# The Uncanny Valley: Effect of Realism on the Impression of Artificial Human Faces

**Abstract**

Roboticists believe that when a humanoid robot has an almost, but not perfectly, realistic human appearance, humans will have unpleasant impressions of such a robot. This hypothetical relationship between a robot's degree of realism in physical appearance and a human's impression of the robot is called the "uncanny valley". The hypothesis of the uncanny valley is not limited to robots, but is also applicable to any type of human-like object, such as dolls, masks, facial caricatures, avatars in virtual reality, and characters in CG movies. The present study reports psychological evidence for the roboticists' traditional belief. We measured observers' impressions of facial images whose degree of realism was manipulated by morphing between artificial and real human faces. The facial images yielded the most unpleasant impressions when they were highly realistic, supporting the roboticists' hypothesis of the uncanny valley. However, the uncanny valley was confirmed only when morphed faces had abnormal features such as bizarre eyes. These results suggest that to have an almost perfectly realistic human appearance is not a sufficient condition for the uncanny valley: it emerges when an abnormality is made apparent for a highly realistic appearance.

## 1. Introduction

Roboticists have attempted to construct humanoid robots whose physical appearance is indistinguishable from real humans (e.g., Kobayashi *et al.*, 2003; Minato *et al.*, 2004a; Minato *et al.*, 2004b). Mori (1970) warned, however, that robots should not be made too similar to real humans because such robots can fall into the uncanny valley (see also, Norman, 2004; Reichardt, 1978).

To summarize his informal observation on and prediction of how a robot's degree of realism in physical appearance (or human-likeness) can affect a human observer's impression of the robot, Mori introduced a hypothetical plot of the impression as a function of the degree of realism. Although the degree of realism was defined as a robot's physical similarity to real humans, the impression for the ordinate of the plot was not clearly defined. One definition consistent with Mori's conjecture is that the ordinate numerically represents degrees of any pleasant impressions (e.g. attractive, pretty, and fascinating impressions) in the positive range and any unpleasant impressions (e.g. unattractive, ugly, and uncanny impressions) in the negative range. In Mori's hypothetical plot, a good impression of a robot grows with an increasing degree of realism. For example, Honda ASIMO (Sakagami et al., 2002) may be more attractive than industrial robots. Mori pointed out, however, that human observers have exceptionally unpleasant impressions of robots that have almost, but not perfectly, realistic human appearance. This effect was illustrated in Mori's hypothetical plot as a negative peak at a relatively higher level of realism. Mori called this negative peak the uncanny valley, by analogizing the function shape of his hypothetical plot to a mountain. Along the abscissa of Mori's hypothetical plot, not only robots but also various kinds of humanlike artificial objects (e.g. dolls, mannequins, and prosthetic hands) were sorted in (Mori's subjective) order of the degree of realism. Thus, Mori's hypothesis is not limited to robots but is also applicable to any type of artificial human-like object.

The physical appearance of robots that are supposed to communicate, cooperate, and coexist with humans should be designed with due consideration of the emotional and psychological impact on human observers. The same holds true for the physical appearances of agents in virtual reality and characters in computer graphics movies. In fact, Mori's advocacy is acknowledged as a guideline to design the physical appearance of robots (Cañamero & Fredslund, 2001; DiSalvo *et al.*, 2002; Fong *et al.*, 2003; Hinds *et al.*, 2004; Minato et al., 2004a; Minato et al., 2004b; Woods *et al.*, 2004) and agents in virtual reality (Aylett, 2004; Fabri *et al.*, 2004; Wages *et al.*, 2004). According to Mori's hypothesis, designers must seek a moderate level of realism for the physical appearances of robots and virtual reality agents in order to avoid falling into the uncanny valley.

However, feasibility of the uncanny valley has not been confirmed with psychological evidence. Thus it is still uncertain whether or not the uncanny valley actually emerges depending on the degree of realism, and why the uncanny valley is expected to emerge at a relatively higher degree of realism. In the present study we measured observers' impressions of facial images with various degrees of realism. The degree of realism was manipulated by morphing between images of artificial and real human faces. Thus, the degree of realism was represented as a morphing percentage (% real human). The artificial face images used in this study were photographs of dolls and computer graphics images of human models. Participants in each experiment rated their impressions of the morphed images using five-point scale scores. The rated scores were plotted against the degree of realism in order to empirically obtain Mori's hypothetical plot.

In addition to the emergence of the uncanny valley, Mori assumed that the level of impression is zero (i.e. neutral impression) when the realism of robots is extremely low (e.g. industrial robots) and highest for perfectly realistic human appearance. In other words, he assumed that the level of impression increases monotonically with an increasing degree of realism, except for the uncanny valley. However, this assumption seems unlikely. In fact, some robots, dolls, and human characters in computer graphics films are highly attractive, but some are extremely unattractive. Similarly, some real humans are highly attractive, but some are not so attractive. Thus, the impression-realism plot would not necessarily show the increasing trend of the impression. Therefore, in the present study, we focus only on whether or not the negative peak, that is, the uncanny valley, would actually emerge in the empirically obtained realism-impression plot.

## 2. Methods

### *2.1. Participants*

The experiments were web-based. Each participant accessed a web page using a web browser. They were first guided to pages where they read instructions, and then they decided whether or not to participate in this study.

### *2.2. Stimuli*

Stimuli were frames of image sequences in which an artificial face was gradually morphed into a real face. Examples of the stimuli are shown in Figures 1, 3, and 5. To define correspondences between the two source images (i.e., artificial and real facial images), landmarks on each face were manually chosen. The numbers of the landmarks were 9 for each eye, 8 for each eyebrow, 9 for nose, 14 for mouth, and

26 for facial contour. Morphing software transformed positions and pixel values between corresponding points of artificial and real faces. Morphing ratios, which controlled the magnitudes of the morphing, were defined as percentages of real human. Thus, an image with a morphing ratio of 0% implied an unmorphed image of an artificial face, and an image with a morphing ratio of 100% implied a perfectly realistic human face image. Each face was presented on a uniform square background with a height and width of 256 pixels. Size and orientation of each face were normalized so that the eyes were aligned along a horizontal line passing through the center of each image. The distance between the left and right pupils was 60 pixels. The actual size of the stimuli measured in visual angle is not known, because it depended on the viewing condition of each participant when he/she accessed the web page for the experiments.

### *2.3. Procedure*

Each participant executed JavaScript programs in a web browser. In each trial a stimulus image and five buttons were presented in the web browser window. Each of the five buttons showed a Japanese phrase implying “extremely unpleasant,” “unpleasant,” “difficult to decide (uncertain),” “pleasant,” or “extremely pleasant.” These buttons represented a five-point scale ranging from -2 (extremely unpleasant) to +2 (extremely pleasant). Each participant rated the impression of the presented image and clicked the appropriate button using a mouse or similar device. After the button was clicked, the stimulus image was replaced with a uniform black field for 1 s, and then the next trial started. The images for each experiment were presented in random order. Participants performed two practice trials at the beginning of each experiment. At the end of each experiment, participants sent the data, as well as their age and gender to the authors. At this stage, participants were able to decide whether or not to send the data.

*2.4. Data analysis*

The impression scores for each experiment were averaged across participants and submitted to repeated-measures ANOVAs, in which the morphing ratio (% real human) defined for each experiment was a factor. When necessary, Bonferroni's multiple comparisons were performed.

## 3. Results and Discussion

*3.1. Experiment 1*

Let us hypothesize that almost, but not perfectly, realistic human appearance possesses an exceptional perceptual significance and that for some reason the human visual system generates an unpleasant impression of such a "special" degree of realism. This hypothesis predicts that the uncanny valley would always emerge during the course while the degree of realism is increased from a relatively lower level toward the highest level.

To test this, we showed the participants images from three types of image sequences, in each of which an artificial face was gradually morphed into a real human face (Figure 1). The morphing ratio varied from 0% to 100% in increments of 10%. Forty-nine participants (mean age 26.5 years, 20 female) rated the impression of the face images. The percentage of real human (i.e., the degree of realism) significantly influenced the impression score for all three morphing sequences ($F(10, 480) \geq 5.96$, $p < .001$). However, the empirically obtained realism-impression plots did not show negative peaks (Figure 2). In one morphing sequence (Figure 1a), the face of a doll (Doll A, Pongratz Puppen) was morphed into a 19-year old Japanese female's face (Human A). This morphing sequence produced a positive rather than a negative peak at 80% real human (Figure 2, open disks). The second morphing sequence, in which the face of another doll (Doll B, BP053-1, CITITOY) was morphed to a one-year old Japanese female's face (Human B), yielded the highest score at 60% real human without producing a negative peak (Figure 2, filled squares). The images based on Doll B are not shown in Figure 1 due to copyright consideration. For the third morphing sequence (Figure 1b), in which a computer graphics (CG) image of an adult female face (CG A, Poser2 model bundled in Poser4, Curious Labs Inc.) was morphed into a 21-year old Japanese female's face (Human C), the impression score increased monotonically with an increasing degree of realism (Figure 2, open triangles). To improve the precision of the data, the step size of the morphing ratio was halved (i.e., 5%) in the morphing sequence from Human A to CG B (Aiko 3.0, DAZ Productions, Inc., Figure 1c). Sixty-eight landmarks were used for the eyes to achieve smoother morphing. In spite of these improvements, however, there was no clear indication of a negative peak corresponding to the uncanny valley (Figure 2, open diamonds). Although the impression scores rated by thirty-seven participants (mean age 24.9 years, 15 female) were significantly influenced by the percentage of real human ($F(20, 720) = 2.48$, $p < .001$), a multiple comparison revealed that significant difference was obtained only between the scores for 0% real human and 70% real human ($p < .05$).

Although the morphing sequences produced different tendencies, none of the four types of morphing sequence showed evidence that to have an almost perfectly realistic human appearance is a sufficient condition for the uncanny valley to emerge.

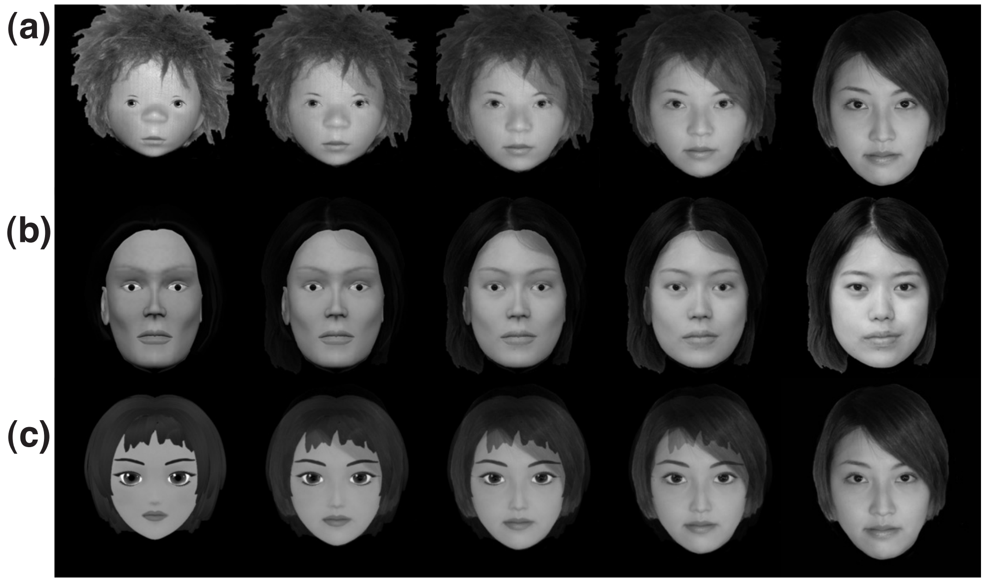


**Figure 1**

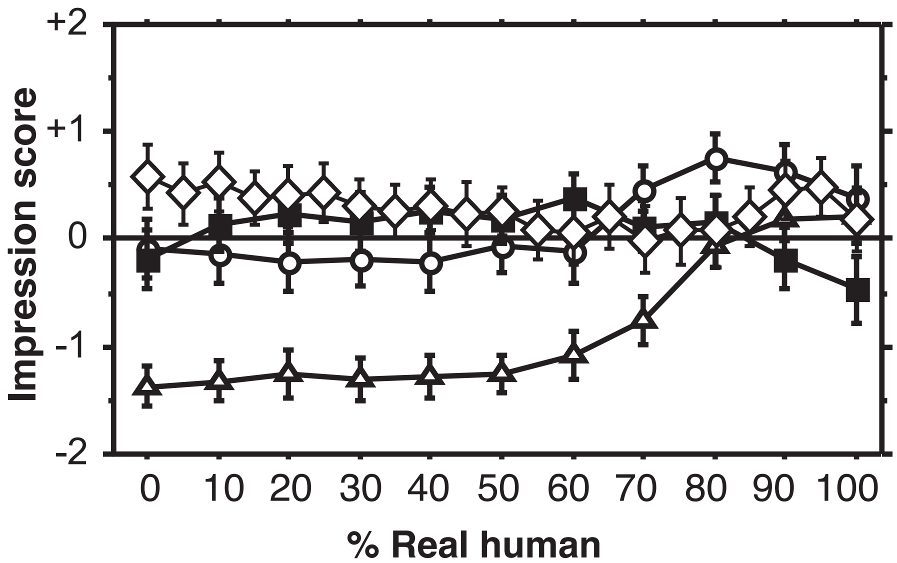


**Figure 2**

*3.2. Experiment 2*

In Mori's (1970) hypothetical plot, robots were supposed to have no resemblance to real humans at the lowest level of realism (e.g., industrial robots equipped with only manipulators). On the other hand, the stimuli used in Experiment 1 had reasonably realistic human appearance even at 0% real human. It should be noted that the morphing ratio of 0% did not imply that the face had no resemblance to real humans, but it simply implied that the image was the same as the original image of an artificial face. Thus, one may argue that Experiment 1 failed to detect the uncanny valley because the uncanny valley would emerge at degrees of realism lower than those tested in Experiment 1. However, in Experiment 2 we found evidence for the uncanny valley within the ranges of realism comparable to those tested in Experiment 1.

Forty-five participants (mean age 23.6 years, 22 female) observed images from morphing sequences where eyes and a head (i.e., facial regions other than the eyes) were asynchronously morphed. In the eyes-first sequence (Figure 3a), only the eyes of Doll A were morphed into those of Human A while the head was unchanged, resulting in realistic human eyes in an artificial head. Next, the artificial head was morphed into that of Human A, resulting in a wholly realistic human face. Participants rated the lowest score when the eyes were 100% real human and the head was 0% real human. This morphed image had higher realism than the unmorphed image of Doll A because of its real human eyes. In the head-first sequence (Figure 3b), the head was morphed first and then the eyes. Participants rated the lowest score when the head was 100% real human and the eyes were 0% real human. This face also had higher realism than the unmorphed image of Doll A because of its real human head. As shown in Figure 4, the percentage of real human significantly influenced the impression score ($F(10, 440) \geq 28.0$, $p < .001$), and the lowest scores were significantly lower than those for the unmorphed images of Doll A and Human A ($p < .001$).

The negative peaks found in Experiment 2 give empirical evidence for the emergence of the uncanny valley. The uncanny valley emerged when the eyes and the head showed the largest mismatch in degree of realism. Such mismatched realism was not evident in Experiment 1, when the facial features were morphed synchronously and the uncanny valley did not emerge. This may suggest the importance of mismatched realism for the uncanny valley's emergence.


**Figure 3**

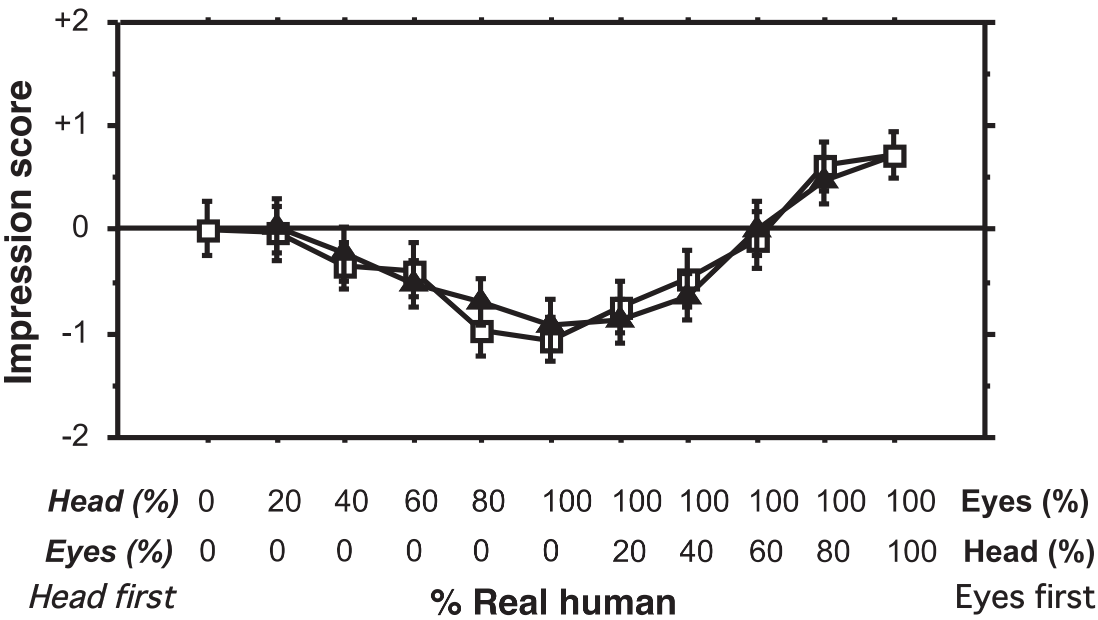


**Figure 4**

We suggest, however, that abnormalities in the stimuli, rather than the mismatched realism per se, were the direct cause of the uncanny valley's emergence.

Doll A's face is abnormal if it is viewed as a real human face, in the sense that its features remarkably deviate from a real human's. Nevertheless, the impression scores for the unmorphed image of Doll A were not significantly lower than zero (one-tailed *t* tests, Experiment 1, $t(48) = .60$, $p > .05$; Experiment 2, $t(44) = .17$, $p > .05$). This suggests that the deviation may have been viewed as an artistic representation rather than abnormality, although Doll A's potential attractiveness for children (Zeit, 1992) may have been underestimated by adult participants. Presumably, the impression of a facial image is judged based on various criteria adequate for the face's realism (Wages et al., 2004); however, the faces at the bottom of the uncanny valley may have been judged abnormal due to their mismatched realism between the eyes and the head. If the eyes were judged based on the head's realism, Human A's eyes in Doll A's head may have been judged abnormal as a doll's eyes (Figure 3a) and Doll A's eyes in Human A's head may have been judged abnormal as a real human's eyes (Figure 3b). Such judgments on the eyes, in reference to the head, are consistent with past findings that visual features of the head can influence the perceptual processes of the eyes (Hietanen, 1999; Kontsevich & Tyler, 2004; Langton, 2000; Seyama & Nagayama, 2002, 2005). The abnormalities induced by the mismatched realism may have produced unpleasant impressions and, in turn, produced the uncanny valley.

The same argument holds true for the judgment of the abnormality of the head based on the realism of the eyes. However, it is still uncertain whether or not the perceptual processes of the face are influenced by the appearance of the eyes.

### *3.3. Experiment 3*

If the uncanny valley reflects unpleasant impressions of abnormalities, any factors of abnormality other than the mismatched realism would also produce the uncanny valley. Among various factors that can make faces bizarre (see e.g., Murray *et al.*, 2003), we tested the effect of abnormal eye size using two morphing sequences in Experiment 3 (Figure 5). Forty participants (mean age 22.5 years, 33 female) rated images from the Doll A-Human A sequence (Figure 5a), and thirty-nine participants (mean age 24.2 years, 19 female) rated images from the CG B-Human C sequence (Figure 5b).

In each sequence, the eye size of an artificial face first increased from the original size (100%) up to 150%; however, the faces of Doll A and CG B did not produce unpleasant impressions (i.e., negative scores) even when their eyes were scaled to 150% (Figure 6, left plot area). The eye size did not significantly influence the impression score for the Doll A-Human A sequence ($F(5, 195) = 1.49$, $p > .05$). Although the eye size significantly influenced the impression score for CG B-Human C sequence ($F(5, 190) = 7.91$, $p < .001$), the score for 150% eye-size was not significantly different from that for 100% eye-size ($p > .05$).

After the eye size was scaled to 150%, each artificial face was morphed into a real human face with 150% eyes. Impression scores for the faces with 150% eyes decreased with an increasing degree of realism (Figure 6, middle plot area). The Doll A-Human A sequence produced the lowest score for 100% real human face with enlarged eyes. Although the CG B-Human C sequence produced the lowest score for 80% real human, the scores for 60-100% were not significantly different from one another ($p > .05$).

Finally, the enlarged eyes of the real human face (150%) came back to their original size. The impression score improved toward positive values with decreasing eye-size (Figure 6, right plot area). For each image sequence, the eye-size significantly influenced the impression score ($F(5, 195) = 49.73$ for Human A, $F$(5,

190) = 51.33 for Human C, *p*s < .001), and the score for 150% eye-size was significantly different from that for 100% eye-size (*p*s < .001). As a result, the uncanny valley emerged around the real human faces with 150% eyes.


**Figure 5**

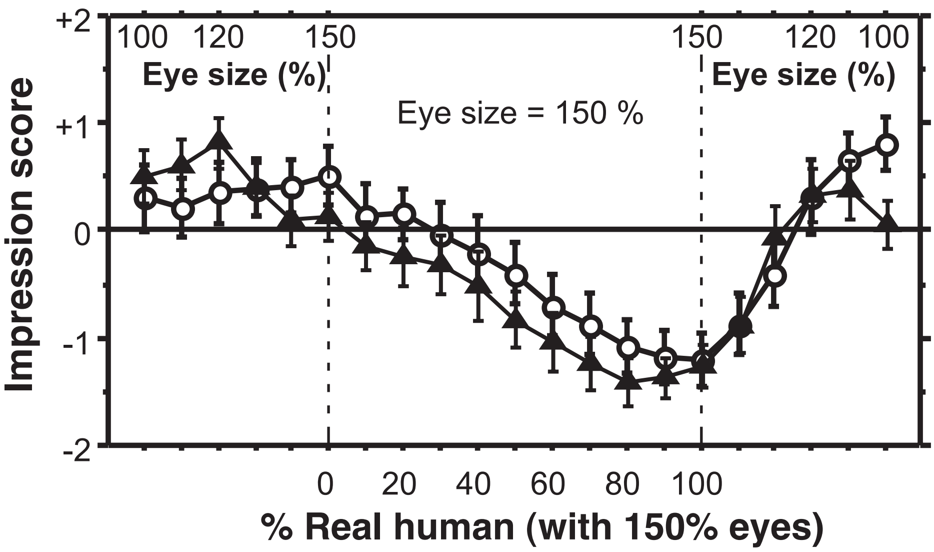


**Figure 6**

Although the abnormality factor applied to artificial and real faces in Experiment 3 were identical (i.e., scaling of the eyes to 150%), its impact was greater for faces with higher realism. Participants may have judged that the eyes scaled to 150% were too large for real human eyes, but such eyes were acceptable as artificial human eyes. This implies that the judgment criterion for real faces was different from that for artificial faces. The human visual system may have knowledge about how eye size varies among real humans (i.e., data of the statistical distribution of eye size of real humans) from past experiences, and such knowledge can serve as the basis for the judgment criterion of abnormality. If the eye size of a face is deviated from the center of the statistical distribution of normal eye size, such a face may be judged abnormal. On the other hand, knowledge about how eye size varies among artificial faces may constitute another judgment criterion of abnormality.

Otherwise, the results of Experiment 3 may reflect that perceptual sensitivity to facial features (i.e., eye size in this experiment) was higher for real faces than for artificial faces, and that the higher sensitivity for real faces produced unpleasant impressions of the huge eye-size but the lower sensitivity for artificial faces did not. Sensitivity to facial features is known to be better for familiar faces than for unfamiliar faces (Walker & Tanaka, 2003). Thus, the results of Experiment 3 may suggest that participants were more familiar with real faces than with artificial faces.

Although we tested only static images, Mori (1970) noted that robots' motion would also influence the uncanny valley. If the judgment criterion of motion is different between real and artificial human appearances (Hodgins *et al.*, 1998), abnormality in motion would produce the uncanny valley for highly realistic human appearance.

## 4. General Discussion

It is assumed that the human visual system involves sophisticated mechanisms for facial information processing (e.g., Haxby *et al.*, 2000). Such mechanisms seem to be broadly tuned to faces with various degrees of realism. Real human faces, artificial faces of dolls and robots, computer generated facial images, schematic line drawings of faces, and even simple face-like patterns consisting of simple geometric shapes (Turati, 2004) are all accepted as “faces”. Past studies showed that facial images with different degrees of realism often yielded comparable experimental results (e.g., Driver *et al.*, 1999 vs. Friesen & Kingstone, 1998; Wilson *et al.*, 2002; Yin, 1969). Nevertheless, in our daily life we rarely confuse artificial faces with real human faces; people do not ask a mannequin in a store window for directions to a train station. This suggests that the visual system has sensitivity to the degree of realism of faces.

The present study investigated an effect of the degree of realism on the impression of artificial human faces; that is, the uncanny valley. The results of our experiments showed that the uncanny valley actually emerged as Mori (1970) had predicted. However, the results also showed that the uncanny valley emerged only when face images involved abnormal features. Thus, to fully understand the nature of the uncanny valley, we need to consider the effects of both the realism and the abnormality of artificial human appearance. For example, if human observers have unpleasant impression of avatars in virtual reality or robots, the unpleasant impression should not be attributed solely to the degree of realism per se. Probably, the physical appearance of such avatars and robots may involve certain visual features that are inappropriate for their level of realism, and such visual features may be the cause of the unpleasant impression. Thus, improving the degree of realism of such avatars and robots without removing the abnormality factor may simply lead to exaggeration of the human observers’ unpleasant impression of the artificial faces.

The participants’ task in the present study can be interpreted as the judgment of facial attractiveness (or unattractiveness). Researchers have shown that the facial attractiveness is influenced by various factors, such as averageness, youthfulness, symmetry, and skin smoothness (see Rhodes & Zebrowitz, 2002 for review). Since past studies were mainly concerned with the facial attractiveness of real human faces, the effect of realism on the facial attractiveness has not been a major subject of research. The present study demonstrated that the degree of realism impacts the judgment of facial impression, suggesting that it is another factor influencing the facial attractiveness.

Further studies are required to unveil other aspects of the effect of realism on facial perception and cognition, and such studies will provide clues to understand human response to artificial human-like objects (e.g., Arita *et al.*, 2005; Breazeal, 2003; Garau *et al.*, 2005; Hinds et al., 2004; Minato et al., 2004a; Minato et al., 2004b; Shinozawa *et al.*, 2005). One outstanding question is how the human visual system extracts the information of realism and that of abnormality from the visual features of face images. This question is equivalent to asking how the visual system defines the degree of realism and abnormality. Although we have implicitly assumed that the realism and the abnormality are different perceptual dimensions, the distinction between the realism and the abnormality is not so straightforward. We have operationally defined the degree of realism as the morphing ratio; that is, the similarity of a morphed image to the photograph of a real human face that was used as a source image for the morphing sequence. In the actual definition of the realism employed by the human visual system, the similarity may be measured between an observed (artificial) face and a certain standard face. The average face of real humans (see e.g., Rhodes *et al.*, 2001; Rhodes & Zebrowitz, 2002) may be a candidate for such a standard face employed by the visual system. According to this definition, unrealistic artificial faces are supposed to have visual features that deviate considerably from those of the average face of real humans. It should be noted, however, that the degree of abnormality (or normality) is also defined based on the similarity to the average (or normal) face. Thus, abnormal faces are also supposed to have deviant visual features. The results of the present study suggest a possibility that the human visual system processes the realism and the abnormality as separate perceptual dimensions. In other words, the human visual system may define the realism and the abnormality based on different visual features, which should be identified in our future study.

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**Figure Captions**

Figure 1

Stimuli used in Experiment 1. (a) Morphing sequence from Doll A to Human A, (b) Morphing sequence from CG A to Human C, and (c) Morphing sequence from CG B to Human A, with morphing percentages of 0, 30, 50, 70, and 100%.

Figure 2

Impression scores averaged across participants (Experiment 1) for the Doll A-Human A sequence (circles), for the Doll B-Human B sequence (squares), for the CG A-Human C sequence (triangles), and for CG B-Human A sequence (diamonds). Error bars are 95% confidence intervals.

Figure 3

Stimuli used in Experiment 2. (a) Morphing sequence from Doll A to Human A, where the eyes were morphed first and then the head. Morphing ratios were 0-0, 60-0, 100-0, 100-60, and 100-100 (eyes %-head %). (b) Sequence where the head was morphed first.

Figure 4

Impression scores averaged across participants (Experiment 2) for the eyes-first sequence (squares), and for the head-first sequence (triangles). Error bars are 95% confidence intervals.

Figure 5

Stimuli used in Experiment 3. (a) Morphing sequence from Doll A to Human A with a manipulation of eye size (Doll A, Doll A with eyes scaled to 150%, 50% morph between Doll A and Human A both with 150% eyes, Human A with 150% eyes, and Human A). (b) Morphing sequence from CG B to Human C.

Figure 6

Impression scores averaged across participants (Experiment 3). Upper abscissa: eye-size scaling factor. Lower abscissa: degree of realism. Circles: Doll A to Human A. Triangles: CG B to Human C. Error bars are 95% confidence intervals.