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The effects of overall robot shape on the emotions invoked in users and the perceived personalities of robot

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A R T I C L E I N F O

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A B S T R A C T

The affective interaction between human and robots could be influenced by various aspects of robots, which are appearance, countenance, gesture, voice, etc. Among these, the overall shape of robot could play a key role in invoking desired emotions to the users and bestowing preferred personalities to robots. In this regard, the present study experimentally investigates the effects of overall robot shape on the emotions invoked in users and the perceived personalities of robot with an objective of deriving guidelines for the affective design of service robots.

In so doing, 27 different shapes of robot were selected, modeled and fabricated, which were combinations of three different shapes of head, trunk and limb (legs and arms) – rectangular-parallelepiped, cylindrical and human-like shapes. For the experiment, visual images and real prototypes of these robot shapes were presented to participants, and emotions invoked and personalities perceived from the presented robots were measured.

The results showed that the overall shape of robot arouses any of three emotions named 'concerned', 'enjoyable' and 'favorable', among which 'concerned' emotion is negatively correlated with the 'big five personality factors' while 'enjoyable' and 'favorable' emotions are positively correlated. It was found that the 'big five personality factors', and 'enjoyable' and 'favorable' emotions are more strongly perceived through the real prototypes than through the visual images. It was also found that the robot shape consisting of cylindrical head, human-like trunk and cylindrical head is the best for 'conscientious' personality and 'favorable' emotion, the robot shape consisting of cylindrical head, human-like trunk and human-like limb for 'extroverted' personality, the robot shape consisting of cylindrical head, cylindrical trunk and cylindrical limb for 'anti-neurotic' personality, and the robot shape consisting of rectangular-parallelepiped head, human-like trunk and human-like limb for 'enjoyable' emotion.

1. Introduction

Today, robots are often perceived as social creatures due to their increasing interaction with human in everyday life. Accordingly, the capability of robot in expressing various emotions and understanding human's emotions are considered important for facilitating communication and enhancing the communication quality (Sakagami et al., 2002). Such affective interaction is essential especially for service robots such as receptionist robots in convention centers, nursing robots in hospitals, instructor robots in schools, and entertaining robots in theme parks. As for these service robots, effectively designed affective interaction would allow for more satisfaction to the users and a better acceptance by general public (Bartneck and Forlizzi, 2004; Kirby et al., 2010; Woods, 2006).

The affective interaction between human and robots could be influenced by various aspects of service robots, which are appearance, facial expression, countenance, gesture, voice, etc. (Goetz et al., 2003; Ku et al., 2005; Nehaniv et al., 2005; Kulic and Croft, 2007; Weinschenk and Barker, 2000). However, it is still not clearly known whether any single factor dominates or how the interactions of these factors work. It is partly because of the nature of problems in designing a robot; since the design space is too big and the design variables are too many, it is practically not feasible to include all the factors and test them in a single shot study. This drives a need to make a series of parametric studies to investigate the effects of design factors one by one independently and then synthesize the results to draw any conclusive or generalized guidelines for service robot design.

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As a first step, the present study seeks to investigate the effects of overall shape of robot on the emotions invoked in users and the perceived personalities of robot with an objective of deriving guidelines for the affective design of service robots. Understanding of the psychological effects of the overall shape of robot is very important for affective design of robot because the overall shape of robot could play a key role in making the first impression of robot to users and thus could have substantial influence on users' acceptance of robot (Bickmore and Picard, 2004; Hegel et al., 2008). However, in reality, the psychological effects of the overall shape of robot are not well understood yet, and there exist no standard guidelines practically available for affective design of overall robot shape.

To investigate the effects of overall shape of robot on the emotions invoked in users and the perceived personalities of the robot, the present study employs a multi-step approach which is composed of robot candidate selection, surface-modeling and fabrication, and evaluation by experiment. This approach also adopts both visual images and real prototypes to verify the effect of the embodiment. This is meaningful in that the previous research for finding the emotions invoked or personalities perceived from robots mostly used pictures and video clips only (DiSalvo et al., 2002; Hegel et al., 2008), while it is known that the perception of images and embodied objects could differ because of the sense of presence (Bartneck, 2002; Lee et al., 2006).

2. Backgrounds

2.1. Appearance of robot

The appearance of robot is an important topic of human–robot interaction studies because it is highly related with the acceptance of the robot (DiSalvo et al., 2002; Hegel et al., 2009). Similar to the fact that people have preferences for other human beings based on their appearance, some robots are preferred to others by the appearance only. Therefore, for the design of more acceptable robot, it is necessary to figure out the characteristics in appearance which would help to gain in more positive feelings toward a robot.

Regarding the appearance of robot, it is worthwhile to note the work by Fong et al. (2003) who classified the appearance of robot into four categories; anthropomorphic, zoomorphic, caricatured and functional. Among these four categories, in general, anthropomorphic robots are expected to be better accepted in the social settings. This is because the human-like shape and behavior of anthropomorphic robots have advantages when a close interaction between a robot and a human is necessary. It is also because people suppose that the more a robot looks like human, the better it performs human-like skills such as verbal communication and intelligence.

However, the effect of anthropomorphic characteristics on the perception of robot revealed non-linear trends. As the anthropomorphic characteristics increased, a sudden drop of familiarity was observed (Woods, 2006). Relating to this phenomenon, Mori (1970) proposed an impactful theory, the Theory of Uncanny Valley. It hypothesizes that the more human-like robots are in motion and appearance, the more positive emotional reaction they can draw from human until it reaches a certain point where the trend rapidly declines and the emotional response quickly becomes negative.

It is interesting to note how this theory would be applied to robots whose bodies consist of one head, one trunk, two arms and two legs — humanoid or near-humanoid robots. This body structure is quite human-like in itself. So, it is wondered how an addition of anthropomorphic characteristics in the appearance of such robots would affect the emotional reaction of human toward them. Also, it is wondered what shapes of such robots would result in more successful acceptance when any addition of anthropomorphic characteristics is negated. However, little has been reported of this yet.

2.2. Personality & emotions

It is known that people treat a robot as a personalized character when interacting with robot or even virtual agent. People may easily apply social norm and exhibit social behavior to the non-living appliances, treating them as social entities (Nass et al., 1994). Naturally, people pick up the personality of robot from its design characteristics (Severinson-Eklundh et al., 2003; Syrdal et al., 2007), and the perceived personality in turn invokes the emotions of the people interacting with the robot. According to the study by Nass et al. (1995), the attribution of personality to computer agent can be achievable with a small set of features, and using these characteristics allows for easy and intuitive prediction of system behavior. In the voice communication, for example, the same contents presented through differently designed robot can invoke different types of emotions according to the context and the perceived personality of the robot (Siegel et al., 2009; Walters et al., 2008).

For the study of robot personality, big five theory could be employed as a representative model which has been developed mainly in psychology over the past 50 years (Goldberg, 1990, 1992; McCrae and Costa, 1987; Norman and Goldberg, 1966). This theory classifies personality into five categories, which are extraversion, agreeableness, conscientiousness, neuroticism and openness although there are some disagreements in the exact items and labels of the proposed five factor model. These dimensions represent broad areas of personality, each of which was not found to be exactly orthogonal, though. One of the advantages of using big five model for the study of robot personality is that the result can be compared to other psychological studies with human subject as well as non-human species (Syrdal et al., 2007; Weiss et al., 2007) in personality traits research. This is contrasted to the data driven approach which uses factor analysis to identify the dimensional structure of personality, in that it does not have solid theoretical basis in psychology but depends on the descriptors preselected.

Regarding emotions, Ekman et al. (1982) suggested the six basic emotions by studying on the facial expression human makes (anger, disgust, fear, joy, sadness, surprise). On the other hand, Arnold (1960) and Frijda (1986) agreed that emotions should be based on the actions that human makes, so they should have emotions like desire, happiness and sadness. Other studies conducted by Gray (1982), Izard (1971), Panksepp (1982) and Watson (1930) have come up with the basic emotions by observing the pattern of human's behavior, and suggested similar emotions like anger and rage. Table 1 summarizes the existing theories of emotions found from several previous studies.

Among these emotion theories, the six basic emotions identified by Ekman seem to be favored by researchers especially for the emotional expression of robot (Bartneck, 2002; Breazeal et al., 2008). For example, the social robot, eMuu, was designed to express happiness, sadness and anger, after the facial expression theory by Ekman (Bartneck, 2002). Another implementation is WE-4RII which was able to express emotions through three dimensional structures of activation, clarity and pleasantness (Breazeal et al., 2008). However, it should be noted that these theories still need to be validated for various design characteristics of robot until they are generally accepted. In this regard, the present study seeks to find emotions invoked from the appearance of robot and compare them with the basic emotions suggested by the previous studies.

2.3. Visual agent vs. embodied agent

Majorities of the human–robot interaction studies used either pictures or videos to capture the responses of the consumers (DiSalvo et al., 2002; Hegel et al., 2008), because of the practical convenience of conducting the experiment. The use of visual agent

Table 1
Basic emotions from many patients.

Author (year)	Fundamental emotion
McDougall (1926)	Anger, Disgust, Elation, Fear, Subjection, Tender, Wonder
Watson (1930)	Fear, Love, Rage
Arnold (1960)	Anger, Aversion, Courage, Dejection, Desire, Despair, Hate, Hope, Love, Sadness
Izard (1971)	Anger, Contempt, Disgust, Distress, Fear, Guilt, Interest, Joy, Shame, Surprise
Plutchik (1980)	Acceptance, Anger, Anticipation, Disgust, Joy, Fear, Sadness, Surprise
Gray (1982)	Rage, Anxiety, Joy
Ekman et al. (1982)	Anger, Disgust, Fear, Joy, Sadness, Surprise
Panksepp (1982)	Expectancy, Fear, Rage, Panic
Tomkins (1984)	Anger, Interest, Contempt, Disgust, Distress, Fear, Joy, Shame, Surprise
Weiner and Graham (1984)	Happiness, Sadness
Frijda (1986)	Desire, Happiness, Interest, Surprise, Wonder, Sorrow
Oatley and Johnson-Laird (1987)	Anger, Disgust, Anxiety, Happiness, Sadness

has its own advantages in a sense that it overcomes the high technological barriers for manufacturing physical body of the robot and allows for the high degree of freedom in expressing gestures and facial expressions. However, a better approach of testing the perception of robot could be using a real prototype rather than images or video clips since the presentation media may reinforce or attenuate the perception of the robots in an unpredicted way. Especially, it is important to evaluate the effect of embodiment in social robot since most of the services that a social robot provides, such as, information delivery and verbal and visual interactions are also available in visual agent, like avatar (Lee et al., 2006; Powers et al., 2007). Differences of fidelity in prototype evaluation may influence the social interaction behavior and decision making process (Dautenhahn et al., 2002; Jenkins et al., 2011).

A series of empirical studies has tested the effects of embodiment, but the result is not unanimous (Lee et al., 2006; Powers et al., 2007; Takeuchi et al., 2006). Bartneck (2002) examined the effects of embodiment of an emotional robot, and found the effect of embodiment on the enjoyment of the interaction was not significant whereas the social facilitation effect was significant. It implied that the participant of the experiment took the social interaction with physical robot more seriously than with the visual agent. Similarly, another empirical study using Aibo™ showed that people evaluated a physically embodied social agent more positively than disembodied agent. The authors reported that social presence is a key mediating variable on the general evaluation of a social agent in human–robot interaction (Lee et al., 2006; Lee and Nass, 2004). However, a recent experiment conducted with elderly participants in the context of persuasive robot assistant revealed somehow different outcome. Although participants rated higher trust on the physical character, the empathic response was significantly higher in virtual characters (Looije et al., 2010). To clarify such ambiguity, the present study also tests the effects of embodiment in terms of personality perceived and emotion invoked from the overall shape of robot.

3. Method

In order to experimentally measure emotions invoked and personalities perceived from the overall shapes of robot, a series of investigation and experiment was conducted as follows: 1) classification of overall shapes of robot, 2) surface-modeling and fabrication of representative robot, 3) construction of questionnaire and 4) experiments for measuring invoked emotion and perceived personality.

3.1. Classification of overall shapes of robot

For the classification of overall shapes of robot, more than one hundred images of robot were first collected from a variety of sources – cartoon, movie, internet, etc. It was found that the majority of these images were humanoid or near-humanoid robots whose bodies consist of head, trunk and limb. Such prevalence of humanoid and near-humanoid robots could be attributed to our intrinsic preference to the robots sharing morphology similar to human. So, the classification was made by focusing onto only humanoid and near-humanoid robots. In so doing, fifty images of humanoid and near-humanoid robots were randomly selected again from the collected images, and the shape of each body part (head, trunk, arms and legs) was classified into 3–5 categories. Then, the frequencies that these shapes were observed in the selected images were counted. The result is shown in Table 2. In the table, the ‘human-like’ shapes correspond to those which resemble the natural shape of human body. The shapes which do not belong to either the geometrically well-defined shapes – rectangular-parallelepiped and cylindrical, or the human-like shape, were classified as ‘undefined’. When employing all the shapes listed in Table 2 for each of the body parts, it is possible to construct 240 different overall shapes of robot (3 for head $\times$ 3 for trunk $\times$ 4 for arms $\times$ 5 for legs). However, due to the inefficiency in surface-modeling and fabricating the overall shapes of robot, the number of shapes was rationally reduced to 27 (3 for head $\times$ 3 for trunk $\times$ 3 for jointly arms and legs) based on the following rules.

- The overall shape of robot should consist of head, trunk, arms and legs. Therefore, ‘none’ is not considered for the shape of either arms or legs.
- For each of the body parts, three shapes with highest frequencies are selected.
- The same shapes are considered for arms and legs, jointly referred to herein as ‘limb’.

According to the above rules, one of the three shapes for the head should be ‘undefined’. However, this shape cannot be represented by any specific shape. Therefore, ‘cylindrical’ was selected because this shape was employed for both trunk and limb likewise. As a result, the shapes finalized for each of the body parts were rectangular-parallelepiped, cylindrical and human-like.

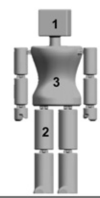
3.2. Surface modeling and fabrication of robot

Once the shapes had been determined for each of the body parts, they were surface-modeled and optimized using a 3D CAD program. The three types of surface models and an example of their assembly are presented in Table 3. In the table, identification (ID) numbers from 1 to 3 were designated to the shapes for each of the

Table 2
Classification of the shape of the body parts.

Shape	Frequency			
	Head	Trunk	Arms	Legs
Rectangular-parallelepiped	7	11	9	15
Cylindrical	–	22	25	8
Human-like	40	17	10	8
Wheeled	–	–	–	6
Undefined	3	–	–	–
None	–	–	6	13

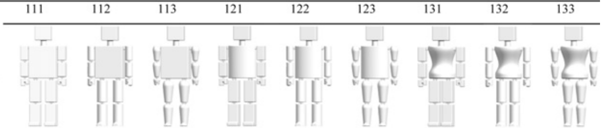
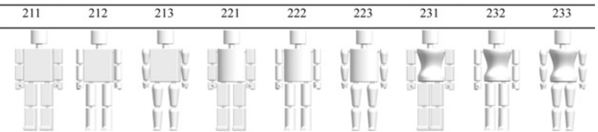
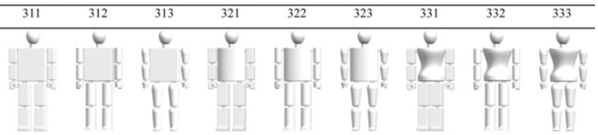
Table 3
Surface-modeled image of the body parts and an example of their assembly.

	Part Shape			Assembly
	Rectangular-parallelepiped ID #: 1	Cylindrical ID #: 2	Human-like ID #: 3	Robot ID # 132
Head Trunk Limb				

body parts. Identification numbers for their assemblies were given by conjugating the ID numbers for the body parts in the order of head, trunk and limb. For example, when the shapes for head, trunk and limb are rectangular-parallelepiped (ID # 1), human-like (ID # 3) and cylindrical (ID # 2), respectively, the ID number for their assembly should be 132 as denoted in Table 3. The surface-modeled images for the body parts shown in the table were transformed to a file format (*.stl) that can be accepted by rapid prototyping machines for fabrication of real prototypes. The real prototypes were fabricated using a 3D printing system manufactured by Objet Geometries Inc. (Model No.: Eden 330). The machine has print resolution of 600 dpi (42 μm) in X axis, 300 dpi (84 μm) in Y axis and 1600 dpi (16 μm) in Z axis, and uses photopolymer for building and support material. All the possible assemblies of the surface-modeled body parts are shown in Table 4 along with their ID numbers. The real prototypes were almost identical to the surface-modeled images shown in the table. Examples of the real prototypes are shown in Fig. 1.

Though very few studies have been made on the psychological effect of robot size, the size of robot seems to influence perceived personalities and invoked emotion. Therefore, a care was taken when determining the height of the real prototypes. Recently, Hiroi and Ito (2011) measured subjective acceptable distance (distance at which a human does not feel any anxiety or threat) and anxiety level varying with the height of robot and participant's posture, and concluded that the acceptable distance and anxiety level decreases with the height of robot. This indicated that, to minimize the anxiety caused by the height of robot, the height needs to be minimized and the distance between participant and robot needs to be maintained beyond the acceptable distance (around 1300 mm for the robot with the height of 1800 mm at seated posture). On the other hand, the height of robots used in the studies on assistive mobile robot is mostly in the range of 700–1850 mm while robots around 1200 mm tall are most often used. This is probably because, for a robot smaller than 700 mm, it would be difficult to integrate the machine components which enable the robot to execute physical tasks such as carrying objects into such a small body. For a robot larger than 1850 mm, it would not only be costly to manufacture such a big body but also difficult to handle it. Considering all, the real prototypes were fabricated with the height of 70 cm, which is the minimum size of robot in practical use as an assistive mobile robot.

Table 4
Possible assemblies of the surface-modeled body parts.

ID #	111	112	113	121	122	123	131	132	133
Overall Shape									
ID #	211	212	213	221	222	223	231	232	233
Overall Shape									
ID #	311	312	313	321	322	323	331	332	333
Overall Shape									

3.3. Questionnaire

Although there are a number of ways to measure emotions, no single solution was validated for answering which component is sufficient for measuring multi-faced emotions. The measurement of emotion ranges from simple pen-and-paper rating scales to complex physiological techniques using brain waves and functional MRI. In spite of several advantages that non-verbal measurement has, such as unobtrusiveness and objectiveness, it also has its limitations in a sense that only limited set of basic emotion can be depicted. This study adopted verbal instrument for measuring emotions since the target emotions were a complex combination of basic emotions and the objective of the study is identifying emotional dimensions invoked by the shape of robot.

In order to match the context of usage, several studies on the emotional responses through human and robot interactions were reviewed. Kanda et al. (2001) adopted 28 adjective pairs and resulted in four emotional factors titled as familiarity, enjoyment, activity and performance. A comparison study of visual agent and embodied robot by Takeuchi et al. (2006) also employed 30 adjective pairs to describe the impression of robot, which are similar to those used by Kanda et al. (2001). Instead of adjective pairs, Scopelliti et al. (2005) used 15 emotional items. Mitsunaga et al. (2008) also used 16 different items to measure the experience of the interaction with robot in their observational study of robot acceptance. The adjectives or adjective pairs used to capture the emotional responses in these studies are summarized in Table 5.

Although the contexts of the previous studies are a bit different, the questionnaire items used in these studies are applicable to the present study. Thus, 15 emotional expressions were finalized for this study by combining similar items used in the previous studies as follows; 'scary', 'dangerous', 'out of control', 'embarrassing', 'overwhelming', 'exciting', 'complex', 'interesting', 'amusing', 'pretty', 'useful', 'relaxing', 'safe', 'accessible' and 'amiable'. Also, 13 personality items were employed from the big-five personality theory to capture the robot's personality. They were 'sociable', 'outgoing', 'confident', 'friendly', 'nice', 'pleasant', 'helpful', 'hard-working', 'emotionally stable', 'adjusted', 'intelligent', 'imaginative' and 'flexible'. The questionnaire used in this study asked how strong these emotion and personalities were invoked and perceived, respectively, when looking at the presented robot. The measurement was made using the 7-point system (1: strongly disagree, 2: disagree, 3: slightly disagree, 4: neutral, 5: slightly agree, 6: agree, 7: strongly agree).

3.4. Experimental design

3.4.1. Variables

In the design of experiment, the overall shape of robot and the presentation type belonged to independent variables. For the overall shape of robot, 27 cases were tested, which were the combination of three different shapes of head, trunk and limb –

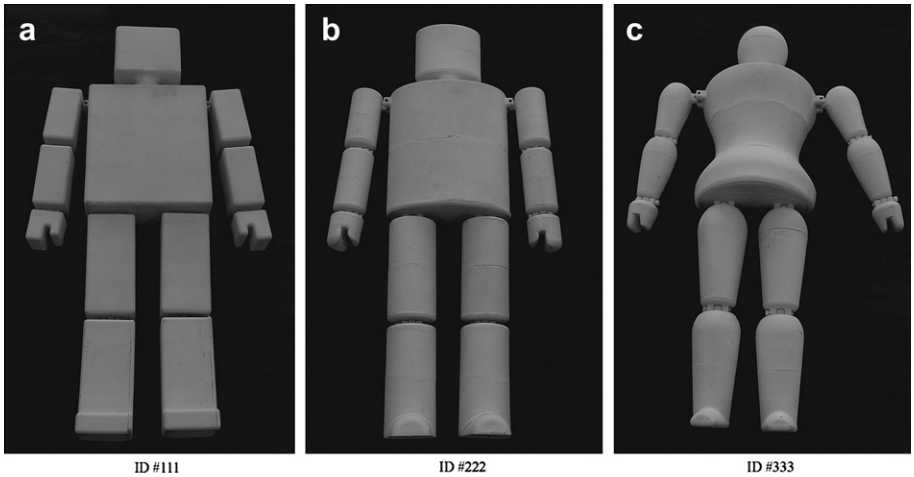


Fig. 1. Examples of real prototypes.

rectangular-parallelepiped, cylindrical and human-like. Two different presentation types were used: visual image and real prototype. For dependent variables, the personalities and emotions specified in the questionnaire were measured using the 7-point system. The independent and dependent variables, and their possible values are summarized in Table 6.

3.4.2. Participants and procedure

A total of 20 university students participated in the experiment. Their ages were in the range of 20–26 (mean: 23.5, SD: 1.61). The numbers of male and female participants were even. The participants were divided into 4 groups, each group having 5 people. The people who belonged to the same group participated in the experiment at the same time. So, the experiment was repeated four times with different participant groups.

During the experiment, all the surface-modeled images and real prototypes of robot were displayed one by one to the participants. For the first two groups, the images were displayed first while, for the other two groups, the real prototypes were displayed first. The display order of the images or the real prototypes was randomly determined prior to the experiment. The participants were given enough time to look at the presented image or real prototype and then completed the questionnaire (about 90 s on average). The next image or real prototype was presented after all the subjects finished answering the questionnaire for the previous one. So, by the time the experiment was completed, a subject had the questionnaire answered for all of the 27 surface-modeled images and 27 real prototypes. That is, 54 sheets of the questionnaire were collected from each participant in total.

Throughout the experiment, other environmental conditions, such as viewing angle, illumination, background color, and screen size were carefully controlled as same. The participants were not allowed to touch but only to see the prototypes beyond a finite distance (around 2.5 m). To prevent potential interaction effects between the participants, they were not allowed to discuss with each other at all throughout the experiment. Table 7 summarizes the environmental conditions used for the experiment.

Table 5
Adjective or adjective pairs used to capture emotional responses.

Author (year)	Adjectives/adjective pairs
Kanda et al. (2001)	Kind–cruel, favorable–unfavorable, friendly–unfriendly, safe–dangerous, warm–cold, pretty–ugly, frank–rigid, distinct–vague, accessible–inaccessible, light–dark, altruistic–selfish, humanlike–mechanical, full–empty, exciting–dull, pleasant–unpleasant, likable–dislikable, interesting–boring, good–bad, complex–simple, rapid–slow, quick–slow, agitated–calm, active–passive, brave–cowardly, showy–quiet, cheerful–lonely, sharp–blunt, intelligent–unintelligent
Takeuchi et al. (2006)	Likable–dislikable, good–bad, pretty–ugly, favorite–unfavorite, interesting–boring, superior–inferior, intelligent–unintelligent, full–empty, considerate–selfish, pleasant–unpleasant, intelligible–unintelligible, warm–cold, exciting–dull, calm–agitated, humanlike–mechanical, friendly–unfriendly, distinct–vague, dynamic–static, cheerful–lonely, showy–quiet, light–dark, frank–rigid, lively–lifeless, active–passive, kind–cruel, rapid–slow, quick–slow, sensible–insensible, aggressive–timid, complicated–simple.
Scopelliti et al. (2005)	Interesting, lively, amusing, dynamic, stimulating, pleasant, useful, relaxing, worrying, scaring, depressing, dangerous, out of control, embarrassing, overwhelming
Mitsunaga et al. (2008)	Cute, amusing, amiable, warm, thoughtful, quiet, awareness, non-obstructive, responsible, diligent, earnest, honest, likeable, active, quick, lively

4. Results

In order to derive guidelines for shaping robots based on perceived personality and invoked emotion, three steps of analyses were conducted. First, the emotion invoked by overall shapes of robots was identified by finding emotional factors from 15

Table 6
Summary of variables.

Variable	Type	Value
Overall shape of robot	Independent	27 cases (3 shapes of head × 3 shapes of trunk × 3 shapes of limb)
Presentation type	Independent	2 cases (visual image, real prototype)
Personalities (sociable, outgoing, confident, friendly, nice, pleasant, helpful, hard-working, emotionally stable, adjusted, intelligent, imaginary, flexible)	Dependent	1–7 points
Emotions (interesting, amusing, useful, relaxing, scary, dangerous, out of control, embarrassing, overwhelming, safe, pretty, accessible, exciting, complex, amiable)	Dependent	1–7 points

Table 7
Summary of the environmental conditions.

	Visual image	Real prototype
Viewing angle	15°	15°
Model color	White	White
Illumination	White light	White light
Background color	Black	Black
Height	70 cm	70 cm

emotional expressions. These emotional factors named the invoked emotion were compared to perceived personality of robots, which consisted of extroverted, agreeable, conscientious, anti-neurotic and open personalities. Second, we examined whether the presentation types – visual image and real prototype, and the shapes of robot head, trunk and limb – rectangular-parallelepiped, cylindrical and human-like shapes, had significant effects on the perceived personality and the invoked emotion. Third, we investigated the interaction effects of the presentation types and the shapes of robot head, trunk and limb on the perceived personality and the invoked emotion.

4.1. Factors for emotional expressions

In this study, 15 emotional expressions – scary, dangerous, out of control, embarrassing, overwhelming, exciting, complex, interesting, amusing, pretty, useful, relaxing, safe, accessible and amiable – were selected and scored to describe the emotion invoked by the overall shapes of robot. Principal components factor analysis on 15 emotional expressions with VARIMAX rotation revealed three underlying factors (see Table 8).

The first factor was found to be related to the emotion of 'concerned' because it involved the emotional expressions of 'scary', 'dangerous', 'out of control', 'embarrassing', 'overwhelming', 'exciting' and 'complex'. These expressions represented relatively negative feelings for robot shapes. The second factor was named the emotion of 'enjoyable' because it belonged to the emotional expressions of 'interesting', 'amusing' and 'pretty'. The third factor was related to 'favorable' because it included the emotional expressions of 'useful', 'relaxing', 'safe', 'accessible' and 'amiable'. The second and the third factors represented relatively positive feelings for robot shapes.

Table 8
Factor analysis for emotional expressions to overall shapes of robot.

Emotional expressions	Factor 1	Factor 2	Factor 3	Communality estimates
Scary	**0.7957**	−0.3366	−0.1233	0.7617
Dangerous	**0.8534**	−0.2609	−0.1357	0.8148
Out of control	**0.8234**	−0.1100	−0.2384	0.7470
Embarrassing	**0.8129**	−0.1200	−0.2457	0.7355
Overwhelming	**0.7848**	−0.2413	−0.0420	0.6759
Exciting	**0.6464**	0.1228	−0.2135	0.4785
Complex	**0.6881**	0.0878	−0.2134	0.5267
Interesting	−0.0516	**0.9020**	0.2191	0.8642
Amusing	−0.0602	**0.9023**	0.2235	0.8676
Pretty	−0.2082	**0.6659**	0.4932	0.7300
Useful	−0.0960	0.2475	**0.7278**	0.6001
Relaxing	−0.3193	0.4677	**0.6043**	0.6859
Safe	−0.2782	0.0774	**0.7824**	0.6955
Accessible	−0.3211	0.5067	**0.6205**	0.7449
Amiable	−0.2300	0.5090	**0.6749**	0.7674
Variance explained by each factor	4.6015	3.1618	2.9322	10.6956

Notes. Factor loadings (>0.60) in bold type were considered to be significant. Three factors explained 71% of total sample variance.

Summing up, the overall shapes of robot aroused any of the three emotions named 'concerned', 'enjoyable' and 'favorable'. These three emotions represented both negative and positive feelings for robot shapes, but the positive feelings were divided into two kinds of emotion: 'enjoyable' and 'favorable'. It seems that the positive feelings were more discernible than the negative feelings for robot shapes.

4.2. Perceived personality and invoked emotion

In this study, perceived personality and invoked emotion were the two main dependent variables. 'Perceived personality' is defined as the personality of robot that is perceived by humans when looking at the overall shapes of robot, and 'invoked emotion' is defined as the emotion of humans that is invoked when looking at the overall shapes of robot. Five personality factors named 'Big Five Personality Traits' were used to measure the perceived personality, and three emotions invoked by overall shapes of robot were explained in the previous section.

In this section, we examined the internal consistency of measures for each factor that belonged to perceived personality and invoked emotion to confirm the reliability of measures based on our data. We also investigated the relationship between perceived personality and invoked emotion. As shown in Table 9, the values of Cronbach's alpha (Cronbach, 1951) for perceived personality factors ranged from 0.8184 to 0.9035, and those for invoked emotion factors existed between 0.8757 and 0.9083. Thus, all measures for each factors of perceived personality and invoked emotion showed high internal consistency ($\alpha > 0.7$).

The correlation analysis was conducted to investigate the relationship between perceived personality and invoked emotion. As seen in Table 10, each of the five 'perceived personality' factors is significantly correlated with the emotion of 'concerned' in a negative direction, and with the emotions of 'enjoyable' and 'favorable' in a positive direction. The correlation of each 'perceived

Table 9
Factors of perceived personality and invoked emotion.

	Factors	Measures	Cronbach's alpha
Perceived personality[a]	Extroverted	Sociable Outgoing Confident	0.8619
	Agreeable	Friendly Nice Pleasant	0.9035
	Conscientious	Helpful Hard-working	0.8212
	Anti-neurotic	Emotionally stable Adjusted	0.8184
	Open	Intelligent Imaginative Flexible	0.8218
Invoked emotion	Concerned	Scary Dangerous Out of control Embarrassing Overwhelming Exciting Complex	0.9083
	Enjoyable	Interesting Amusing Pretty	0.8848
	Favorable	Useful Relaxing Safe Accessible Amiable	0.8757

[a] Source: Big five personality inventory.

Table 10
Correlation between factors of perceived personality and invoked emotion.

		Concerned	Enjoyable	Favorable
Extroverted	r-Value	−0.2845	0.6846[a]	0.6113[a]
	p-Value	<0.0001	<0.0001	<0.0001
	n	1079	1080	1080
Agreeable	r-Value	−0.4399	0.7310	0.7152
	p-Value	<0.0001	<0.0001	<0.0001
	n	1079	1080	1080
Conscientious	r-Value	−0.3953	0.4165[b]	0.6844[b]
	p-Value	<0.0001	<0.0001	<0.0001
	n	1079	1080	1080
Anti-neurotic	r-Value	−0.5365	0.4243[c]	0.7329[c]
	p-Value	<0.0001	<0.0001	<0.0001
	n	1079	1080	1080
Open	r-Value	−0.3391	0.6287	0.6663
	p-Value	<0.0001	<0.0001	<0.0001
	n	1079	1080	1080

Notes. There are statistically significant differences between r-values of 'Enjoyable' and 'Favorable'.
[a] 'Extroverted–Enjoyable ($r = 0.6846$)' > 'Extroverted–Favorable ($r = 0.6113$)' with $p = 0.0033$.
[b] 'Conscientious–Enjoyable ($r = 0.4165$)' < 'Conscientious–Favorable ($r = 0.6844$)' with $p < 0.0000$.
[c] 'Anti-neurotic–Enjoyable ($r = 0.4243$)' < 'Anti-neurotic–Favorable ($r = 0.7329$)' with $p < 0.0000$.

personality' with the two positive emotional factors of 'enjoyable' and 'favorable' was compared using Fisher's z transformation to test the degree of correlation. The results show that 'extroverted' personality is more correlated with 'enjoyable' emotion than with 'favorable' emotion ($p = 0.0033$); 'conscientious' personality is more correlated with 'favorable' emotion than with 'enjoyable' emotion ($p < 0.0000$); and 'anti-neurotic' personality is more correlated with 'favorable' emotion than with 'enjoyable' emotion ($p < 0.0000$). In sum, 'perceived personality' factors are negatively correlated with 'concerned' emotion and positively correlated with 'enjoyable' and 'favorable' emotions. More specifically, 'extroverted' personality is highly correlated with 'enjoyable' emotion, but 'conscientious' and 'anti-neurotic' personalities are highly correlated with 'favorable' emotion.

4.3. Main effects of presentation type and appearance type of robots

Analysis of Variance (ANOVA) was conducted to investigate the effects of presentation type and appearance type of robot on perceived personality and invoked emotion. Table 11 summarizes ANOVA results, which show the main effects of presentation type and appearance type of robot head, trunk and limb. First, the presentation type has significant effects on all of the five 'perceived personality' factors and two 'invoked emotion' factors. Specifically, all of the five 'perceived personality' factors and 'enjoyable' and 'favorable' emotions are more strongly perceived through the real prototype than through visual image (see 'Presentation' column in Table 11).

Second, the robot head has significant effects on 'extroverted', 'conscientious' and 'anti-neurotic' personality factors, and 'enjoyable' and 'favorable' emotion factors. For instance, the cylindrical head makes robots perceived as more extroverted, conscientious and anti-neurotic, and invokes more 'favorable' emotion than the human-like head. Also, the rectangular-parallelepiped head invokes more 'enjoyable' emotion than the human-like head (see 'Head' column in Table 11).

Third, the robot trunk has significant effects on all of the five 'perceived personality' factors and 'enjoyable' and 'favorable' emotion factors. According to the results of multiple comparison tests, specifically, the human-like trunk makes robots perceived as more extroverted than the cylindrical and rectangular-parallelepiped trunks; as more agreeable than the cylindrical and rectangular-parallelepiped trunks; as more conscientious than the rectangular-parallelepiped trunk; and as more open than the cylindrical and rectangular-parallelepiped trunks. Also, the human-like trunk invokes more 'enjoyable' emotion than the cylindrical and rectangular-parallelepiped trunks, and more 'favorable' emotion than the rectangular-parallelepiped trunk. In the mean time, the cylindrical trunk makes robots perceived as more anti-neurotic than the human-like and rectangular-parallelepiped trunks (see 'Trunk' column in Table 11).

Finally, the robot limb has significant effects on all of the five 'perceived personality' factors and all of the three 'invoked emotion' factors. For instance, the cylindrical limb makes robots perceived as more extroverted, agreeable and open than the rectangular-parallelepiped limb; as more conscientious than the human-like limb; and as more anti-neurotic than the rectangular-parallelepiped and human-like limbs. Also, the cylindrical limb invokes more 'enjoyable' emotion than the rectangular-parallelepiped limb; and more 'favorable' emotion than the human-like and rectangular-parallelepiped limbs. By the way, the human-like limb makes robots perceived as more extroverted, agreeable and open than the rectangular-parallelepiped limb. Also, the human-like limb invokes more 'concerned' emotion and 'enjoyable' emotion than the rectangular-parallelepiped limb (see 'Limb' column in Table 11).

In sum, compared to the visual images, the real prototypes of robot result in higher scores on all of the personality of robots, and the positive emotions of 'enjoyable' and 'favorable'. As for the robot head, the cylindrical type is recommended to make humans perceive 'extroverted', 'conscientious' and 'anti-neurotic' personality, and to invoke 'favorable' emotion from robots. As for the robot trunk, the human-like type is the best to make humans perceive 'extroverted', 'agreeable', 'conscientious' and 'open' personality, and to invoke 'enjoyable' and 'favorable' emotion from robots, whereas the cylindrical type is the best to make humans perceive 'anti-neurotic' personality from robots. As for the robot limb, the cylindrical type is recommended to make humans perceive all of the five personality factors, and to invoke the least 'concerned' emotion and the most 'enjoyable' and 'favorable' emotions from robots, whereas the human-like type is also recommended to make humans perceive 'extroverted', 'agreeable' and 'open' personality and to invoke 'enjoyable' emotion from robots. These results are reflected in Table 12, which shows the recommendation of overall shapes of robots.

4.4. Interaction effects between presentation type and appearance type of robots

In this section, we investigated whether the effects of appearance type of robots would vary with the presentation type. The last three columns in Table 11 show the results of interaction effects between the presentation type and the appearance type of robot head, trunk and limb.

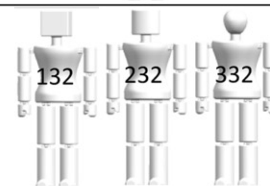
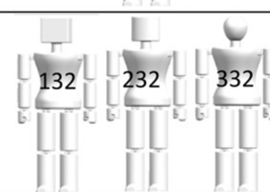
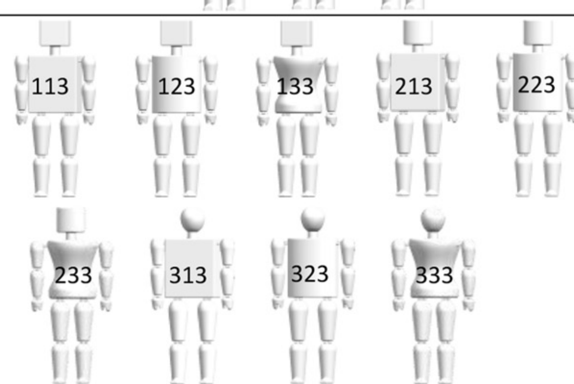
First of all, the interaction effects between the presentation type and the appearance type of robot head are significant on 'conscientious' personality factor and 'enjoyable' emotion (see 'Presentation * Head' column in Table 11). Specifically, the human-like head of the real prototype is significantly perceived as more 'conscientious' than the human-like head of the visual image, and the cylindrical heads of the real prototype invoke significantly more

Table 11
ANOVA results for perceived personality and invoked emotion.

Dependent variables		Presentation	Head	Trunk	Limb	Presentation * head	Presentation * trunk	Presentation * limb
Perceived personality	Extroverted	$F(1,1066) = 21.35$, $p < 0.0001$ (Real > Visual)	$F(2,1066) = 3.94$, $p = 0.0197$ (Cy, Pa > Hu)	$F(2,1066) = 25.21$, $p < 0.0001$ (Hu > Cy > Pa)	$F(2,1066) = 24.56$, $p < 0.0001$ (Hu, Cy > Pa)	$F(2,1066) = 0.55$, $p = 0.5794$ –	$F(2,1066) = 4.20$, $p = 0.0153$ (Real: Hu > Pa), (Visual: Hu > Cy > Pa)	$F(2,1066) = 7.46$, $p = 0.0006$ (Real: Cy, Hu > Pa), (Visual: Hu > Cy > Pa)
	Agreeable	$F(1,1066) = 25.96$, $p < 0.0001$ (Real > Visual)	$F(2,1066) = 1.94$, $p = 0.1446$ –	$F(2,1066) = 21.32$, $p < 0.0001$ (Hu > Cy > Pa)	$F(2,1066) = 14.14$, $p < 0.0001$ (Cy, Hu > Pa)	$F(2,1066) = 0.49$, $p = 0.6122$ –	$F(2,1066) = 2.77$, $p = 0.0631$ –	$F(2,1066) = 11.43$, $p < 0.0001$ (Real: Cy > Pa, Hu), (Visual: Hu > Cy > Pa)
	Conscientious	$F(1,1066) = 6.01$, $p = 0.0144$ (Real > Visual)	$F(2,1066) = 6.90$, $p = 0.0011$ (Cy > Pa, Hu)	$F(2,1066) = 3.61$, $p = 0.0273$ (Hu, Cy > Pa)	$F(2,1066) = 7.24$, $p = 0.0007$ (Cy, Pa > Hu)	$F(2,1066) = 3.84$, $p = 0.0217$ (Real: Cy, Hu, Pa), (Visual: Cy, Pa > Hu)	$F(2,1066) = 0.46$, $p = 0.6286$ –	$F(2,1066) = 2.52$, $p = 0.0810$ –
	Anti-neurotic	$F(1,1066) = 4.81$, $p = 0.0286$ (Real > Visual)	$F(2,1066) = 4.27$, $p = 0.0142$ (Cy > Hu)	$F(2,1066) = 4.84$, $p = 0.0081$ (Cy > Hu, Pa)	$F(2,1066) = 24.77$, $p < 0.0001$ (Cy > Pa > Hu)	$F(2,1066) = 1.75$, $p = 0.1736$ –	$F(2,1066) = 0.90$, $p = 0.4074$ –	$F(2,1066) = 1.46$, $p = 0.2317$ –
	Open	$F(1,1066) = 25.68$, $p < 0.0001$ (Real > Visual)	$F(2,1066) = 0.73$, $p = 0.4824$ –	$F(2,1066) = 21.25$, $p < 0.0001$ (Hu > Cy > Pa)	$F(2,1066) = 12.42$, $p < 0.0001$ (Cy, Hu > Pa)	$F(2,1066) = 0.47$, $p = 0.6226$ –	$F(2,1066) = 5.72$, $p = 0.0034$ (Real: Hu > Pa), (Visual: Hu > Cy > Pa)	$F(2,1066) = 4.41$, $p = 0.0124$ (Real: Cy > Hu, Pa), (Visual: Hu, Cy > Pa)
Invoked emotion	Concerned	$F(1,1065) = 1.37$, $p = 0.2428$ –	$F(2,1065) = 0.95$, $p = 0.3885$ –	$F(2,1065) = 2.85$, $p = 0.0585$ –	$F(2,1065) = 19.00$, $p < 0.0001$ (Hu > Pa > Cy)	$F(2,1065) = 1.36$, $p = 0.2559$ –	$F(2,1065) = 1.07$, $p = 0.3451$ –	$F(2,1065) = 1.27$, $p = 0.2819$ –
	Enjoyable	$F(1,1066) = 46.32$, $p < 0.0001$ (Real > Visual)	$F(2,1066) = 3.94$, $p = 0.0198$ (Pa > Hu)	$F(2,1066) = 16.61$, $p < 0.0001$ (Hu > Cy > Pa)	$F(2,1066) = 28.42$, $p < 0.0001$ (Hu, Cy > Pa)	$F(2,1066) = 3.35$, $p = 0.0353$ (Real: Cy, Pa > Hu), (Visual: Pa > Cy)	$F(2,1066) = 3.32$, $p = 0.0366$ (Real: Hu > Pa), (Visual: Hu > Cy > Pa)	$F(2,1066) = 14.89$, $p < 0.0001$ (Real: Cy > Hu, Pa), (Visual: Hu > Cy > Pa)
	Favorable	$F(1,1066) = 24.05$, $p < 0.0001$ (Real > Visual)	$F(2,1066) = 4.46$, $p = 0.0118$ (Cy, Pa > Hu)	$F(2,1066) = 10.13$, $p < 0.0001$ (Hu, Cy > Pa)	$F(2,1066) = 8.95$, $p = 0.0001$ (Cy > Hu, Pa)	$F(2,1066) = 2.06$, $p = 0.1285$ –	$F(2,1066) = 1.70$, $p = 0.1839$ –	$F(2,1066) = 8.86$, $p = 0.0002$ (Real: Cy > Pa > Hu), (Visual: Hu, Cy > Pa)

Notes. Real: Real prototype, Visual: Visual image, Pa: Rectangular-Parallelepiped, Cy: Cylindrical, Hu: Human-Like, (): Results from the multiple comparison tests ($\alpha = 0.05$).

Table 12
Overall shapes of robot that is recommended to grant the specified personalities or invoke the specified emotions.

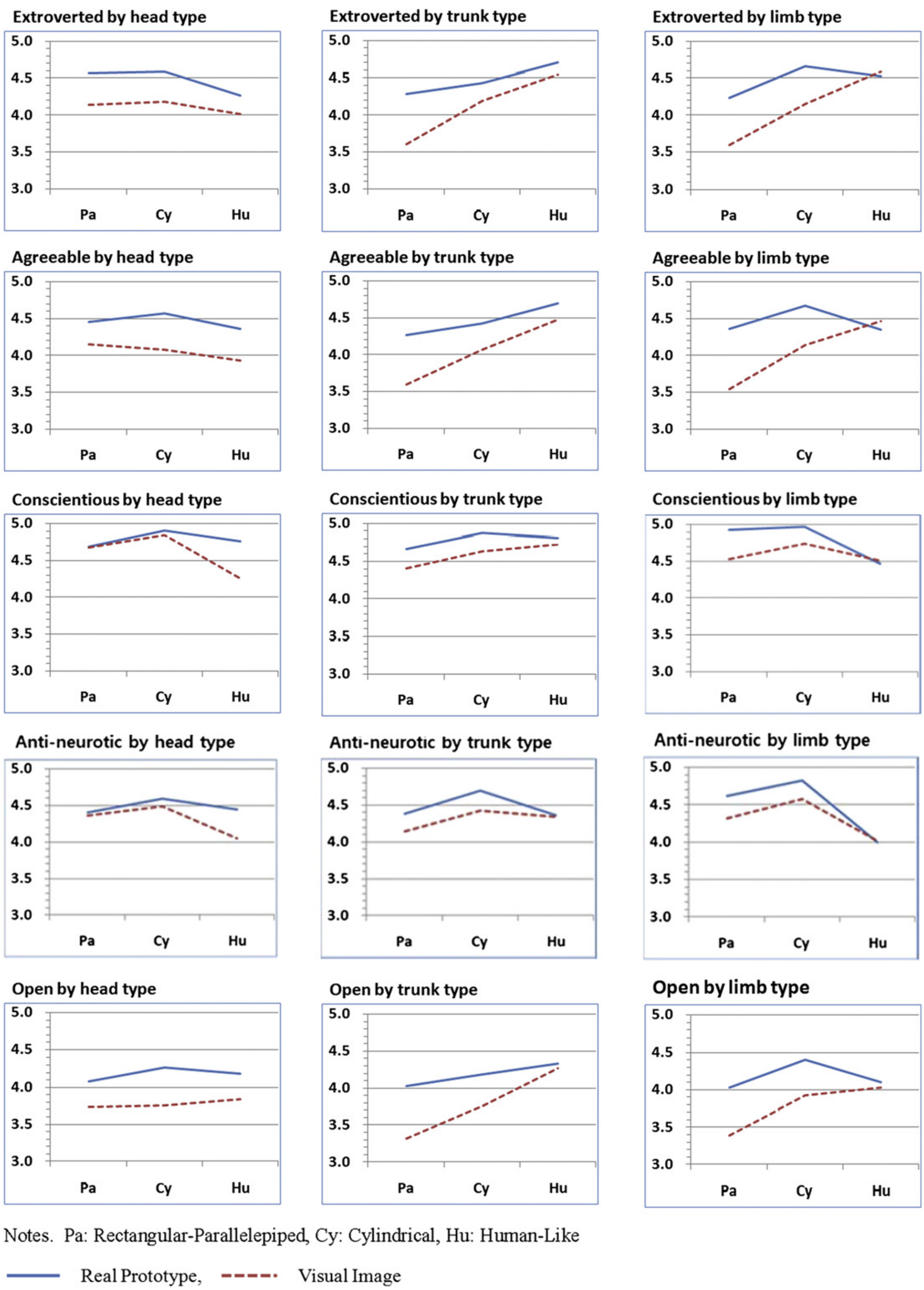
Dependent Variables		Head	Trunk	Limb	Assembly
Perceived Personality	Extroverted	Cy (2)	Hu (3)	Hu (3)	
	Agreeable		Hu (3)	Cy (2)	
	Conscientious	Cy (2)	Hu (3)	Cy (2)	
	Anti-neurotic	Cy (2)	Cy (2)	Cy (2)	
	Open		Hu (3)	Cy (2)	
Invoked Emotion	Concerned			Hu (3)	
	Enjoyable	Pa (1)	Hu (3)	Hu (3)	
	Favorable	Cy (2)	Hu (3)	Cy (2)	

Notes. Pa: Rectangular-Parallelepiped, Cy: Cylindrical, Hu: Human-Like, (): Identification number.

‘enjoyable’ emotion than those of the visual image (see ‘conscientious by head type’ and ‘enjoyable by head type’ in Fig. 3).

Second, the interaction effects between the presentation type and the appearance type of robot trunk are significant on ‘extroverted’ and ‘open’ personality factors and ‘enjoyable’ emotion (see ‘Presentation * Trunk’ column in Table 11). For instance, the rectangular-parallelepiped trunk of the real prototype is significantly perceived as more ‘extroverted’ and ‘open’, and invokes significantly more ‘enjoyable’ emotion than the rectangular-parallelepiped trunk of the visual image (see ‘extroverted by trunk type’ and ‘open by trunk type’ in Fig. 2; and ‘enjoyable by trunk type’ in Fig. 3).

Finally, the interaction effects between the presentation type and the appearance type of robot limb are significant on ‘extroverted’, ‘agreeable’ and ‘open’ personality factors, and ‘enjoyable’ and ‘favorable’ emotions (see ‘Presentation * Limb’ column in



Notes. Pa: Rectangular-Parallelepiped, Cy: Cylindrical, Hu: Human-Like

Fig. 2. Interaction plots for perceived personality (presentation type vs. head, trunk, limb type).

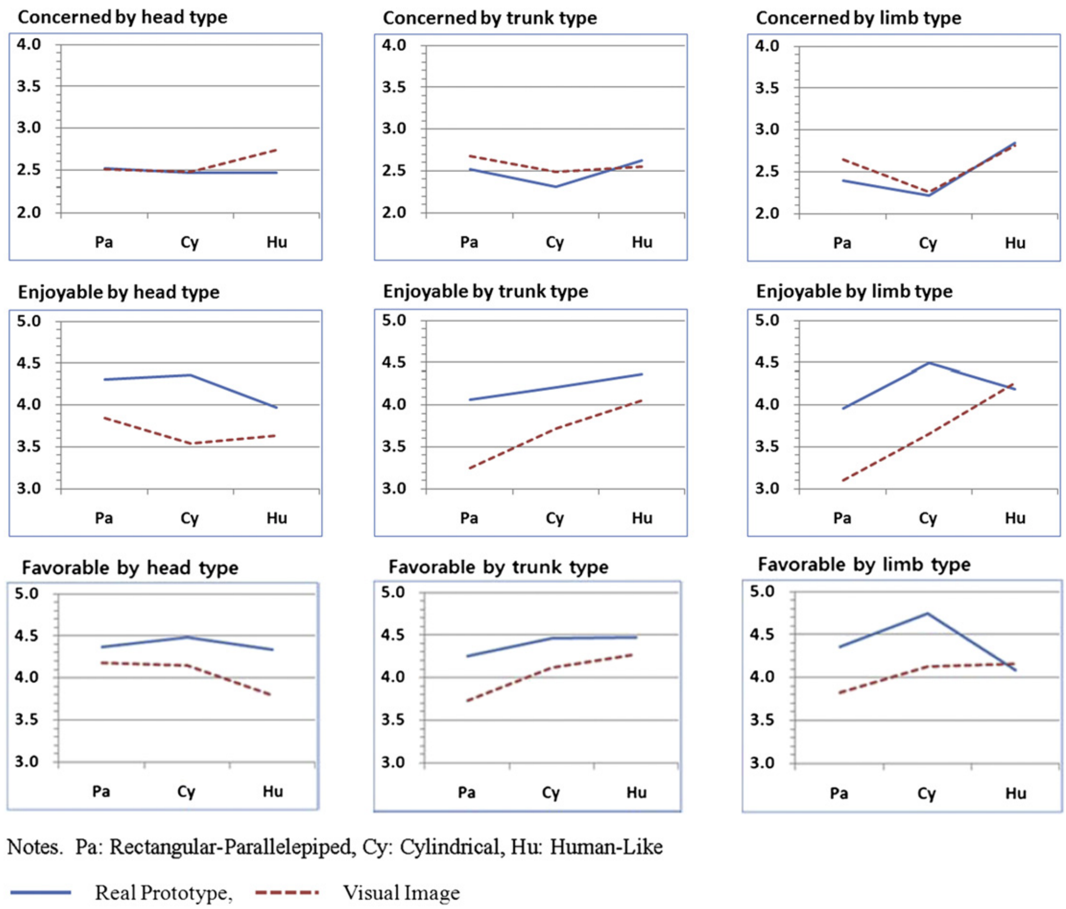


Fig. 3. Interaction plots for invoked emotion (presentation type vs. head, trunk, limb type).

Table 11). Specifically, the rectangular-parallelepiped limbs of the real prototype are significantly perceived as more 'extroverted', 'agreeable' and 'open', and invoke significantly more 'enjoyable' emotion than those of the visual image (see 'extroverted by limb type', 'agreeable by limb type' and 'open by limb type' in Fig. 2; and 'enjoyable by limb type' in Fig. 3). Likewise, the cylindrical limbs of the real prototype invoke significantly more 'favorable' emotion than those of the visual image (see 'favorable by limb type' in Fig. 2).

In sum, the significant and relatively big difference between the real prototype and the visual image exists in the human-like head for 'conscientious' personality factor, the rectangular-parallelepiped trunk for 'extroverted' and 'open' personality factors, the rectangular-parallelepiped limb for 'extroverted', 'agreeable' and 'open' personality factors, the cylindrical head for 'enjoyable' emotion, the rectangular-parallelepiped trunk for 'enjoyable' emotion, the rectangular-parallelepiped limb for 'enjoyable' emotion, and the cylindrical limb for 'favorable' emotion. When rendering these perceived personalities onto a robot or invoking these emotions from a robot, the real prototype is more effective than the visual image.

5. Discussion and conclusions

In the present study, the effects of overall shape of robot on the emotions invoked in users and the perceived personalities of robot have been experimentally investigated. Here, the implications of the findings made in this study are discussed, and the guidelines for the affective design of robot shapes are drawn based on the discussion as follows.

First, it was found that the perceived personality factors are negatively correlated with the 'concerned' emotion but positively correlated with the 'enjoyable' and 'favorable' emotions. More specifically, the 'extroverted' personality is highly correlated with the 'enjoyable' emotion, and the 'conscientious' and 'anti-neurotic' personalities are highly correlated with the 'favorable' emotion. Such information on the relationships between perceived personalities and invoked emotions as described above is very useful for affective design of robot shapes. For example, when one intends to design a robot whose overall shape invokes the 'enjoyable' emotion but has a clearer image of the robot shape which has the 'extroverted' personality instead, he or she can use the shape for 'extroverted' personality effectively due to the correlation between the 'extroverted' personality and the 'enjoyable' emotion. Also, when one intends to design a robot which has the 'conscientious' or 'anti-neurotic' personality but has a clearer image of the robot shape which can invoke the 'favorable' emotion, the shape for 'favorable' emotion can be employed for the purpose likewise.

Second, it was found that all of the five 'perceived personality' factors, and 'enjoyable' and 'favorable' emotions are more strongly perceived or invoked through the real prototype than the visual image. This result matches with the previous findings in a sense that embodied model generates more sense of presence and, in turn, increases the ratings of perceived personality and emotions (Lee et al., 2006; Lee and Nass, 2004). This finding indicates that the evaluation of perceived personality and emotion through visual image tends to be conservative. That is, robot shapes capable of invoking desired emotions to users or bestowing preferred personalities to robot can be ruled out in the evaluation process if the evaluation is made through only visual images. This is contrasted to the case for 'concerned' emotion which did not show significant difference in the effects of the presentation type. This indicates that the evaluation of robot shapes for affective design should be made through appropriate evaluation media depending upon the interested personality and emotion.

On the other hand, the difference in the effects of the presentation type tends to increase in the order of rectangular-parallelepiped, cylindrical and human-like for head. For both trunk and limb, the difference is highest in rectangular-parallelepiped but almost negligible in human-like. This may be because reality of the visual images is enhanced when the shapes for trunk and limb are human-like. This also indicates that, when the human-like shapes are preferred for the shapes of both trunk and limb, design concepts can be validated and optimized through their visual images.

Third, the best combination of the shapes for head, trunk and head which would grant the preferred personality to robot or invoke the desired emotion to human was recommended as shown in Table 12. This can be utilized to establish guidelines for affective design of overall robot shape. For example, in the table, it is noticed that the robot shape consisting of cylindrical head, human-like trunk, and cylindrical head (232) is best for 'conscientious' personality and 'favorable' emotion. So, this shape would be most appropriate for service robots such as reception robot, telling robot and housekeeping robot which need to make the users feel comfortable and thus accept them easily. For the same reason, the robot shape which consists of cylindrical head, cylindrical trunk, and cylindrical limb (222) and was found to be best for 'anti-neurotic' personality would be most appropriate for these kinds service robot. In the mean time, the robot shape consisting of cylindrical head, human-like trunk, and human-like limb (233) was found to be best for 'extroverted' personality. Therefore, for education robots which need to encourage students to be actively involved in the class, this shape could be considered most appropriate. For entertaining robots which need to give pleasure to users, the robot shape of rectangular-parallelepiped head, human-like trunk and human-like limb (133) would be the best because this shape was found to invoke 'enjoyable' emotion most effectively. Besides to these, various combinations of the shapes for head, trunk and limb could be selected so that they can meet the requirements in terms of the perceived personality and the invoked emotion.

As described above, the findings made in the present study could be utilized when one intends to make affective design of robot shape in terms of perceived personality and invoked emotion. To utilize them more effectively, it is worthy to speculate the limitations of the present study. One of them would be that it did not cover wider population since the participants were from university student samples. If the participants were from bigger population covering different age groups and backgrounds, the findings of this study would be more widely generalizable. However, considering that the selected participants represented young adults with good education background who were supposed to be the early adopter of the social robot in the future, the experimental outcome could be used as a directional guideline for designing humanoid robots.

Another main limitation of this study is that the tested robot does not exhaustively represent the total design spaces. In other words, the selected design cannot cover all sorts of design features considered in the development of humanoid or near-humanoid robot. However, since the design space is too big and design variables are too many, it is not feasible to include all the factors and make it as a single shot study. Instead, it would be more practical to make a series of parametric studies to investigate the effects of design factors one by one independently, and then synthesize the results to draw any conclusive or generalized guidelines. In this context, this study is meaningful in that it made a first step for such a long journey, and the tendency found in this study would give the directions for development of humanoid robots.

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