International Journal of Human-Computer Interaction

ISSN: 1044-7318 (Print) 1532-7590 (Online) Journal homepage: http://www.tandfonline.com/loi/hihc20

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To cite this article: Fang-Wu Tung (2016) Child Perception of Humanoid Robot Appearance and Behavior, International Journal of Human-Computer Interaction, 32:6, 493-502, DOI: 10.1080/10447318.2016.1172808

To link to this article: http://dx.doi.org/10.1080/10447318.2016.1172808

Accepted author version posted online: 11 Apr 2016.
Published online: 11 Apr 2016.

Intl. Journal of Human–Computer Interaction, 32: 493–502, 2016

ISSN: 1044-7318 print / 1532-7590 online
DOI: 10.1080/10447318.2016.1172808

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Child Perception of Humanoid Robot Appearance and Behavior

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This study investigated children's attitudes toward humanoid robots that exhibit various anthropomorphic appearances and behaviors. A total of 578 children aged from 8 to 14 years were recruited to evaluate humanoid robots depicted either in still images (*N* = 267) or videos (*N* = 311). The results showed that the degree of anthropomorphism affected children's attitudes toward the robots. An uncanny valley was observed in this study, indicating that children prefer robots created with a moderate level of human likeness over those that have a highly human-like appearance but remain distinguishable from humans. A striking finding was that moving robots exhibiting social cues moderate the uncanny valley plot, thus contradicting Mori's uncanny valley hypothesis, which posits that emotional responses are greater for moving robots than for static robots. In addition, the children in this study perceived the robots as more socially and physically attractive when the robots exhibited social cues. In summary, the current results suggest that children prefer moderately realistic robots and that robot behavior is a key determinant of how children perceive robots. A moderate level of anthropomorphic appearance combined with appropriate social cues can enhance child preferences for and acceptance of robots.

1. INTRODUCTION

With the advancement of robotic technology, robots serving as assistants or companions or performing other social roles in daily life are feasible in the near future. The paradigm of robotics is shifting from a specific industrial technology to consumer, home, and service markets. Because robots are designed and built for purposes such as service, education, therapy, or entertainment, human–robot interactions have become increasingly socially situated and multifaceted (Bartneck & Forlizzi, 2004; Kachouie, Sedighadeli, Khosla & Chu, 2014; Kiesler & Hinds, 2004). Previous studies have examined the social aspects of human–robot interaction to determine how people respond to the appearance and behavior of robots in various contexts (Thrun et al., 2000; Falcone, Gockley, Porter & Nourbakhsh, 2003). In a study examining views toward household robot companions, Dautenhahn et al. (2005) found that most people were in favor of such robot companions and saw positive potential for robots to serve as assistants, companions, or servants. People desire human-like communication with potential robot companions. Attributing anthropomorphic characteristics to robots that exhibit a human-like appearance is a design consideration because such characteristics can facilitate human–robot interaction (Friedman, Kahn & Hagman; 2003). Goetz, Kiesler and Powers (2003) indicated that people consider human-like robots to be optimally suited for interactive tasks and mechanical-looking robots to be optimally suited for routine jobs.

Comparing three generations of attitudes toward domestic robots, Scopelliti et al. (2004) found that younger people reported more positive feelings (e.g., amused, pleasant, or relaxed) about domestic robots than did adults and elderly people. The younger people did not express any anxiety regarding the notion of a domestic robot. Scopelliti et al. reported that people prefer robots with human-like attributes for interacting with for entertainment rather than practical purposes. These findings suggest that the human receptivity of robots has evolved over generations and that younger people are more willing to view a robot as a companion or social entity. Applying anthropomorphic characteristics in a robot can facilitate child understanding of its functionalities and foster meaningful human–robot interactions. Anthropomorphism can refer not only to appearance but also to behavioral characteristics such as voice and movement. Robots are not developed to remain motionless, but rather to respond to and interact with people. Understanding people's perceptions of the behavior of humanoid robots provides insight essential for designing robots that facilitate human–robot interaction. This is a topic of increasing interest in robotics; however, research on the interplay between the appearance and behavior of humanoid robots is scant. Because children are potential users of educational and entertainment robots, numerous humanoid robots have been created to serve as social companions or learning partners for children. This study investigated children's attitudes toward humanoid robots that exhibit various anthropomorphic appearances and behaviors to provide empirical evidence for the design of social robots with anthropomorphic characteristics.

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2. ANTHROPOMORPHIC DESIGN OF ROBOTS

According to the Oxford Dictionary, anthropomorphism is the attribution of human characteristics or behavior to a god, animal, or object. People tend to humanize nonhumans to understand an agent's behavior and thereby reduce feelings of uncertainty. Norman (2004) argued that people have evolved to interpret even the most subtle of indicators and are predisposed to anthropomorphize, and thus project human emotions onto nearly everything. Such anthropomorphic responses can increase user enjoyment of a product; endowing products with human-like forms is a prevalent trend in product design (Chandler & Schwarz, 2010; Landwehr, McGill & Herrmann, 2011). Designers use the anthropomorphic form to provide users with clues regarding a product's function, mode of use, and qualities, as well as to associate the product with personal and social significance (Choi & Kim, 2009). The three-factor model of anthropomorphism proposed by Epley, Waytz and Cacioppo (2007) posits that people anthropomorphize objects and nonhuman agents on the basis of three core psychological determinants: the accessibility and applicability of anthropocentric knowledge, the motivation to explain and understand the behavior of the agents, and the desire for social contact and affiliation. According to the model, anthropomorphizing the appearance and interaction design of a robot can help people understand the robot's functionality and satisfy their motivation for social connection. As described in Duffy (2003), a robot expected to engage in meaningful social interaction with people inherently requires a degree of human-like qualities whether in form or behavior or both. Applying an anthropomorphic form and behavior in a robotic system helps dissolve the barrier between people and digital information, enriches the explanation of the system's function, and creates familiarity with robots.

The uncanny valley hypothesis proposed by Mori (1970) has been widely applied in fields involving human–robot interaction throughout the development of increasingly human-like androids. The hypothesis suggests that human-like appearance and motion are positively correlated with people's positive emotional reactions to them. However, as human likeness increases, there is a point beyond which familiarity decreases sharply and robots become eerie. When emotional reaction is plotted against a robot's level of human likeness on a graph, this dip can be observed and is commonly referred to as the uncanny valley (Figure 1). The nonlinear curve between human likeness and familiarity poses a challenge to designing a humanoid robot that does not fall into the uncanny valley. According to the uncanny valley hypothesis, moving robots yield a stronger emotional response than do static robots. Accordingly, if a robot's appearance is sufficiently human-like to be uncanny, its associated human-like behavior might amplify this negative perception.

To elucidate how the appearance of android robots affects people's acceptance, researchers have attempted to empirically retrace the uncanny valley curve. However, collecting robots that cover a range from considerably low to considerably high

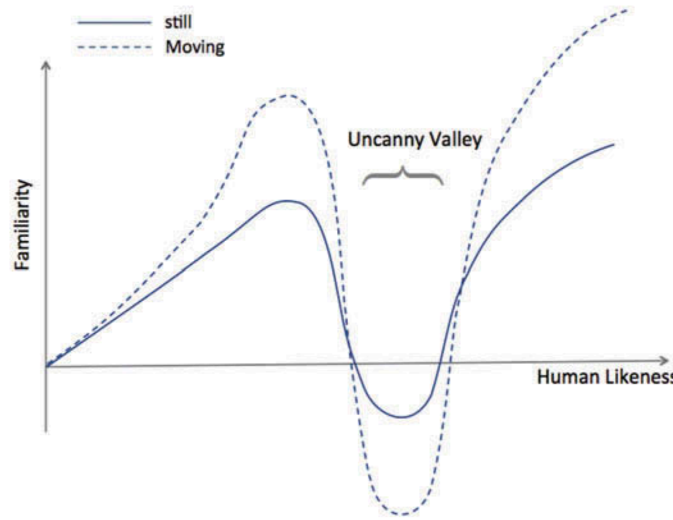

FIG. 1. Uncanny valley proposed by Mori.

human likeness has been difficult. The morphing technique has been widely adopted to create a series of pictures by morphing a robot to a human, whereby the degree of anthropomorphism is represented as the percentage of morphing (Hanson, 2006; MacDorman & Ishiguro, 2006). This is useful for examining the uncanny valley hypothesis, but it inevitably generates images of features that would not be included in an actual android design, leading to unreliable results. To address this problem, Bartneck, Kanda, Ishiguro and Hagita (2007) used actual robots and humans as stimuli to investigate the effect of anthropomorphism on people's perception of robots. They proposed an "uncanny cliff" model as an alternative to the uncanny valley model because even pictures of real humans were not rated as being as likeable as pictures of toy robots. Regardless of how Mori's uncanny valley hypothesis has been supported or modified, avoiding the uncanny valley is still a useful guideline for designing the appearance of robots (Aylett, 2004; Fabri, Moor & Hobbs, 2004). Although anthropomorphic design is a strategy for enriching the explanation of a robot's function and for creating familiarity with robots, designers should be careful to avoid a level of anthropomorphism that triggers feelings of eeriness. Furthermore, an anthropomorphic design refers not only to the appearance but also to the interaction design of robots. With advances in robotic technologies, many humanoid robots are being developed for wide-ranging applications. Such robots, exhibiting various human-like appearances and behaviors, enable researchers to use actual robots as stimuli to investigate people's attitudes toward robots.

3. CHILDREN AND ROBOTS

Various robots have been developed or are in the process of being developed for children to fulfill various functions such as those for educational, entertainment, and therapeutic purposes. Pearson and Borenstein (2014) argued that these types of robot serve as a "companion" for children by playing games or passively keeping a child company. Several current robotics projects exemplify this tendency. For instance, the NEC Corporation developed a humanoid robot, PaPeRo ("Partner-type Personal Robot"), as a teacher's assistant to help motivate children and play games. Because robots are under development for a wide variety of purposes, including accompanying children, understanding children's receptivity and social responsiveness to robots is critical. Regarding children's social perception of objects, Piaget (1929) used animism to describe children's tendency to attribute life and consciousness to inanimate objects. Children use their animistic intuition to attribute intelligence, biological function, and intention to the objects they encounter (Carey, 1987; Okita et al., 2005). Children currently grow up in a digital world, and inquiry into children's attitudes toward digital devices has intrigued researchers such as Turkle (1984), who studied the relationship between children and technology for two decades. Her findings have revealed that contemporary children are not confused about whether computers are alive; however, they are comfortable with the idea that inanimate objects can think and have a personality (Turkle, 1995).

Children's treatment of digital devices as social beings is also relevant to how they view robots. Kahn et al. (2012) recruited 90 children—aged 9, 12, and 15 years—to interact with Robovie, an Advanced Telecommunications Research-designed humanoid robot that acts as a museum guide. The results revealed that the children believed that Robovie had mental states, such as being intelligent and having feelings, and was a social entity capable of being a friend and confidante. Fior et al. (2010) empirically proved that most children were willing to engage in friendship with robots by showing positive affiliation with and social support for it. Fridin and Belokopytov (2014) demonstrated that the use of a humanoid robot as a coach could effectively engage preschool children in motor activities. These studies have suggested that children can view humanoid robots as social beings, thereby enabling them to develop deep relationships with robots. Because of the wide use of human-like features, such as behavior and appearance, to reinforce the sociability of robots, a major design consideration is whether and to what degree robots should be human-like. Because avoiding the uncanny valley remains an objective when designing a robot for adults, the question of how to design robots for children motivated us to examine whether the uncanny valley hypothesis can be applied to children. Most studies have focused on testing Mori's hypothesis with adult participants; few researchers have investigated whether the uncanny valley observed from adults' perceptions of robots is applicable to children. Woods (2006) studied children's attitudes toward the appearance of distinct robots and the results provided tentative empirical support for the uncanny valley. They presented children with pictures of robots exhibiting a machine-like appearance and others with a human-like appearance; the children judged the machine-like robots as friendly and the human-like robots as aggressive. However, these judgments were made using still images as stimuli. To gain a deeper insight into how people perceive humanoid robots, further research must expose participants to not only still images but also video of robots. To fill these gaps in the literature, this study investigated how children perceive robots across the spectrum of anthropomorphic appearance and whether the movements of a robot exaggerate children's perceptions of robots.

4. METHOD: PRE-EXPERIMENT AND EXPERIMENT I

4.1. Pre-Experiment

Pre-experimental research was conducted to identify appropriate experimental stimuli according to children's perceptions of the anthropomorphism of robots. We accessed numerous robot resources developed by companies, institutes, research labs, and media, and collected images of 54 robots ranging from "barely human" to "fully human"; one of the 54 robots was actually a robot character portrayed by a human. Several related studies have used robot heads as stimuli to investigate people's perceptions of anthropomorphism in a robot's appearance. Researchers have empirically proven that people's perceptions of the anthropomorphism of whole robots and robot heads are highly correlated (DiSalvo, Gemperle, Forlizzi & Kiesler, 2002). This finding indicates that the appearance of a robot head plays a critical role in the perception of humanness. Therefore, this study adopted robot heads as the stimuli for exploring children's perceptions of humanoid robots. Each robot head was printed on one 3×3-in card. This study recruited 29 children, aged between 10 and 11 years, to sort the 54 images according to the degree of realism. The cards were shuffled into a random order and presented to each participant, who was asked to sort the cards into low, moderate, and high anthropomorphism groups. After completing the first round, the participant then divided each subset into three groups according to identical criteria. Thus, each participant sorted the robot images into nine groups ranging from low to high human likeness. This study analyzed the data by using Ward's hierarchical clustering method and obtained four groups representing the degrees of anthropomorphism perceived by the children. From low to high degrees of anthropomorphism, the four groups were labeled as Groups A, B, C, and D, which are described as follows. (a) Group A: Basic humanoids exhibiting mechanical appearances that do not feature complete facial features but primarily mimic human form through eyes and cranial shapes. (b) Group B: Moderate humanoids exhibiting distinct facial outlines with partial facial features such as eyes or mouths, but the characteristics and proportions of these features differ considerably from those of humans. (c) Group C: Simulated humanoids exhibiting higher similarity to humans compared with the previous groups of robots. Facial features are particularly detailed; the facial proportions are similar to those of humans. However, simulated humanoids can still be distinguished from humans. (d) Group D: Lifelike humanoids with an external appearance

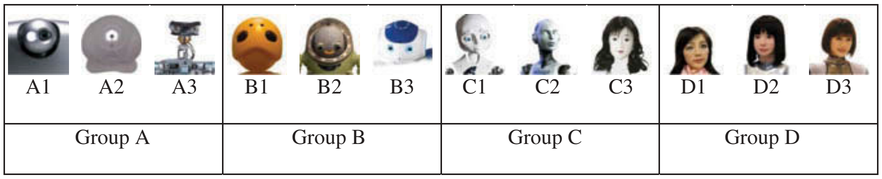

FIG. 2. Experimental stimuli.

that closely resembles that of humans, exhibiting lifelike facial features and skin color. According to the clustering analysis results, the robots rated in each group as having low, moderate, and high anthropomorphism were selected as the experimental stimuli. Twelve robots were selected from the four groups to illustrate how the children rated robots on a scale from low to high anthropomorphism (Figure 2).

4.2. Experiment I

A single-factor experiment with repeated measurements was performed to investigate the effects of anthropomorphism on children's attitudes toward robots. The independent variable was the degree of anthropomorphism; the 12 experimental stimuli derived from the pre-experiment are presented in Figure 2. The dependent variables were social attraction and physical attraction.

Participants

A sample of 267 children was recruited, comprising 87 fourth graders (42 girls and 45 boys) with an average age of 9.8 years, 86 sixth graders (42 girls and 44 boys) with an average age of 11.9 years, and 94 eighth graders (45 girls and 49 boys) with an average age of 14.3 years from five schools. Their ages ranged from 8 to 14 years, with an average age of 12.1 years.

Measurement Tool

This study used a Likert-scale questionnaire to measure the children's social and physical attraction toward robots exhibiting various degrees of realism. A Likert scale-based questionnaire using psychometric testing to measure beliefs, attitudes, and opinion was suitable for this study. The questionnaire of social and physical attraction was modified from a version of McCroskey and McCain's social and physical attraction scale (McCroskey & McCain, 1974), as well as from relevant studies that have adapted the same scale to measure users' attitudes toward computers, robots, or media (Moon, 1996; Lee, Peng, Yan & Jin, 2006). Social attraction and physical attraction are two key dimensions of interpersonal attraction, and have been determined to be facilitators of interpersonal communication, which leads to the formation of friendships. Several humanoid robots have been developed to enhance attitudes of social acceptance among users for building social relationships. Thus, in this experiment, whether various levels of anthropomorphic appearance influence children's social and physical attraction to robots was investigated.

The social attraction scale consisted of five items: (1) "I think this robot is friendly"; (2) "I like this robot"; (3) "I think this robot could be my friend"; (4) "I would like to have a friendly chat with this robot"; and (5) "I think this robot is pleasant to be with." The physical attraction scale consisted of three items: (1) "I think this robot is good-looking"; (2) "I think this robot is attractive"; and (3) "I like the way this robot looks." The two scales were measured using a set of paper-and-pencil questionnaire, and each item was scored using a 7-point Likert scale ranging from 1 (*very strongly disagree*) to 7 (*very strongly agree*). The wording used in the questionnaire was discussed with teachers and the children to prevent any misunderstanding.

Procedure

Each robot image was high-quality color-printed on a single sheet of paper and presented with the aforementioned questionnaires. The participants were asked to evaluate the images of the 12 robots by completing the questionnaire. The order of the 12 sheets was randomized for each child. The participants completed the questionnaire survey either in their classroom or a quiet place such as a school library.

Results

Internal consistency was calculated to assess the reliability of the scales. Cronbach's alphas for social and physical attraction among the fourth, sixth, and eighth graders were all higher than 0.7. According to Nunnally (1967), a Cronbach's α of 0.7 is adequate for internal consistency reliability; therefore, the measures used in this study demonstrated adequate reliability.

Table 1 shows the mean scores of social and physical attraction rated by the participants. According to the descriptive statistics reported in Table 1, Robot B3 received the highest scores for both social and physical attraction, whereas Robot C3 received the lowest scores. Figure 3 illustrates how the participants evaluated each robot regarding the two dimensions. The two curves present similar plots, with the positive responses increasing with the degree of anthropomorphism until the point of Robot C1, after which the robots closely resemble humans, but not perfectly. At that point, the participants began to react negatively to the robots before reaching the point of Robot D2, which perfectly mimicked human appearance.

TABLE 1
Robots' Social and Physical Attraction as Rated by the Children

		A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	F-value
Social attraction	M	3.31	3.30	3.40	4.30	4.49	5.57	3.76	2.93	2.62	2.68	4.45	5.06	97.96***
	Std	1.94	1.98	1.90	1.99	1.91	1.61	1.91	1.85	1.73	2.04	1.92	2.09	
Physical attraction	M	3.03	2.85	2.96	3.75	3.76	5.09	3.07	2.64	2.37	2.53	4.40	5.00	98.83***
	Std	1.88	1.86	1.79	1.98	2.00	1.81	1.86	1.70	1.68	1.79	2.07	2.01	

***$p < 0.001$ (two-tailed).

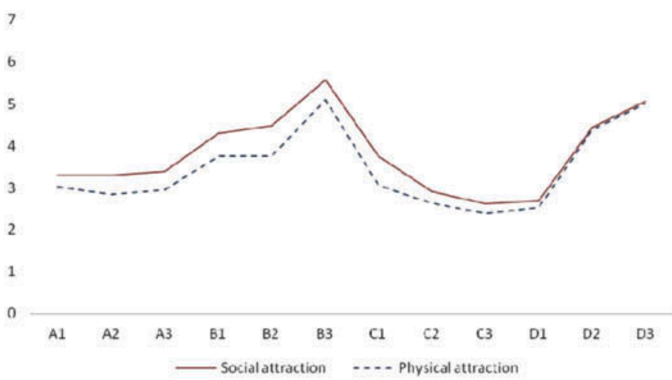

FIG. 3. Children's ratings of social and physical attraction of robots.

An analysis of variance (ANOVA) was performed to examine whether the various degrees of anthropomorphism affected the children's perceptions of robots regarding social and physical attraction. The results showed a significant effect of anthropomorphism on social attraction ($F(11,2827) = 97.96$, $p < 0.001$) and physical attraction ($F(11,2827) = 98.83$, $p < 0.001$).

5. DISCUSSION: EXPERIMENT I

The results from Experiment I showed that the degree of anthropomorphism of robots affected the children's attitudes toward them. Figure 3 shows a continuously positive change of anthropomorphism versus the children's evaluation of social and physical attraction until a point of realism beyond which the children's evaluation abruptly decreased. As the appearance became less distinguishable from that of a human, the children's responses became positive again. An uncanny valley was observed in this study, indicating that the children were less attracted to images considered highly human-like but distinguishable from humans, which evoked a feeling of discomfort. This finding supports Mori's uncanny valley hypothesis. The results showed that the top of the first peak of the curve is slightly higher than the point at which Robot D3 is located, differing from the results of Mori's uncanny valley, where humans are rated highest. Robot D3 is a human, whereas Robot B3 was rated by the children in the pre-experiment research as having a moderate degree of anthropomorphism. The two robots received high evaluation from the children regarding social and physical attractiveness. This suggests that a moderate level of anthropomorphism (i.e., Group B) is sufficient to elicit children's social responses and to endear them to the appearance of the robot. Hence, it is unnecessary to exert effort to adopt a highly human-like form to obtain maximal acceptability in children.

The findings suggested that anthropomorphic design in a robot's appearance could enhance children's preference for the robot. Anthropomorphic design does not necessitate human form; rather, it requires visual elements inspired by the human form to increase a robot's potential to arouse positive emotion in users. The human visual system is equipped with sophisticated mechanisms to process facial information (Ekman, 1993). People have a natural predisposition to detect human-like forms rapidly and without cognitive effort. Guthrie (1997) stated that it is one of the most crucial needs of humans to note the presence of other humans; hence, any schema for detecting humans has priority over other schemata. From this perspective, it is easy to understand why people automatically see faces in inanimate objects by scanning for patterns and analyzing and interpreting them as subtle indicators or stimuli to anthropomorphize. Thus, real human faces, artificial faces, synthetic computer facial images, abstract facial icons, and even simple face-like patterns are all accepted as faces (Robert & Robert, 2000; Turati, 2004). When designing a humanoid robot for children, reducing the anthropomorphism to a moderate level, such as that of Group B, is sufficient to elicit social responses. This implies more possibilities for designing a humanoid robot by extracting and representing human facial features. Robot designers can focus on aesthetic considerations rather than merely imitating humans to create a social robot for children.

6. METHOD: EXPERIMENT II

According to the findings of Experiment I, this study further examined the effects of movements and behaviors of robots on the children's measurement of the robots used in Experiment I. A single-factor experiment with repeated measurements was conducted to investigate the children's attitudes toward the robots under the moving condition.

6.1. Participants

To avoid interference effects, this study recruited 311 additional children to participate in Experiment II, namely 108 fourth graders (49 girls and 59 boys) with an average age of 9.9 years, 118 sixth graders (53 girls and 65 boys) with an average age of 11.7 years, and 85 eighth graders (43 girls and 42 boys) with an average age of 14.5 years from five schools. Their ages ranged from 8 to 14 years, with an average age of 11.8 years.

6.2. Experimental Stimuli

We gathered videos that demonstrated the movements of the robots used in Experiment I as the stimuli. Robots C2, D1, and D3 were absent in this experiment because no videos were available. Thus, nine robot videos were used as the stimuli employed for the movement experiment. The length of each edited video clip was approximately 60 s, and the content demonstrated the movements of each robot. To ensure that all robots were presented in a similar context, we selected videos in which the robots only demonstrated movement and behavior without engaging in specific activities. In the videos, the robots' movement and behavior were classified into five types: head movement, arm or hand movement, facial-feature movement, locomotion, and speech. The videos did not show every type of movement or behavior for every robot. Table 2 outlines the movements and behaviors of each stimulus presented in the videos. Regarding audio, B2 and C1 exhibited speech, whereas the remaining videos were accompanied by identical background music.

6.3. Procedure

The experiment was conducted in computer classrooms, with the videos played on the computers, as shown in Figure 4. An average of 12 participants attended each session. Each participant was assigned to one computer in the lab and each computer played the nine videos in a random sequences. After watching a video, each participant was asked to complete the questionnaire for the robot. Research assistants were present to assist the participants in watching the robot videos and completing the questionnaire. The measurement tools involved adopting the same questionnaires used in Experiment I. The Cronbach's α results for the social and physical attraction items were all higher than 0.7. The total duration of the experiment was approximately 40 min.

6.4. Results

Table 3 lists the mean scores of social attraction and physical attraction as rated by the participants. Robot B2 received the highest scores for both social and physical attraction, whereas Robot C3 received the lowest scores. One-way ANOVA was

FIG. 4. Video-viewing interface.

TABLE 2
Movement and Behavior of the Experimental Stimuli Presented in the Videos

	Head movement	Arm or hand movement	Facial-feature movement	Locomotion	Speech
A1		Arms movement		Two-legged	
A2			Eye winking	Wheeled	
A3	Head turning	Arms movement		Wheeled	
B1	Head turning	Arms and hands movement		Wheeled	
B2			Eyes winking/rolling Lip movement		Yes
B3	Head turning	Arms movement		Two legged	
C1	Head nodding, tilting	Arms and hands movement	Eyes winking/rolling, eye brows movement, lip movement		Yes
C3	Head turning	Arms movement	Eyes winking	Wheeled	
D2	Head nodding, turning, tilting	Arms and hands movement	Eyes winking	Two-legged	

TABLE 3
Moving Robots' Social and Physical Attraction as Rated by the Children

		A1	A2	A3	B1	B2	B3	C1	C3	D2	*F*-value
Social attraction	M	4.89	4.72	4.74	4.81	5.71	5.26	4.85	4.12	5.03	50.66***
	Std	1.35	1.39	1.35	1.36	1.28	1.23	1.48	1.51	1.43	
Physical attraction	M	4.52	4.39	4.28	4.49	5.00	4.91	4.04	4.02	4.91	29.39***
	Std	1.51	1.15	1.45	1.60	1.52	1.43	1.63	1.71	1.52	

***$p < 0.001$ (two-tailed).

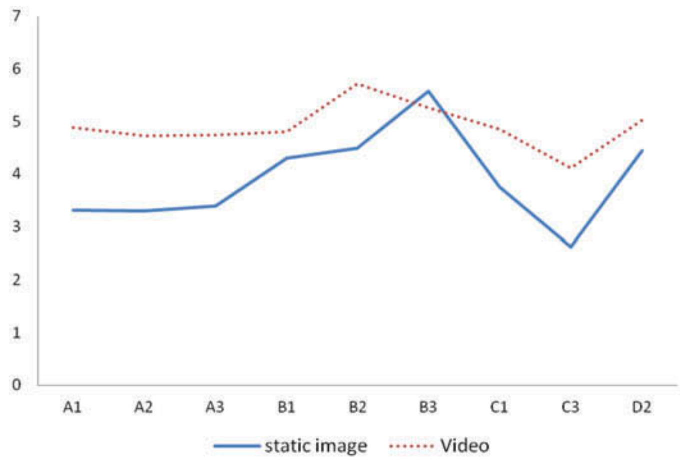

FIG. 5. Robots' social attractiveness in the form of static image and video.

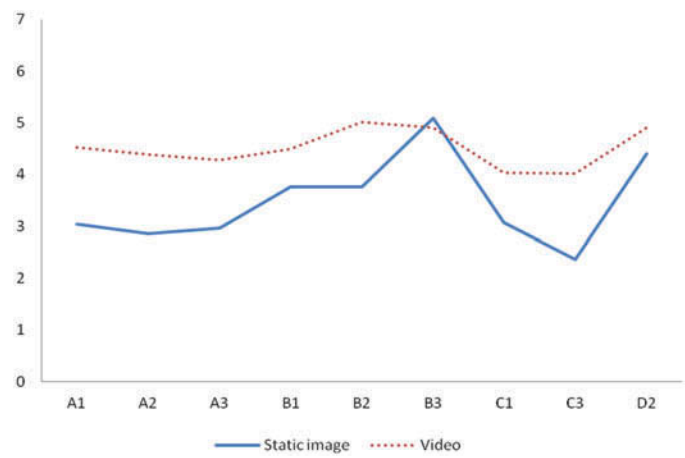

FIG. 6. Robots' physical attractiveness in the form of static image and video.

used to determine if there were statistical differences among robots. The results showed a significant difference on social attraction ($F(8,2480) = 50.66$, $p < 0.001$) and physical attraction ($F(8,2480) = 29.39$, $p < 0.001$).

6.5. Comparing the Results of Experiments I and II

As illustrated in Figures 5 and 6, the curves resulting from Experiment II are flatter than those from Experiment I. The children generally felt higher social and physical attraction to moving robots than to those that were static. The results of Experiments I and II were compared using a *t*-test. Table 4 shows the statistical differences in social and physical attraction as rated by the participants in the two experiments. In addition to Robot B3, robots demonstrating movement or behavior were perceived more favorably by children than were static robots.

7. DISCUSSION: EXPERIMENT II

Comparing the children's attitudes toward static and moving robots revealed a relatively flat curve for the moving robots. This contradicts Mori's uncanny valley theory, which states that movements exaggerate emotional response. The fact that moving robots can moderate the uncanny valley effect suggests that movement and behavior could mitigate the negative effect of appearance and reduce the uncanny response. Kanda et al. (2007) reported that participants had a more positive impression of robots when they exhibited social behaviors. In the current study, robots exhibiting social behaviors such as facial expressions, speech, head movements, and gestures generally enhanced the children's acceptance of robots. Social agency theory (Mayer, Sobko, & Mautone, 2003) argues that a greater frequency of social cues in an interaction improves the quality of that interaction. Studies related to computers as social actors (CASA) have empirically proven that people tend to treat a computer as a social entity when it exhibits an adequate degree of social cues (Nass & Steuer, 1993; Reeves & Nass, 1996). CASA concepts argue that computers exhibiting social cues convey a sense of sociability and intimacy, thereby inducing social responses from people. Khan and Sutcliffe (2014) suggested that the CASA model be used not only to describe human–computer interaction but can also be extended to human–agent interaction. This relationship between social cues and interaction quality also applies to child–robot interactions; children perceive a robot as more socially and physically attractive when its behaviors involve social cues. The design of robots with anthropomorphic characteristics aims to form the basis of a potential social relationship. Anthropomorphic characteristics refer not only to human-like appearance but also social cues derived from human–human interaction.

TABLE 4
t-test Results of Social and Physical Attraction Scores for Static and Moving Robots

	Social attraction			Physical attraction		
	Moving ($N = 311$)	Static ($N = 258$)	*t*-value	Moving ($N = 311$)	Static ($N = 258$)	*t*-value
A1	4.89 (1.35)	3.31 (1.94)	11.41***	4.52 (1.51)	3.03 (1.88)	10.42***
A2	4.74 (1.39)	3.37 (1.91)	9.90***	4.39 (1.52)	2.96 (1.79)	10.31***
A3	4.72 (1.35)	3.30 (1.99)	10.04***	4.28 (1.45)	2.85 (1.86)	10.22***
B1	4.81 (1.36)	4.30 (1.99)	3.62**	4.49 (1.60)	3.75 (1.98)	4.96***
B2	5.71 (1.28)	4.49 (1.92)	9.04***	5.01 (1.52)	3.76 (2.00)	8.43***
B3	5.26 (1.91)	5.57 (1.61)	−2.58	4.91 (1.43)	5.08 (1.82)	−1.33
C1	4.85 (1.23)	3.76 (1.91)	7.6***	4.01 (1.63)	3.07 (1.86)	6.6***
C3	4.12 (1.50)	2.62 (1.73)	10.96***	4.02 (1.72)	2.37 (1.68)	11.5***
D2	5.03 (1.43)	4.45 (2.05)	3.96***	4.91 (1.53)	4.40 (2.08)	3.37**

$^{**}p < 0.01$, $^{***}p < 0.001$ (two-tailed).

The results of the current experiments showed that the children tended to rate dynamic robots more favorably than they did static robots. In general, the robots exhibiting behaviors received higher ratings in terms of social and physical attraction than did the static robots. One exception was Robot B3, which received lower scores in Experiment I than in Experiment II. In terms of behaviors, both robots A3 and B3 exhibited similar capabilities such as head as well as arm and hand movement. The results showed that these behaviors rendered Robot A3 more socially and physically attractive. These behaviors can enhance children's acceptance of robots that are less human-like in appearance. However, these behaviors did not have the same effect for Robot B3, which was viewed as being more human-like than Robot A3. In the field of human–robot interaction, researchers have suggested that matching human-like appearance and behavior can increase acceptance (Goetz, Kiesler & Powers, 2003; Minato et al., 2006; Walters, Syrdal, Dautenhahn, Boekhorst, & Koay, 2008). Robot capabilities and appearance are strongly correlated. A robot's appearance affects people's perception of the robot and prediction of its capabilities (Komatsu & Yamada, 2011). Children expect robots with more human-like appearance to exhibit more social behavior. Thus, Robot B3, which was rated more human-like than was Robot A3, was expected to exhibit more social behavior capabilities rather than head movement or locomotion. In the video, Robot B3 demonstrated less social behaviors, which did not meet the children's expectations, which were based on its appearance; this might explain the lower rating of Robot B3 in Experiment II.

In contrast to Robot B3, Robot B2 was capable of facial expression and speech but not body movement or locomotion. In the videos, Robot B2 speaks and makes simple facial expressions using its eyes and lips. Robot B2 received the highest scores of social and physical attraction, echoing previous findings that both speech and facial expressions are powerful social cues (Allison et al., 1994). Nass and Brave (2005) wrote that "humans have become voice-activated with brains that are wired to equate voices with people" (p. 3). To interact with others in social groups, people have become sensitive to voice and are adept at identifying the social aspects of speech. Facial expressions also play a crucial role in social communication, and the dynamic display of facial expressions provides unique temporal information about expressions that do not appear in static displays (Ambadar, Schooler & Cohn, 2005). A dynamic display can enhance abstract facial icons in communication (Biele & Grabowska, 2006; Tung, 2013). Accordingly, Robot B2, with its talking and facial-expression capabilities, elicited greater social and physical attraction from the children. As mentioned, human perceptions of a robot's social behavior depend on its appearance. A robot with a highly human-like appearance is expected to exhibit more social behaviors; those that do not might disappoint users. To supplement the limited fluidity of facial movement, a robot's sociability can be increased by reducing its human-like appearance to match the limited facial expression. Moreover, the behavior and embodiment should be consistent in order to meet users' expectations; otherwise, conflicting cues can give rise to negative reactions (Moore, 2012). A robot demonstrating consistent behavior plays an essential role in human–robot interaction because consistent behavior is more predictable and generally lightens the cognitive load (Fiske & Taylor, 1991). In the pursuit and design of social robots, whether a robot's behavior matches its appearance and is consistent with the embodiment remains a critical topic in the field of human–robot interaction.

8. CONCLUSION

The development of robots capable of interacting with humans has progressed considerably in the past decade. Among the wide range of potential uses for robots, educational or entertainment-oriented robots for children are a particularly notable focal point. Robots designed for children are typically endowed with a human-like appearance and interaction abilities to facilitate child–robot interaction. Although anthropomorphism has been applied to enhance the social acceptance of robots, understanding how to apply anthropomorphic design in a robot's form and interaction is a critical step in developing robots for children. The findings of the present study suggest that applying human-like traits in a robot's appearance can render the robot more socially acceptable and visually appealing. However, the use of anthropomorphism in robot design should not replicate the human form exactly. Children growing up in the digital era have been exposed to various digital toys and devices such that the concept of robots is not novel to them. Thus, attempting to blur the boundary between robots and humans is unnecessary for designing a social robot for children. Applying an anthropomorphic form in a robot to elicit children's emotions and preferences can be achieved using a few visual human-like features. Furthermore, the results of children ratings for moving robots have revealed that the degree of anthropomorphic appearance might not play a dominant role in affecting children's attitudes to robots. A robot's social cues, such as facial expressions, speech, and gestures, can augment its sociability and substantially enhance children's social perceptions and preferences. This empirical study provides initial guidance for designing robots with anthropomorphic characteristics for children. Children's preferences for a robot's appearance must be further investigated in a more controlled experiment in which only a single feature changes between each robot. The development of a sociable robot does not necessitate the direct embedding of social cues without prudential consideration. Future studies should further explore the impact of various cues and more possibilities in creating sociable interaction by identifying the features of interpersonal interaction that can be applied in the design of social robots for children.

FUNDING

This material is based upon research supported by the Ministry of Science and Technology of the Republic of China (grant number MOST100-2410-H-011-035-MY2).

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