
</table>
consisting of three ‘pure categories’ (i.e. animal-like, human-like, machine-like) as well as two ‘mixed categories’ (i.e. animal–machine like and human–machine like). Using this modified classification of the robots based on children’s ratings we calculated the means of emotional expression and behavioural intention, and ranked the five groups of robots along these two dimensions (Table 10).

The rankings shown in Table 10 illustrate that human-like robots had the highest mean negative BI scores suggesting that children perceived these robots as the most aggressive and bossy, and a combination of animal–machine or human–machine like as the most friendly and shy. How do these results compare to the Uncanny Valley as discussed in Section 1.3.5? According to Mori’s theoretical stance when plotting the emotional response against similarity to human appearance and movement, the curve is not a simple, steady upward trend. Instead there is a peak before a completely human-like ‘look’, followed by a dramatic decline into negative responses (discomfort), before recovering to a second peak where human resemblance is complete. 

Fig. 4 illustrates children’s perception of robot appearance and their judgements of a robot’s BI from the current study, in relation to the theoretically proposed Uncanny Valley. According to our interpretation, children’s judgements provide tentative support for the Uncanny Valley; as a robot increases in humanness there is point when the robot is not 100% similar to humans and the balance between humanness and robotness becomes uncomfortable. For example, robots rated by the children as being human–machine like in appearance (see Table 9 for robot images) had the highest positive scores for BI and fall mid-way between familiarity and similarity. In contrast, robots rated by the children as human-like (e.g. robot no. 91) in appearance were rated as having the most negative BI scores, which indicate that they fall into the Uncanny Valley, and children found these types of robots more
uncomfortable. Note, that we did not assess quantitatively the degree of similarity to humans of different robot designs. The positioning of the robot categories (machine-like, animal-like, etc.) on the horizontal axis is therefore only tentative and would need further investigation in a separate study.

4. Discussion

The major aims of this exploratory study were to examine how children evaluated different types of robots and whether specific robot physical attributes were related to distinct personality and emotional traits. We also related these results to the previously theoretically proposed construct of the Uncanny Valley. A summary of the main results would suggest that: (a) children had consistent opinions towards robots differing considerably in appearance in terms of whether they had feelings or whether they thought robots could understand them, (b) two dimensions emerged from children’s evaluations of robots’ personality features. These were termed ‘Emotional Expression’ and ‘Behavioural Intention’, (c) emotional expression constituted the bi-polar
emotions happiness and sadness and behavioural intention was made up of friendliness, shyness and fright versus aggressiveness, bossiness, and anger, (d) Sad robots were characterised as having two legs, a rectangular body, human-like appearance, facial features and male gender, (e) Happy robots as judged by children had animal-like or human-like appearance, facial features and a male or female gender, (f) Aggressive, bossy and angry robots were characterised by children as using two legs or wheels as the mode of locomotion, rectangular body, machine-like appearance, and male gender, (g) Friendly, shy and fearful robots were classified as using legs for mode of locomotion, having a rectangular body, facial features and a gender, (h) overall robot appearance was an important characteristic for children with pure animal-like robots rated as the happiest and pure human-like robots rated as the most

<table>
<thead>
<tr>
<th>Behavioural intention</th>
<th>Human-like</th>
<th>Machine-like</th>
<th>Animal-like</th>
<th>Animal-machine</th>
<th>Human-machine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n = 5$</td>
<td>$n = 16$</td>
<td>$n = 6$</td>
<td>$n = 4$</td>
<td>$n = 9$</td>
</tr>
<tr>
<td>Aggressive bossy angry</td>
<td>-0.39 (.80)</td>
<td>-0.31 (.88)</td>
<td>-0.30 (1.18)</td>
<td>0.58 (.61)</td>
<td>0.71 (.99)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emotional expression</th>
<th>Human-like</th>
<th>Machine-like</th>
<th>Animal-machine</th>
<th>Human-machine</th>
<th>Animal-like</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n = 5$</td>
<td>$n = 16$</td>
<td>$n = 4$</td>
<td>$n = 9$</td>
<td>$n = 6$</td>
</tr>
</tbody>
</table>

Table 10
Means and (SD) for each of the children’s robot appearance prototypes, for emotional expression (EE) and behavioural intention (BI)

Fig. 4. The Uncanny Valley in relation to our findings, illustrating children’s perceptions of robot appearance in relation to behavioural intention (BI). Note, that the values for BI were derived from our statistical analysis of the data (mean values), while Mori’s curve was theoretically motivated. Robot appearance plotted along X-axis according to levels of familiarity and similarity. The data plotted are only for one sample of children and did not control for prior experience with robots.
aggressive and angry, (i) animal–machine and human–machine robots were rated by children as being the most friendly, (j) with respect to behavioural intention we found tentative empirical evidence for the Uncanny Valley, suggesting that children’s positive attitudes towards robots increases from pure machine-like to human–machine-like robots, with a sharp drop towards very human-like robots.

4.1. Design implications for children’s robots

The results of this study are in line with previous studies (Drui, 1999; Scaife and Rogers, 2001; Rode et al., 2003) showing that valuable input can be gained from evaluating children’s views about robots, as their perception of robots as well as the attribution of feelings or mental capabilities (e.g. understanding) are very different compared to an adult perspective. Our study would suggest that primary school aged children are still able to develop a symbolic relationship with a robot and regard it as a person notably if its appearance is human or animal like. Adults, on the other hand, have abstract knowledge enabling them to clearly distinguish between a person and a machine independent of the physical appearance of the robot. This is particularly important if robots were to be used as tools within an educational context for school children as success would depend on children being prepared to engage with the robots and accept it as part of a relationship having well defined social roles (e.g. regard it as a playmate, friend or teacher).

An important observation from the findings was that facial features, male gender, and robot body shape did not enable distinctions to be made between friendly, aggressive, sad and happy robots as robots in all of these categories possessed facial features, a male gender and a rectangular body. These results indicate that it is important for robot designers/researchers to consider a combination of physical characteristics rather than focusing specifically on certain features in isolation. For example, many designers focus predominantly on specific types of facial features and facial expressions of a robot whilst not addressing the issue of a robot’s mode of locomotion and overall body shape. Certain robot features such as faces and speech are likely to be important in the overall perception and attitudes towards robots (DiSalvo et al., 2002). We do not claim that speech and facial features of a robot do not imbue important cues. However, our data suggests that children use a combination of robot features to form an opinion about the personality of a robot and do not solely focus, e.g. on its face. These results provide supporting evidence for the need of consistency and a balanced design that has been discussed extensively in the virtual agent literature, e.g. (Dautenhahn and Nehaniv, 2000; McBreen and Jack, 2001; Vinayagamoorthy et al., 2005), and more recently in robotics, e.g. Goetz et al. (2003), Lindblom and Ziemke (2005) and te Boekhorst et al. (2005).

In contrast to Bumby and Dautenhahn (1999), a study based on imagined robots not actual pictures of robots, the current results highlighted that children aged 9–11 years assigned a gender to the robot images, in particular male gender. It was interesting that female gender was associated with positive robot traits such as happiness and friendliness, whereas male gender was not distinguishable for positive and negative robot traits.

Our findings support some previous research findings for the assertion that robot humanoid features should not be designed to be identical to humans, but have some
human-like characteristics (Breazeal, 2002, 2003; Dario et al., 2001). The present
results indicated that children felt some discomfort towards the images rated as
human-like, providing some tentative evidence for the Uncanny Valley. This was
illustrated in Fig. 4 where human-like robots fell into the Uncanny Valley for nega-
tive behavioural intention. In contrast, human–machine like robots (i.e. robots with
human-like features in addition to some machine-like traits) were rated the most pos-
itively, providing support for the theory that as a robot increases in humanness,
there is a point when the robot is not yet 100% indistinguishable from humans and the balance becomes uncomfortable. Based on our empirical data, the design implications for robots designed for children \(^{12}\) can be summarised as follows:

- Robots should have cartoon-like features, exaggerated facial features, a female
gender and be brightly coloured for positive behaviours.
- Robots should have realistic features, less clear facial features, and be dully col-
oured to depict negative behaviours.
- The whole appearance of a robot should be considered at the outset of the design
phase rather than focusing on specific aspects such as the face.
- Robots for children should not be designed to look completely human-like, unless
they are perfect replicas, indistinguishable of humans. A mixture of human–
machine features is most desirable since it would restrict the effort towards the
first peak of the Uncanny Valley where we find humanoid robots (‘stylish’ robots
combining human and machine features according to Mori a most promising area
of research), rather than attempting to perfectly replicate human appearance and
behaviour which, in comparison, is a long-term perspective that might or might
not be reached in the future. \(^{13}\)

4.2. Future directions

The results from this study have shown that a psychological approach within
robotics research can be valuable to gain insights about children’s attitudes and per-
ceptions of robots. As Scopelliti et al. (2004) point out ‘the implications of human–
robot interactions still remain a scarcely explored field’ and more studies are needed
to examine different user groups’ perceptions and interaction styles with robots to
provide input to robot design. Also, differences can be expected for different roles
and functions of robots in various application areas (Dautenhahn, 2003; Dautenhahn and Werry, 2004).

Several strengths and weaknesses of the present study need to be addressed in
future work. Some of the children had seen some of the images before, e.g. in robot

\(^{12}\) Note, our study targets typically developing children. For children with special needs other design
considerations might apply cf. a study into robot appearance in the context of therapy and education of
children with autism (Robins et al., 2004a,b).

\(^{13}\) Note, android research, no matter how distant the ultimate goal of complete human-likeness is, can
provide an interesting framework for the study of human–human communication and interaction, cf.
wars and this may have influenced their perceptions if they were familiar with them. Questionnaires have been shown to be economical and can be used with a large sample size of children. However, behavioural data of children encountering physical robots are needed to confirm our findings (cf. Kahn et al., 2004). Reliance on robot photographs makes it difficult to set the context and relate appearance to actual robot behaviour and interaction. However, this avoids behavioural stereotypes and allowed us to consider robot appearance in isolation for robot behaviour. Due to time constraints, and the amount of questionnaires that the children had to complete, we were unable to gain data about children’s prior exposure and experience with robots. This should be included in future studies as differences in robot exposure could have influenced perceptions and attitudes. A future design framework to continue this research could include ‘real’ static robots, followed by robots seen moving, and finally live human–robot interaction. It should be emphasised that differences in cultural contexts concerning perceptions of robots were not investigated in this study. However, we are aware that different cultures may have had more or less exposure, and different experiences with robots according to media outlets, toys and robots. Cultural differences could be considered in future studies.

Exploring children’s perceptions of robots could have useful implications for our future research that aims to explore the use of robotics as a possible intervention tool for children to deal with aggressive and bullying behaviour. Bullying behaviour is a widespread problem in schools (Wolke et al., 2001) and intervention programmes to date have revealed little long-term success. Innovative ideas are required to assist in dealing with this problem and it is hoped that robotics may provide a useful medium to explore issues surrounding bullying and friendship problems (Kanda and Ishiguro, 2004). For example, the VICTEC project (www.victec.org) has developed a new innovative platform using virtual learning environments populated with synthetic agents. Children work individually on the computer and interact with different bullying dramas. The child acts as a ‘friend’ or ‘advisor’ to a victim character in the drama and assists them in trying out different coping strategies to counteract the bullying problems. The next step in our work will be to have some robot demos or videos to determine whether we get the same findings when children are shown real robots that are actually moving. If our results are confirmed, we will have some concrete information about what design requirements are necessary for setting up different child–robot interactions where robots can depict different bullying roles such as the bully (the aggressor), the victim robot, a defender robot (robot that assists the victimised robot), a bully-assistant robot (where they help the bully out) and bystander/onlooker robot who does not get involved in the bullying episodes. Robot interactions could possibly provide children with the opportunity to explore the issues surrounding bullying and friendship problems within a safe environment. Interaction with physically embodied robots are hoped to facilitate the generalisation of what has been learnt to the real world, a problem that software based intervention programmes face.

In terms of the design space of robots, cf. Dautenhahn (2002), the results of our empirical study provided some tentative evidence for the Uncanny Valley that had been proposed theoretically. Note, investigating the Uncanny Valley is a programme of research in itself (cf. MacDorman, 2004), reflected in recent workshops and publications in this area. Our work could only provide some initial hints that would need
to be further validated and investigated in greater depth in studies that are systematically exploring the Uncanny Valley. Since movement and appearance play an important role in this research, such studies would need to expose subjects not only to still images by also to videos of robots, or even study interactions of children with a diverse range of humanoid and android machines (which might be impossible due to practical, experimental, safety or ethical considerations).

5. Conclusion

This exploratory study has provided a clearer understanding that children have distinct and consistent views about robot personality traits, emotional characteristics and levels of robot–child comprehension and how these related to a robot’s appearance. We provided some tentative empirical evidence for the Uncanny Valley, which predicts that if robots become too close to realism (appearing very human), but are not perfect (indistinguishable from humans), then the imperfections can be viewed extremely negatively (the ‘Zombie Effect’). Note, the existence of the Uncanny Valley still has to be confirmed in rigorous experimental studies. A lot of anecdotal data, but hardly any experimental evidence is available that can backup Mori’s theoretical considerations. While our study cannot comprehensively close this gap, our results tentatively support the Uncanny Valley in children’s perceptions of robots.

The advantages of using a psychological approach towards designing robots for children and other target groups has been demonstrated and has useful implications for the design process of robots and interaction styles. In particular, the study highlights the need to focus on the overall design of a robot’s appearance, rather than focussing specifically on, for example facial features, and that robots for children should not appear too human-like. Robot–child interactions that yield behavioural data to complement a questionnaire approach are needed in future studies to determine whether the results of the present study are replicable.

Acknowledgements

We would like to thank the following schools for taking part in this research: High Beeches Primary School, St Albans, UK; Applecroft Primary School, Welwyn Garden City, UK; Commonswood Primary School, Welwyn Garden City, UK and Cunningham Primary School, St Albans, UK. This paper is an extensively revised and expanded version of: S. Woods, K. Dautenhahn, J. Schulz, The design space of social robots: Investigating children’s views, in Proceedings of IEEE Int. Workshop on Robots and Human Interactive Communication; RoMan, Japan, 2004. We would like to thank three anonymous reviewers for their very constructive comments that greatly helped in modifying the manuscript.
References


