Does the categorization difficulty elicit the uncanny-valley-like phenomenon without animacy?

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Abstract—**We feel strong eeriness for non-human objects that are highly similar to humans (a phenomenon known as uncanny valley). Previous research has accounted for this phenomenon based on animacy perception (e.g., the avoidance to threat or the lack of mind) or cognitive processes irrespective of animacy (categorization difficulty hypothesis). However, whether animacy perception is responsible for uncanny valley to be elicited is unclear at present. This is because all the previous studies used objects related to animacy (creature-like features) as stimuli (e.g., faces). Therefore, the present study examined whether uncanny valley occurs for non-animacy objects, using geometric figures (square, circle, and triangle). In Experiment 1, we made stimulus figures by systematically morphing an original geometrical figure (e.g., circle) into another figure (e.g., triangle). Participants first categorized which original figure (e.g., circle or triangle) the morphed figure was perceived as and then evaluated its likability with a 7-point Likert scale. As the result, we found the uncanny-valley-like phenomenon with non-animacy objects; that is, the figures that took longer times to be categorized (difficult-to-categorize objects) were rated as being less likeable as compared to the figures that were quickly categorized (easy-to-categorize objects). The subsequent experiments hypothesized that the categorization difficulty deteriorates perceptual and cognitive fluency of the morphed figures, resulting in the lower evaluation for them. To assess this hypothesis, we independently manipulated the perceptual (Experiment 2) and cognitive (Experiment 3) fluency of to-be-evaluated figures and investigated how the uncanny-valley-like phenomenon is modulated in response to the processing fluency. The results demonstrated the uncanny-valley-like phenomenon, but no effects of the processing fluency on it. These results suggest that the categorization difficulty is one factor underlying the uncanny-valley-like phenomenon, but the deteriorated processing fluency associated with it does not elicit the phenomenon by itself. We conclude that the uncanny-valley-like phenomenon can be robustly elicited by the stimuli without animacy (or creature-like features), which are in favor with the categorization difficulty hypothesis; that is, animacy perception is not a necessary condition for the occurrence of uncanny valley.**

Keywords—uncanny valley, processing fluency, categorization

I. INTRODUCTION

Robots of a human-like appearance often make us strong negative feelings (a phenomenon known as *uncanny valley* [1-2], Fig. 1). Although lots of hypotheses have been proposed to account for uncanny valley as far in the fields of not only robotics but also psychology and neuroscience (for reviews, see [3-5]), they could be categorized into an animacy-based model [6-8] or a cognitive-processing-based model [9].

An animacy-based model hypothesizes that uncanny valley reflects our avoidance (or instinctive threat) to a human manque due to the lack of life or mind [1,6-8]. On the other hand, a cognitive-processing-based model centers more on how we process (or categorize) a human manque [9]. In their study, participants were asked to categorize and evaluate morphed images made from different types of faces (e.g., cartoon characters and real human). The results showed that morphed images that took longer time to be categorized were rated lower in likeability. They suggested that categorization difficulty associated with the processing fluency is responsible for uncanny valley (a categorization-based hypothesis).

Note that the cognitive-processing-based model (or the categorization-based hypothesis) does not premise animacy perception, though the previous study [9] used the stimuli with animacy (or creature-like features). If the categorization-based hypothesis were correct, we could obtain the uncanny-valley-like phenomenon even with the stimuli without animacy. The present study examined this point in Experiment 1. Furthermore, we also investigated whether perceptual (Experiment 2) and cognitive (Experiment 3) fluency associated with the categorization difficulty contributes to the uncanny-valley-like phenomenon elicited by the non-animacy stimuli.

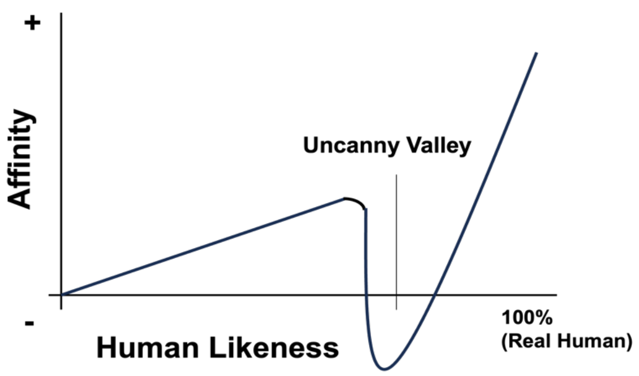

Fig. 1. A schematic illustration of uncanny valley [1-2].

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II. Experiment 1

A. *Methods*

Participants. According to a priori power analysis conducted using G*Power software [10], 11-19 participants were required to detect a medium effect (f = 0.25) with a power of .80-95 and a significance level of .05. Hence, 18 participants (12 females, M_{age}= 21.0), who were naïve to the purpose of this study, were recruited.

Apparatus. The stimuli were presented on a 23.5-in. monitor (BenQ GW2470) with a refresh rate of 60 Hz and a screen resolution of 1920 × 1080 pixels. We used Lab.js Builder to control the stimulus presentation and data collection.

Stimuli. Stimuli consisted of a black fixation cross (0.8 × 0.8 deg in visual angle) and white morphed images (14.0 × 24.4 deg in a categorization task, 7.2 × 13.1 deg in an evaluation task) made from geometrical figures (a circle, triangle, and square shape). The morphed images with 11 equal-stepped morphing percentages (0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 %) were made with Adobe After Effects (Adobe, CA, USA) for each morphing pair (triangle-square, circle-square, and circle-triangle pair, Fig. 2); that is, 33 stimulus images were made in total. The morphed figure was presented on a gray background. The viewing distance was 57 cm fixed by a chin-head rest.

Procedure. The experiment consisted of the categorization session followed by the evaluation session and was conducted individually, as in Yamada et al. (2013). In the initial categorization task, after participants pressed the space bar on the keyboard, the fixation cross was displayed at the center of the screen for 500 ms, which was replaced by one of the stimulus figures; each morphing pair (triangle-square, circle-square, and circle-triangle) was presented in a separate block of 110 trials. Participants were required to categorize the presented figure, i.e. which the original figure (triangle vs. square, circle vs. square, or circle vs. triangle) the presented (morphed) figure was perceived as, as quickly and accurately as possible by pressing corresponding key (J or F) on the keyboard. The stimulus figure was presented until participants' response and the next trial automatically began with an inter-trial interval (ITI) of 500 ms. The categorization session consisted of 330 experimental trials (33 stimulus figures × 10 repetitions) in total. The order of the morphing-pair block was counterbalanced, and the order of the stimulus figures was randomized across participants.

In the subsequent evaluation task, participants began the first trial with pressing the space bar on the keyboard. After the 500-ms exposure of the fixation cross at the center of the screen, one of the stimulus figures, which were same but a little smaller as those presented in the categorization session, were displayed at the center. Participants were required to evaluate the likeability of the presented figure with a 7-point Likert scale from 1 (strongly dislike) to 7 (strongly like) by clicking the corresponding score displayed in the screen. The stimulus figure was presented until participants' response, which was followed by the next trial with an ITI of 500 ms. The evaluation session consisted of 33 trials; each stimulus figure was presented only once without repetition. The order of the stimulus figures was randomized across participants.

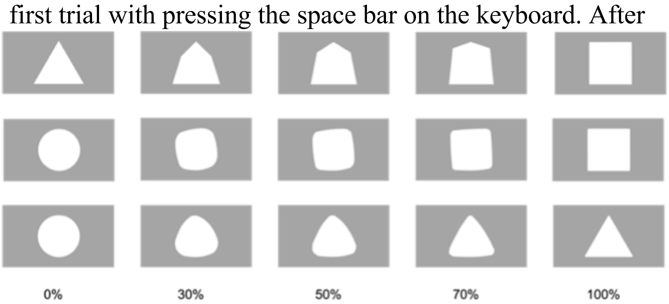

Fig. 2. Examples of original (0 and 100 %) and morphed (10-90 %) stimulus figures used in this study. Eleven morphing percentages were used in the actual experiments.

B. *Results*

Mean response times in the categorization task were calculated for each stimulus figure and participant respectively. Fig. 3a shows the mean response times averaged over participants, collapsing the morphing pair type. A within-subject one-way (morphing percentage: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 %) analysis of variance (ANOVA) revealed a significant main effect of the morphing percentage (F(10,170)= 18.145, p < .001, η^2 = .516). Multiple comparisons (Holm-Bonferroni method) revealed the significantly longer response times for the figures of the morphing percentages of 20-60 % than for the figure of 0 % (ps < .05). The response times for the figures of the morphing percentages of 20-50 % were significantly longer than those for the figure of 100 % (ps < .05). The reaction times did not significantly differ among morphing pairs (F(2,51) = 1.124, p = .333).

Fig. 3b shows mean rating scores of the likeability for each stimulus figure, averaged over participants. The ANOVA revealed a significant main effect of the morphing percentage (F(10,170) = 13.180, p < 001, η^2 = .437). Multiple comparison revealed the significantly lower scores for the figures of the morphing percentages of 10-90 % than those of 0 and 100 % (ps < .05).

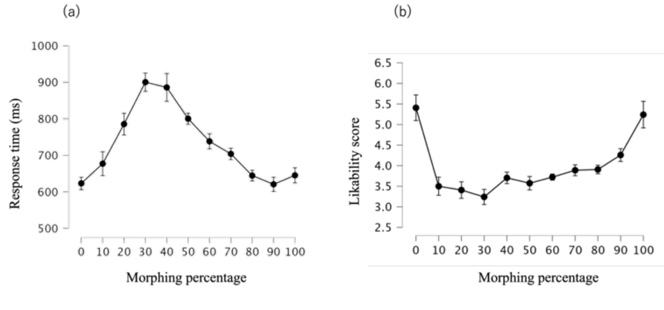

Fig. 3 Results of Experiment 1. Error bar is standard error of the mean.

III. Experiment 2

A. *Methods*

Participants. The sample size was 18 (8 females, M_{age} = 21.6) as in Experiment 1.

Apparatus and Stimuli. They were same as those used in Experiment 1.

Procedure. The procedure was same as that of Experiment 1, except that the stimulus figure was presented twice as the prime and to-be-evaluated target in the evaluation task. After the fixation, the prime was presented for 500 ms, during which participants only viewed without response. After a blank screen of 750 ms, the target appeared, the likeability of which participants evaluated (Fig. 4.).

B. *Results*

Mean reaction times in the categorization task were calculated as in Experiment 1 and shown in Fig. 5a. The ANOVA revealed a significant main effect of the morphing percentage ($F(10,170) = 20.221$, $p < .001$, $\eta^2 = .543$). Multiple comparisons (Holm-Bonferroni method) revealed the significantly longer response times for the figures of the morphing percentages of 10-50 % than for the figure of 0 % (*p*s < .05). The response times for the figures of the morphing percentages of 20-50 % were significantly longer than those for the figure of 100 % (*p*s < .05).

Fig. 5b shows the mean likeability scores in the evaluation task in Experiment 2, along with those found in Experiment 1. First, the one-way ANOVA was conducted to the data in Experiment 2 and demonstrated the significant main effect of the morphing percentage ($F(10,170) = 19.215$, $p < .001$, $\eta^2 = .531$). Multiple comparison revealed the significantly lower scores for the figures of the morphing percentages of 10-90 % than for those of 0 and 100 % (*p*s < .05). Second, a two-way mixed-factor (experiment: 1 (control) and 2 (perceptual priming) × morphing percentage: 11 percentages) ANOVA revealed a significant main effect of the morphing percentage ($F(10,340) = 31.456$, $p < .001$, $\eta^2 = .390$). However, the main effect of the experiment (the presence/absence of the perceptual priming) and the interaction were not significant ($F(1,34) = 3.595$, $p = .066$, $\eta^2 = .011$; $F(10,340) = 30.604$, $p = .560$, $\eta^2 = .017$).

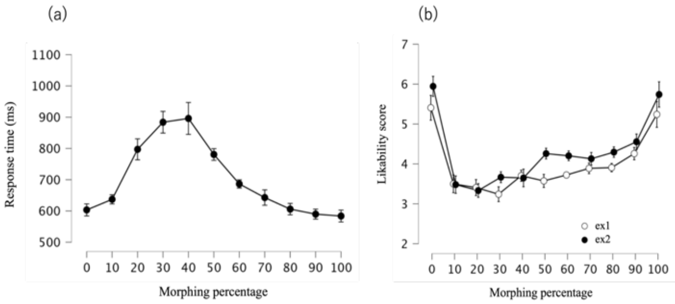

Fig. 5. Results of Experiment 2. Error bar is standard error of the mean. mixed-factor (experiment: 1 (control) and 2 (perceptual priming) × morphing percentage: 11 percentages) ANOVA revealed a significant main effect of the morphing percentage

IV. Experiment 3

A. *Methods*

Participants. The sample size was same as in Experiments 1 and 2, that is, 18 participants (10 females, $M_{age} = 20.6$).
Apparatus and Stimuli. They were same as those used in Experiments 1 and 2.
Procedure. The procedure was same as that of Experiment 2, except that the original figure, which was used for the morphing, was presented as the prime (the categorization cue) in the evaluation task in order to help participants to categorize. The original figure that the morphed figure was more often categorized as in Experiment 1 was used as the categorization cue for each morphed image (Fig. 6).

B. *Results*

Mean reaction times in the categorization task were shown in Fig. 7a. The ANOVA revealed a significant main effect of the morphing percentage ($F(10,170) = 18.863$, $p < .001$, $\eta^2 = .526$). Multiple comparisons (Holm-Bonferroni method) revealed the significantly longer response times for the figures of the morphing percentages of 10-60 % than for the figure of 0 % (*p*s < .05). The response times for the figures of the morphing percentages of 20-60 % were significantly longer than those for the figure of 100 % (*p*s < .05).

Fig. 7b shows the mean likeability scores in the evaluation task in Experiment 3, along with those found in Experiment 1. First, the one-way ANOVA was conducted to the data in Experiment 3 and demonstrated the significant main effect of the morphing percentage ($F(10,170) = 17.835$, $p < .001$, $\eta^2 = .512$). Multiple comparison revealed the significantly lower scores for the figures of the morphing percentages of 10-90 % than for the figure of 0 % (*p*s < .05). The likability rating scores for the figures of the morphing percentages of 10-80 % were significantly lower than those for the figure of 100 % (*p*s < .05). Second, a two-way mixed-factor ANOVA revealed a significant main effect of the morphing percentage ($F(8,272) = 9.043$, $p < .001$, $\eta^2 = .106$). However, the main

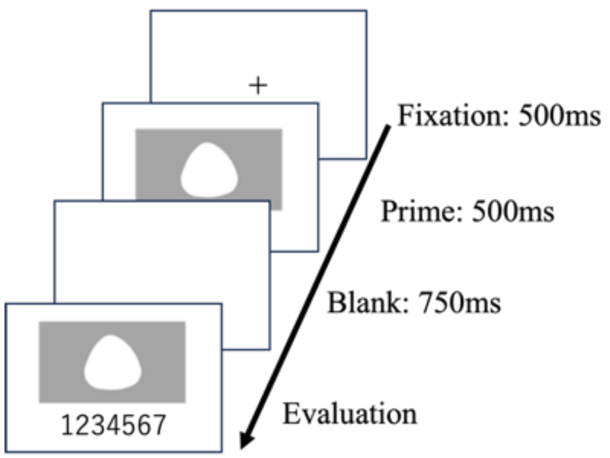

Fig. 4. Procedure of the evaluation task in Experiment 2.

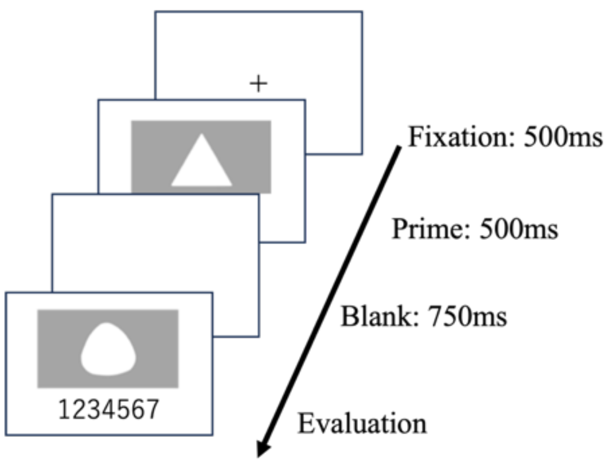

Fig. 6. Procedure of the evaluation task in Experiment 3.

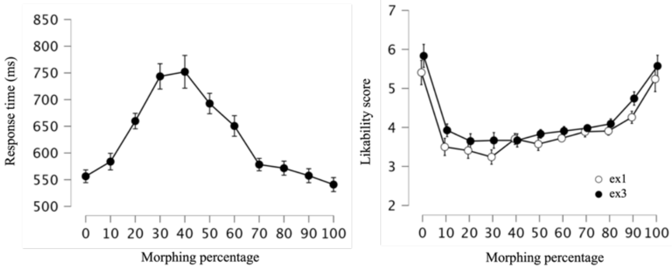

Fig. 7 Results of Experiment 3. Error bar is standard error of the mean.

effect of the experiment (the presence/absence of the categorization cue) and the interaction were not significant ($F(1,34) = 1.426$, $p = .241$, $\eta^2 = .008$, $F(8,272) = 0.678$, $p = .711$, $\eta^2 = .020$).

V. General discussion

The present study aimed at investigating whether the categorization difficulty elicits the uncanny-valley-like phenomenon even with the stimuli without animacy (i.e., geometrical figures). In Experiment 1, the likeability of the morphed images (difficult-to-categorize images) was lower than that of the original images (easy-to-categorize images), demonstrating the occurrence of the uncanny-valley-like phenomenon with the non-animacy stimuli. This result was robustly replicated in Experiments 2 and 3. Therefore, our findings suggest that the categorization difficulty is one factor underlying the uncanny-valley-like phenomenon, supporting the categorization-based hypothesis [9].

Although the present study predicted that the deteriorated processing fluency associated with the categorization difficulty contributes to the uncanny-valley-like phenomenon, the likeability ratings were not recovered by the processing fluency heightened by the perceptual priming (Experiment 2) or the cognitive cue (Experiment 3). That is, the uncanny-valley-like phenomenon cannot be explained by the processing fluency at present. For this, we raise five possible explanations below.

First, the perceptual priming in Experiment 2 was not enough to increase the perceptual fluency. In fact, previous research on mere exposure effect [11] reports that the likeability of objects increases as the number of repetitions of objects' exposure increases. One-time presentation of the prime in Experiment 2 might not sufficiently facilitate the subsequent perceptual processing. Therefore, increasing the number of exposures of the morphed figure would heighten the perceptual fluency so that we can adequately investigate the effect of the perceptual fluency on uncanny valley in future.

Second, the cognitive cue in Experiment 3 unexpectedly worked. We had expected that the original prime figure helped the categorization of the following morphed target figure. However, the prime figure might lead participants to be sensitive to the difference of the prime and target. That is, some sort of aftereffect might occur for perception of the target figure, which would no longer help the categorization, rather disrupt it. In future, the verbal cue that explicitly informs the category of the morphed image would be a good method to investigate the effects of the cognitive fluency on uncanny valley.

Third, the sample size of Experiments 2 and 3 might be too small to investigate the effects of the processing fluency among the experiments. Although we recruited 18 participants in all the experiments respectively, this sample size was determined based on the factorial design in Experiment 1. In fact, the appropriate sample size turned out to be 72 to 116 to compare the results between the experiments ($f = 0.25$, $\alpha = .05$, $1 - \beta = .80$-$.95$). That is, Type-II error might occur in Experiments 2 and 3, which will be tested with the increased sample size in the future investigation.

Fourth, since the participants in this study were encouraged to categorize the object due to the preceding categorization task, they were likely to manage to categorize the morphed figure even if the categorization was difficult. That is, it is possible that the uncanny-valley-like phenomenon observed in this study reflects the affective evaluation for the categorized, or managed-to-categorize, objects, whereas the typical uncanny valley phenomenon reflects the evaluation for the uncategorized, or failed-to-categorize, objects. If so, the current uncanny-valley-like phenomenon would be established based on the higher (above baseline) level of the likeability compared to the typical uncanny valley. Hence, the failure to detect the effects of the processing fluency in this study was likely due to the ceiling effect. We speculate that uncanny valley basically occurs when participants spontaneously categorize objects and can stop the categorization freely, and that it is weakened when they are induced to categorize them as in this study.

Fifth and finally, even though the methodological issues were present as above, the possibility that the processing fluency is not related to the uncanny-valley phenomenon still remains. In general, when we encounter a new object, the visual system quickly registers it and then automatically processes the meaning (category or identity) of the registered object [12]. If the visual system is difficult in categorizing the registered object, it gives up processing it and rejects it. Such an incomplete, unidentified representation might lead us to feel the eeriness, producing uncanny valley. That is, we speculate that the failure of the categorization, not the processing fluency, leads unpleasant feelings in uncanny valley.

Note that the current findings do not deny the hypotheses [1,7-8] other than the categorization-based hypothesis [9] because they are not mutually exclusive. We would like to emphasize that the categorization difficulty is at least one factor underpinning the eeriness of the morphed objects in uncanny valley. Indeed, there is a possibility that the uncanny valley with animacy objects (as observed in previous studies) and the uncanny-valley-like phenomenon with non-animacy objects (as observed in this study) may differ regarding their mechanism(s). However, at present, the categorization-based hypothesis can well explain them in general. The current findings may contribute to the future investigation regarding how to design and interact with humanoid robots.

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