The uncanny valley of a virtual animal

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Abstract
Virtual robots, including virtual animals, are expected to play a major role within affective and aesthetic interfaces, serious games, video instruction, and the personalization of educational instruction. Their actual impact, however, will very much depend on user perception of virtual characters as the uncanny valley hypothesis has shown that the design of virtual characters determines user experiences. In this article, we investigated whether the uncanny valley effect, which has already been found for the human-like appearance of virtual characters, can also be found for animal-like appearances. We conducted an online study (N = 163) in which six different animal designs were evaluated in terms of the following properties: familiarity, commonality, naturalness, attractiveness, interestingness, and animateness. The study participants differed in age (under 10–60 years) and origin (Europe, Asia, North America, and South America). For the evaluation of the results, we ranked the animal-likeness of the character using both expert opinion and participant judgments. Next to that, we investigated the effect of movement and morbidity. The results confirm the existence of the uncanny valley effect for virtual animals, especially with respect to familiarity and commonality, for both still and moving images. The effect was particularly pronounced for morbid images. For naturalness and attractiveness, the effect was only present in the expert-based ranking, but not in the participant-based ranking. No uncanny valley effect was detected for interestingness and animateness. This investigation revealed that the appearance of virtual animals directly affects user perception and thus, presumably, impacts user experience when used in applied settings.

KEYWORDS
animal-likeness, animateness, attractiveness, commonality, familiarity, interestingness, naturalness, uncanny valley, virtual animals, virtual characters, virtual pandas

1 | INTRODUCTION

Technological advances in animation over the past decade have brought upon new challenges regarding the design of virtual characters (in robotic, animal, or human forms). In particular, a high quality, realistic appearance can negatively impact user acceptability. This negative effect has been described by the widely known uncanny valley hypothesis.
According to the hypothesis, human-like appearance of artificial objects (e.g., robots) can, in some cases, have a detrimental impact on their perceived familiarity and affinity toward them. The uncanny valley hypothesis provides a useful account of which features of the appearance give rise to a low user acceptance. This hypothesis has been used in robotics, video games, virtual reality, and computer-animated movies in which virtual character appearance serves to establish emotional connection with the audience.

Past studies of the uncanny valley hypothesis clearly demonstrate the importance of human-like properties. In this context, researchers have evaluated the impact of virtual humans used as pedagogical agents, bots, chatbots, virtual android robots, and avatars. Recent work by Schwind et al. established the possibility to analyze the uncanny valley hypothesis for virtual animals as well. However, in their work, a human-likeness scale was employed rather than an animal-likeness scale. Arguably, when studying the perception of virtual animals, an animal-likeness scale would be more appropriate.

To investigate the uncanny valley effect for virtual animals using an animal-likeness scale, we designed a virtual panda with different features, building on previous work including the scale originally developed by Mori et al. Next to that, we explored the effect of using either still or moving (animated) images and of morbid appearance features. Below, we first summarize existing research findings and subsequently report on the outcomes of our online experiment in which characters were ranked for animal likeness both by experts and by naive participants.

2 RELATED WORK

2.1 The uncanny valley hypothesis

The uncanny valley model, as visualized in the well-known graph presented by Mori et al., captures the relation between the appearance of robots and the sense of “shinwakan” a person feels toward them. “Shinwakan” is a Japanese word that can be translated with terms such as “familiarity,” “affinity,” and “comfort level.” The uncanny valley hypothesis describes how the feeling of familiarity increases steadily when an artificial object obtains more human-like aspects. However, at some point, the familiarity suddenly drops, creating what is known as the uncanny valley effect. After this dip, the familiarity rises again sharply when the character’s appearance approaches the resemblance of a real-life human (see Figure 1). The uncanny valley effect (the “dip”) is most likely to occur when it is difficult to determine whether an object is alive/animate or dead/inanimate, for example, in the case of a zombie or an extremely realistic human robot.

Mori et al. in a translation of Mori’s original article, described the shape of the uncanny valley as follows: “The mathematical term monotonically increasing function describes a relation in which the function $y = f(x)$ increases continuously with the variable $x$. [ … ] An example of a function that does not increase continuously is climbing a mountain—the relation between the distance ($x$) traveled by a hiker toward the summit and the hiker’s altitude ($y$)—owing to the intervening

![Figure 1](image-url)
hills and valleys. I have noticed that, in climbing toward the goal of making robots appear like a human, our affinity for them increases until we come to a valley [...] which I call the *uncanny valley*" (p. 98).

Despite some inconclusive evidence, the effect has been demonstrated both for robots and virtual characters. While some studies in the past did not find an uncanny valley effect for familiarity, strangeness, and eeriness, recent articles describe the effect in likability and eeriness for the appearance of android robots and familiarity for computer-generated characters.

### 2.2 The uncanny valley in virtual animals

Previously published studies on the uncanny valley hypothesis have been limited to robots or virtual characters resembling humans, such as androids or virtual humans. Virtual animals, however, are currently quite popular in the entertainment industry and have only received limited attention in the area of human–computer interaction studies. To our knowledge, there are only two studies that explore the uncanny valley effect for virtual animals. The first study, by Schneider et al., reported that non-human characters (e.g., animals and robots) are perceived favorably if they display human-like features. The second study, developed by Schwind et al., noted that it is possible to avoid the uncanny valley for a virtual animal when it is completely natural or when it has a stylized appearance. Their study concentrated on how realism has an effect on a virtual animal (e.g., a cat). As far as we know, no studies analyzed in-depth their animal-like appearance leads to an uncanny valley effect. In this sense, a systematic understanding of how the uncanny valley hypothesis contributes to the perception of virtual animals and their possible effect on the users’ experience is still lacking.

### 2.3 Current study

In our previous study, we investigated whether the uncanny valley effect observed for human-like objects can be found for virtual animals. In particular, we determined that there is an uncanny valley effect for the user’s perception toward still images of a virtual animal with respect to familiarity, commonality, naturalness, attractiveness, interestingness, and animateness. The current study first sets out to replicate this result and confirm that the uncanny valley hypothesis can be applied to virtual animals using the original scales. Second, we tested the so-called “movement hypothesis” according to which the movement of the object can influence affinity because the bodily activity is important for the perception of live entities. For this aim, we included dynamic stimuli in our experimental material. Finally, we explored the effect of morbid virtual character features in combination with other character traits.

Figure 2 shows a simulation graph of the expected uncanny valley effect for animal-likeness when directly related to the original human-likeness uncanny valley graph presented by Mori. To determine the existence of the uncanny valley for the animal-likeness scale, we propose that four conditions need to be met: (1) the graph decreases when x is between points (a) and (c); (2) the uncanny valley (point c) must be found near the maximum value of x; (3) there are significant differences on the y-axis when varying on the x-axis; and (4) the real animal (at the right side of the graph) compared to uncanny valley images of the animal at point c, are on opposite extremes in the plot.

According to Kätsyri et al., five main hypotheses can influence the uncanny valley effect. Of these hypotheses, we are interested in the movement hypothesis, which indicates that movement in the stimuli can amplify the uncanny valley curve (both in a positive and negative direction), and the morbidity hypothesis, which states that morbid characters lead to a more negative perception compared to other characters. Based on these hypotheses, we expect to find an uncanny valley graph that can be affected by ranking the animal-likeness scale, the movement of stimuli, and the morbidity of images. To our knowledge, these hypotheses have not previously been tested on virtual animals.

The overarching research question addressed in this article is as follows:

*Which conditions influence the existence of an uncanny valley effect for virtual animals?*

In order to answer this question, in our experiment, we focused on three design features likely to influence the uncanny valley effect, two of which—movement and morbidity—are based on the findings of Kätsyri et al. The following research sub-questions were investigated:

**RQ1. Ranking**

Does the expert-based ranking of virtual animals lead to different uncanny valley effects than the participant-based ranking of virtual animals?
FIGURE 2  Expected uncanny valley graph relating participant’s perception to the animal-likeness scale. The uncanny valley occurs between points a and c

RQ2. Movement
Does movement of the virtual animals amplify the affinity responses (changes in familiarity, commonality, naturalness, attractiveness, interestingness, and animateness) compared to still images of the virtual animals?

RQ3. Morbidity
Does a morbid virtual animal (e.g., one with zombie features) elicit more negative familiarity, commonality, naturalness, attractiveness, interestingness, and animateness than other characters?

In the sections below, we first describe our experimental methods followed by the quantitative and qualitative results of the study and their discussion.

3  |  METHODS

This study aimed to collect information on the perception of familiarity, attractiveness, commonality, naturalness, interestingness, and animateness using six still images as well as six moving videos of virtual pandas. Participants ranked the pandas on their level of animal-likeness using a scale adapted from Mori’s original human-likeness scale. The participant-based ranking was compared to the expert-based ranking.

3.1  |  Participants

In total, 163 participants were recruited via the University of Grancolombia (Colombia), High School “I.E.D Quiroga Alianza” (Colombia), High School “I.E.D Almirante Padilla” (Colombia), and directly from the student population of Tilburg University (the Netherlands). We provide demographic information of the participants in Table 1.

3.2  |  Survey procedure

The survey was developed in Qualtrics (a web-based platform for distributing surveys). Participants accessed the online survey using a hyperlink. For the participants younger than 18 years old, informed consent was obtained from their
TABLE 1  Demographic data of the participants

|                          | n = 163 | %   |
|--------------------------|---------|-----|
| **Age**                  |         |     |
| Under 10                 | 2       | 1.2 |
| 10–19                    | 65      | 39.9|
| 20–29                    | 78      | 47.9|
| 30–39                    | 16      | 9.8 |
| 40–50                    | 1       | 0.6 |
| Over 50                  | 1       | 0.6 |
| **Gender**               |         |     |
| Female                   | 81      | 49.7|
| Male                     | 82      | 50.3|
| **Geographic location**  |         |     |
| Asia                     | 8       | 4.9 |
| Asia/Europe              | 2       | 1.2 |
| Europe                   | 73      | 44.7|
| North America            | 1       | 0.7 |
| South America            | 79      | 48.5|
| **Frequency of playing video games** | |     |
| Daily                    | 27      | 16.6|
| Several times a week     | 43      | 26.4|
| Several times a month    | 18      | 11  |
| Several times a year     | 35      | 21.5|
| Never                    | 40      | 24.5|
| **Highest grade or school level** | |     |
| Primary school           | 21      | 12.9|
| Highschool               | 60      | 36.8|
| MBO                      | 7       | 4.3 |
| HBO/University of Applied Sciences | 8      | 4.9 |
| University Bachelor      | 32      | 19.6|
| University Master        | 32      | 19.6|
| PhD                      | 3       | 1.8 |

parents and caretakers. The survey, which contained 79 questions, took approximately 10 min to complete. We collected participants’ information about their age, gender, the country where they lived longest, the highest educational degree they received, and how frequently they played video games. Each participant was presented all six (different) still images and movies of the pandas in random order. For each image and movie, they answered questions using semantic differential scales anchored at the following poles: familiar/strange, common/unusual, attractive/ugly, interesting/boring, natural/artificial, and animate/inanimate. Data preprocessing and analysis were performed using SPSS version 27.0 (a software package used to perform statistical analysis on quantitative data).

3.3 Stimuli

The panda is considered a charismatic species\(^{17,18}\) and is perceived as attractive, cute, and charming by most respondents. As such, we expected the panda to stimulate a sense of familiarity in participants of the study. Researchers have explored the relationship between the uncanny valley effect on familiarity.\(^{5,8,10,19}\) However, here we extend this work and use the panda to investigate not only its familiarity aspect, but also attractiveness, commonality, naturalness, interestingness, and animateness traits in a virtual setting.
In this study, we use six versions of the virtual panda: (1) mechanical panda (own design), (2) stuffed toy panda (own design), (3) robot panda (own design), (4) zombie panda (own design), (5) photo-realistic panda, and (6) real panda. The original images were 1024×768 pixels, and Qualtrics automatically resized the images to 551×301 pixels.

The moving panda images used in this study are based on the still images and have been animated using software called “Crazy animator 8” (https://www.reallusion.com/crazytalk/download.html). Figure 3 shows the fitting face editor used in Crazy Animator 8 to control the facial points of the animal's face that are used to animate it. All pandas have a neutral expression. Each animation has a 10 s duration. In total this means that six still images and six animated versions of the virtual pandas are used as stimulus material in this study. The videos of the virtual pandas can be found via the following links: mechanical panda (https://youtu.be/6SrCiUXszuY), robot panda (https://youtu.be/W-D2fLekMd8), stuffed toy panda (https://youtu.be/2ULKk4-CX98), zombie panda (https://youtu.be/O3pzSVu-Ys), photorealistic panda (https://youtu.be/hpSN9l2fsZ0), and real panda (https://youtu.be/tL2WJTO272E).

3.4 | Measurement of animal-likeness scale

3.4.1 | Expert-based ranking

We ranked the six different faces of a panda according to the animal-likeness scale, which is based on the human-likeness scale developed by Mori (see Figure 6, left column). Masahiro Mori, a Japanese roboticist and the author of the uncanny valley hypothesis proposed a human-likeness scale on which he placed 13 types of stimuli in the original graph (see Figure 1): an industrial robot, a humanoid robot, a stuffed toy animal, a zombie, a bunraku puppet, and a healthy human. Following the same expert-based ranking, we ordered the panda characters as follows: (1) a mechanical panda (i.e., a simulation of the industrial robot in Mori’s studies), (2) a stuffed toy panda (i.e., a simulation of the stuffed animal in Mori’s studies), (3) a robot panda (i.e., a simulation of the humanoid robot in Mori’s studies), (4) a zombie panda (i.e., a simulation of the zombie in Mori’s studies), (5) a photo-realistic panda (i.e., a simulation of the bunraku puppet in Mori’s studies), and (6) a real panda (i.e., a simulation of the healthy person in Mori’s studies). Here, panda 1 represents the least animal-like panda, whereas panda 6 represents the most animal-like panda. We call this ranking the expert-based ranking in this article as it follows the ranking proposed in Mori’s research.

3.4.2 | Participant-based ranking

Since it is possible that non-experts perceive the animal-likeness of the pandas differently from the expert-based ranking, participants were instructed to rank the six panda images based on animal-likeness with the value of 1 representing the most animal-like and 6 the least animal-like character. The order of the presentation of the images in the questionnaire was
randomized. To align the participant-based ranking with the expert-based ranking (x-axis in the figures), the participant scale was subsequently inverted in the analysis.

### 3.4.3 Questionnaire of perception regarding virtual characters

Following the ranking, each participant was presented with six still images of the pandas (randomized) as shown in Figure 4a and for each image answered the questions provided in Table 2. Next, the participants were presented with six animations of the pandas (randomized) as shown in Figure 4b and answered the same questions as for the still images. A reliability analysis using Cronbach’s alpha revealed that the questions were answered consistently ($\alpha = .948$).

### 3.4.4 Ethics approval

Ethics approval was received from the Research Ethics Committee of the Tilburg School of Humanities with the reference REDC#2019/89. The data that support the findings of this study are openly available in the Dataverse repository name “Data of uncanny valley of a virtual animal” at https://doi.org/10.34894/JIBXBU.

## 4 RESULTS

In the analysis below, we first compared the expert-based ranking to the participant-based ranking. Next, we investigated the relationship between the judgments of familiarity, commonality, naturalness, attractiveness, interestingness, and animateness, as well as the effect of movement and morbidity.

### 4.1 Ranking

Figure 5 provides an overview of the participant-based ranking in terms of animal-likeness. The real panda was ranked to be most animal-like by 134 (82%) respondents. The photorealistic panda was ranked second by 127 respondents (77%).
The stuffed toy panda was ranked next on the scale by 110 respondents (67%), followed by the zombie panda (76 respondents [46%]) and the mechanical panda (67 respondents [41%]). Finally, the robot panda was ranked as least animal-like by 65 respondents (40%). Note that participants agreed mostly on the ranking of the real, photorealistic, and stuffed toy panda, but were less consistent in their ranking of the other characters. Overall, this resulted in the following ranking from most to least animal-like: real—photorealistic—stuffed toy—zombie—mechanical—robot.

Comparing the expert-based ranking to the participant-based ranking (as illustrated in Figure 6), we see that the rankings of the real and photo-realistic pandas are the same, but the other pandas are ranked differently. In particular, participants ranked the stuffed toy panda as more animal-like compared to the expert-based ranking and the robot and mechanical pandas swapped places in the ranking. This means that the expert-based ranking is different from the participant-based ranking.

4.2 Uncanny valley

Below, we present the analysis of the uncanny valley scales for perceived familiarity, commonality, naturalness, attractiveness, interestingness, and animateness.

Figure 7a plots the mean values of the different properties assigned to the different still panda images according to the expert-based ranking. The familiarity perception starts with the mechanical panda ($M = 3.62, SD = 2.311$) and moves up toward the stuffed toy panda ($M = 5.54, SD = 2.335$). After this, familiarity drops toward the robot panda ($M = 3.49, SD = 2.330$) and zombie panda ($M = 2.67, SD = 2.000$). Next, the familiarity rises gradually from the photorealistic panda ($M = 6.89, SD = 2.316$) to the real panda ($M = 7.88, SD = 2.044$).

Likewise, the perception of commonality starts from the mechanical panda ($M = 3.23, SD = 2.157$) and rises toward the stuffed toy panda ($M = 4.98, SD = 2.252$). After the stuffed toy panda, the commonality value decreases for the robot panda ($M = 3.09, SD = 1.823$) and zombie panda ($M = 2.70, SD = 1.995$). After that, the commonality increases progressively from the photorealistic panda ($M = 6.61, SD = 2.247$) to the real panda ($M = 7.71, SD = 1.922$).

The attractiveness perception shows similar behavior to familiarity and commonality. There is a lower value in attractiveness perception for the mechanical panda ($M = 4.65, SD = 2.121$). Next, it increases toward the stuffed toy panda ($M = 5.31, SD = 2.320$). Then attractiveness decreases from the robot panda ($M = 4.32, SD = 2.190$) to the zombie panda ($M = 3.70, SD = 2.348$). Following these low values, the attractiveness increases gradually from the photorealistic panda ($M = 5.98, SD = 2.206$) to the real panda ($M = 7.18, SD = 2.197$).

The perception of naturalness follows the same behavior as the previous perceptions. The perception of naturalness begins with the mechanical panda ($M = 2.93, SD = 2.390$), and increases to the stuffed toy panda ($M = 4.88, SD = 2.332$). After that, it decreases to the robot panda ($M = 2.51, SD = 1.974$) and zombie panda ($M = 2.94,
SD = 2.239). Next, the naturalness rises gradually from the photorealistic panda (\(M = 6.62, SD = 2.382\)) to the real panda (\(M = 7.74, SD = 2.215\)).

In contrast, interestingness and animateness do not show the similar trends as familiarity, commonality, attractiveness, and naturalness. The interestingness values show only moderate changes from the mechanical panda (\(M = 5.76, SD = 2.212\)) to the real panda (\(M = 6.46, SD = 2.353\)). The animateness perception also shows moderate changes between the mechanical panda (\(M = 5.42, SD = 2.818\)) and the real panda (\(M = 5.32, SD = 3.107\)). Summarizing, we find an uncanny valley effect for the measures of familiarity, commonality, attractiveness, and naturalness toward still images when organized according to the expert-based ranking, but no such effects are found for the measures of interestingness and animateness.

Figure 7b plots the mean familiarity assigned to the different still panda images where the pandas are organized by the participant-based ranking. The familiarity perception starts with the robot panda (\(M = 3.49, SD = 2.330\)) and moves toward the mechanical panda (\(M = 3.62, SD = 2.311\)). After this, the familiarity decreases toward the zombie panda (\(M = 2.67, SD = 2.83\)), after which the familiarity increases again gradually from the stuffed toy panda (\(M = 5.54, SD = 2.335\)) to the real panda (\(M = 7.88, SD = 2.044\)).

Similarly, the perception of commonality starts with the robot panda (\(M = 3.09, SD = 1.823\)), then decreases from the mechanical panda (\(M = 3.23, SD = 2.157\)) to the zombie panda (\(M = 2.70, SD = 1.995\)). After this, the commonality increases gradually from the stuffed toy panda (\(M = 4.98, SD = 2.252\)) to the real panda (\(M = 7.71, SD = 1.922\)).

The attractiveness perception follows similar behavior of familiarity and commonality, where there is a decrease in attractiveness starting with the robot panda (\(M = 4.32, SD = 2.190\)) and decreasing from the mechanical panda (\(M = 4.65, SD = 2.121\)) to the zombie panda (\(M = 3.70, SD = 2.348\)).

Next, the attractiveness increases gradually from the stuffed toy panda (\(M = 5.31, SD = 2.320\)) to the real panda (\(M = 7.18, SD = 2.197\)). In contrast, naturalness, interestingness, and animateness show different behavior. The naturalness perception shows a steady rise from the robot panda (\(M = 2.51, SD = 1.974\)) to the real panda (\(M = 7.74, SD = 2.215\)). The interestingness perception shows moderate changes between the robot panda (\(M = 5.30, SD = 2.303\)) to the real panda (\(M = 6.46, SD = 2.323\)) and the animateness perception also shows moderate changes between the robot panda (\(M = 4.90, SD = 2.846\)) to the real panda (\(M = 5.32, SD = 3.107\)). Summarizing, we find an uncanny valley effect for the measures of familiarity, commonality, and attractiveness toward still images organized on the participant-based ranking, but no such effects are found for the measures of naturalness, interestingness, and animateness.

**Figure 6** Expert-based ranking and participant-based ranking (1 is least animal-like and 6 is most animal-like)
When considering the perception of the moving images according to the expert-based ranking (as shown in Figure 8a), we see that the familiarity perception shows the lowest value for the mechanical panda ($M = 3.66, SD = 2.279$), increases to the stuffed toy panda ($M = 4.80, SD = 2.188$). After this, familiarity drops toward the robot panda ($M = 3.76, SD = 2.297$) and zombie panda ($M = 2.83, SD = 2.050$). Next, the familiarity rises steadily from the photorealistic panda ($M = 5.90, SD = 2.525$) to the real panda ($M = 6.49, SD = 2.551$).

The commonality scores reveal similar behavior to that of familiarity with the mechanical panda ($M = 3.51, SD = 2.074$), then rising to the stuffed toy panda ($M = 4.38, SD = 2.055$). After this, the score decreases to the robot panda ($M = 3.54, SD = 2.068$) and zombie panda ($M = 2.80, SD = 1.922$). The commonality score then increases gradually from the photorealistic panda ($M = 5.77, SD = 2.441$) to the real panda ($M = 6.04, SD = 2.429$).

The perception of familiarity and commonality of moving images had the same behavior as that of the still images by expert-based ranking. The attractiveness perception values follow similar behavior to that of familiarity and commonality,
where we find a decrease in attractiveness starting with the mechanical panda ($M = 4.79, SD = 2.236$) and increasing to the stuffed toy panda ($M = 5.84, SD = 2.079$). After this the scores decrease to the robot panda ($M = 4.72, SD = 2.296$) and zombie panda ($M = 3.46, SD = 2.197$). Next, the attractiveness increases gradually from the photorealistic panda ($M = 5.63, SD = 2.241$) to the real panda ($M = 6.52, SD = 2.077$).

Likewise, the naturalness perception begins with the mechanical panda ($M = 3.25, SD = 2.327$) and increases with the stuffed toy panda ($M = 4.05, SD = 1.981$). After dropping to the robot panda ($M = 3.01, SD = 2.193$) and zombie panda ($M = 2.84, SD = 1.915$), the naturalness score rises gradually from the photorealistic panda ($M = 5.93, SD = 2.420$) to the real panda ($M = 6.43, SD = 2.420$).

The perception of interestingness only shows slight changes between the mechanical panda ($M = 5.50, SD = 2.239$) and the real panda ($M = 6.24, SD = 2.199$). Similarly, the animateness perception values show moderate variation between the mechanical panda ($M = 5.80, SD = 2.531$) and the real panda ($M = 5.68, SD = 2.491$). To summarize, uncanny valley effects can be found for familiarity, commonality, attractiveness, and naturalness, but no such effects are found for interestingness and animateness for the moving images when considering the expert-based ranking.
Looking at the perception values for the moving images ordered according to the participant-based ranking, we see that the familiarity perception shows the lowest value for the robot panda ($M = 3.76$, $SD = 2.297$), moving toward the mechanical panda ($M = 3.66$, $SD = 2.279$). After this, familiarity decreases toward the zombie panda ($M = 2.80$, $SD = 1.922$). Next, the familiarity increases progressively from the stuffed toy panda ($M = 4.38$, $SD = 2.055$) to the real panda ($M = 6.04$, $SD = 2.429$).

The commonality perception shows similar behavior to that of familiarity. As can be seen from Figure 8b, commonality starts with the robot panda ($M = 3.54$, $SD = 2.068$), showing a decrease from the mechanical panda ($M = 3.51$, $SD = 2.074$) to the zombie panda ($M = 2.84$, $SD = 1.915$). Next, the naturalness increases gradually from the stuffed toy panda ($M = 4.05$, $SD = 1.981$) to the real panda ($M = 6.43$, $SD = 2.420$). In contrast, attractiveness shows significant variation between the stuffed toy ($M = 5.84$, $SD = 2.079$) and photorealistic pandas ($M = 5.63$, $SD = 2.241$) and we expected the photorealistic panda to have a higher score than the stuffed toy panda.

The perception of interestingness toward the moving images has moderate variation between the robot panda ($M = 5.21$, $SD = 2.275$) and the real panda ($M = 6.24$, $SD = 2.199$). Also, the animateness perception has moderate changes between the robot panda ($M = 5.75$, $SD = 2.541$) and the real panda ($M = 5.68$, $SD = 2.491$). To summarize, uncanny valley effects are found for the perception of familiarity, commonality, and naturalness, but no such effects are found for attractiveness, interestingness, and animateness for the moving images when considering the participant-based ranking.

We can observe the different orders of animal-likeness (participant-based ranking vs. expert-based ranking) in relation to the uncanny valley effects by comparing the graphs of Figures 7a and 8b as well as Figures 8a and 9b. Overall, we see consistent patterns: perception of familiarity, commonality, attractiveness, and naturalness display an uncanny valley effect. However, for naturalness in the participant-based ranking, the uncanny valley effect is unclear and the shape of the graph for attractiveness for the still images is slightly different in the participant-based ranking. In contrast, measures of interestingness and animateness do not show such effects. This holds for both still as well as moving images. The differences between the participant-based and expert-based ranking is consistent as well. Due to the differences in ranking, the uncanny valley effects are already found with less animal-like pandas (to the left of the graph) for the participant-based ranking. To sum up, the ranking of animal-likeness does not seem to affect the main characteristics of the uncanny valley line graphs. The only difference is in the naturalness case, which cannot be found for the participant-based ranking. Similar patterns are also found comparing still and moving images.

### 4.3 Movement

The second research question focuses on whether the movement of the virtual animals can amplify the affinity responses (familiarity, commonality, naturalness, attractiveness, interestingness, and animateness) compared to still images of the virtual animal. Figure 9 provides graphs of both still and moving images for the perception of familiarity, commonality, naturalness, attractiveness, interestingness, and animateness. This representation shows small changes in the participant’s perceptions when the virtual animal is still versus when the virtual animal is moving. We can observe that the values for the moving pandas are slightly amplified for familiarity and commonality. Similarly, for the expert-based ranking, we see an amplification for naturalness, but this is less clear for the participant-based ranking. In contrast, for attractiveness, we see that the still images have more extreme values. Given that interestingness and animateness do not have uncanny valleys, no clear effect on the affinity responses can be established.

### 4.4 Morbidity

In line with previous literature, we hypothesized that a morbid virtual animal (e.g., one with zombie features) will elicit more negative familiarity, commonality, naturalness, attractiveness, interestingness, and animateness than other characters. The Kruskal–Wallis tests (data not normally distributed) show that there were significant differences for the familiarity of still images ($\chi^2(5) = 412.310$, $p < .001$), familiarity of moving images ($\chi^2(5) = 227.446$, $p < .001$),
FIGURE 9  Graphs of the perceived familiarity, commonality, attractiveness, naturalness, interestingness, and animateness of the virtual pandas for still and moving images according to the expert-based and participant-based rankings.
commonality of still images ($\chi^2(5) = 434.438, p < .001$), commonality of moving images ($\chi^2(5) = 222.322, p < .001$), attractiveness of still images ($\chi^2(5) = 210.907, p < .000$), attractiveness of moving images ($\chi^2(5) = 163.988, p < .001$), naturalness of still images ($\chi^2(5) = 419.731, p < .001$), naturalness of moving images ($\chi^2(5) = 275.973, p < .001$), interestingness of still images ($\chi^2(5) = 30.473, p < .001$), and interestingness of moving images ($\chi^2(5) = 21.448, p < .001$). However, no significant differences were found for animateness of still images ($\chi^2(5) = 3.362, p = .644$) and animateness of moving images ($\chi^2(5) = 2.316, p = .804$).

The differences between the panda images were further explored using post-hoc tests for familiarity, commonality, attractiveness, naturalness, and interestingness (see Figure 10). We will first consider the still images. Most of the combinations between images for the familiarity perception were significantly different ($p < .001$), except for the robot and mechanical versions of the panda ($p = .712$). The majority of the combinations between images for the perception of commonality were significantly different ($p < .001$), except for the zombie and robot versions of the panda ($p = .125$), and the photorealistic and real versions ($p = .699$). Similarly, most of the combinations between images in the attractiveness perception were significantly different ($p < .001$), except for the robot and mechanical versions of the panda ($p = .291$). For naturalness, we found that the majority of the combinations were significantly different, except for the robot and mechanical versions of the panda ($p = .228$), the robot and zombie versions of the panda ($p = .194$), and the mechanical and zombie versions of the panda ($p = .925$). In contrast, for interestingness many of the combinations were not significantly different and the only combinations that were significantly different were the robot, mechanical, zombie, and stuffed toy pandas with respect to the real panda ($p < .001$).

We now consider the differences between the values of the moving images. The majority of the combinations between the images for the familiarity perception were significantly different ($p < .001$), except for the robot and mechanical versions of the panda ($p = .730$) and the photorealistic and real versions ($p = .068$). Most of the combinations between images for the commonality perception were significantly different ($p < .001$), except for the mechanical and robot versions of the panda ($p = .905$), and the photorealistic and real versions ($p = .382$). Similarly, the majority of the combinations between images for the attractiveness perception were significantly different ($p < .001$), except for the robot and mechanical versions of the panda ($p = .886$), and the photorealistic and stuffed toy versions ($p = .488$). For naturalness, we found that the majority of the combinations were significantly different, except for the zombie and robot versions of the panda ($p = .650$), the zombie and mechanical versions of the panda ($p = .196$), the mechanical and robot versions of the panda ($p = .402$), and the photorealistic and real version ($p = .132$). In contrast, for interestingness many of the combinations were not significantly different. The only combinations that were significantly different were the robot, zombie, and stuffed toy versions with respect to the real version ($p < .001$).

We compared the results of the current study to those of our previous study$^{15}$ where we used the identical still images with the exception of the color of the zombie panda (green as opposed to white in the current study). To investigate the effect of color, we performed a series of independent-samples $t$-tests (Figure 11). These demonstrated significant differences for commonality, $t(324) = -3.983, p < .001$ and attractiveness, $t(324) = -1.973, p = .049$. No significant differences for familiarity, $t(324) = -1.249, p = .212$; naturalness, $t(324) = -1.850, p = .065$; interestingness, $t(324) = 1.090, p = .276$, and animateness, $t(324) = -1.042, p = .298$ were found.

5 DISCUSSION

This study investigated the existence of the uncanny valley effect for virtual animals. The original publication on the hypothesis of the uncanny valley by Mori$^{2,6}$ does not mention explicitly how the ordering on the human-likeness scale was established. However, Mori$^{2,6}$ notes that characters higher on the human-likeness scale have more anthropomorphic characteristics, and characters lower on the scale have more object-like characteristics. In another study conducted by Burleigh et al.$^{22}$ participants were instructed to rate a face on a Likert scale of human-likeness. In general, the human-likeness scale is associated with the perception of realism by participants.$^{5,22}$ According to Kätsyri et al.$^{16}$ human likeness perception can be influenced by aspects of the appearance or aesthetics of the character (e.g., a healthy or morbid appearance). Our study assumed that the human-likeness scale can be converted into animal-likeness. We first compared two rankings of animal-likeness, one based on expert judgment and the other one participant-based. Building on our previous study, we then explored the concept of animal-likeness in more detail using six subscales representing the properties of familiarity, commonality, naturalness, attractiveness, interestingness, and animateness. In order to test the effect of movement, participant responses were collected for both still images and moving images of virtual pandas. Finally, we examined the impact of morbid features given that morbidity has been assumed to influence the uncanny valley effect in the literature.
FIGURE 10  Summary graphs of familiarity, commonality, naturalness, attractiveness, interestingness, and animateness perception of the six stimuli of the virtual panda. Dashed lines indicate significant differences at $p < .05$ and solid lines indicate significant differences at $p < .001$. The absence of lines indicates no significant differences.
5.1 Ranking

The first research question of this study investigated the shape of an animal-likeness scale. We compared an expert-based ranking (which was based on Mori’s ranking) with the ranking provided by the participants. Both groups of respondents considered the photorealistic and real animals the most animal-like. One unanticipated finding is that the mechanical, stuffed toy, robot, and zombie pandas were ordered differently by participants compared to the expert-based ranking. For the experts, the mechanical panda was the lowest on the animal-likeness scale, whereas this was the robot panda for the participants.
The results show that the different rankings do not affect the properties of familiarity and commonality. However, participant-based ranking eliminates the uncanny valley effect of naturalness for still and moving images when compared to the expert-based ranking. Also, the uncanny valley effect of attractiveness in participant-based ranking for moving images has a slightly different shape. Interestingness and animateness show no uncanny valley, no matter which ranking. Overall, this shows that ranking of the virtual animals has an effect on uncanny valley studies. This means that the way the animals are ranked should be taken into account in the analysis for the future studies of the uncanny valley effect.

5.1.1 | Uncanny valley effect on familiarity

The results of the study show that an uncanny valley effect can be found for familiarity, both for still and moving images and for both rankings. This demonstrates that the results reported by Mori et al., which focus on human-likeness, can also be applied to virtual animals, specifically in the area of familiarity perception. The results also show that the participants feel less familiar with a zombie and a robot panda when using the expert-based ranking and with a zombie panda for participant-based ranking.

It is possible that familiarity can be related to certain aesthetic characteristics that are conventionally associated with a given entity. However, in the results on the perception of familiarity, we did not find a significant difference between the zombie rendered in two different colors (green as opposed to white).

5.1.2 | Uncanny valley effect on commonality

The commonality dimension describes how much the viewer recognizes characteristics of an object or living being frequently or rarely occurring in nature. In virtual reality technology, some experiments reported that when the virtual human image is more unusual (meaning its features are less anthropomorphic), this affects the presence, engagement, and interest of the participants. This means that the sense of unusualness relates to the anthropomorphic features of a virtual character. Another example of models of strange living creatures (e.g., reptile, beast, and alien) applied to the uncanny valley hypothesis can be found in the study by Burleigh and Schoenherr. This study confirmed an uncanny valley phenomenon in non-human characters for both still and moving images. When we relate that result to our study, we see that the perception of commonality can be associated with animal-like features. Interestingly, our results also confirm an association between familiarity and commonality.

5.1.3 | Uncanny valley effect on attractiveness

A possible uncanny valley effect on the attractiveness of the virtual character can form a crucial factor in the desirability for a large number of users. According to Kim et al., users preferred to play with an attractive virtual character rather than an ugly one. Likewise, Roys et al. suggested that users, especially women, do not want to play with ugly characters, which is likely a reaction to the players’ desire to look attractive in the virtual world. Schneider et al. showed there is a second highest mean attraction toward non-human virtual characters (e.g., animals or robots) when they present mild human-like features. The results on attractiveness in this study are interesting in that we observed an uncanny valley effect for still but not for moving images, independently of whether the ranking on animal-likeness was done by experts or by non-experts.

5.1.4 | Uncanny valley effect on naturalness

The appearance of naturalness is an essential component for representing biological systems. Participants experience a lack of naturalness when, for example, the image of the animal has some missing traits or there is a perceptual mismatch with the real animal. Moreover, Schwind et al. described that three factors can affect humans’ reactions toward virtual animals: “the violations of the naturalness of the virtual animal, the facial expression, and body pose, as well as how the animal fits into the scene” (p. 58). Likewise, Löffler et al. identified the animal-likeness scale from extreme values as machine-like to animal-like, artificial to natural, and inanimate to living. They found an uncanny valley effect for
zoomorphic robots, where the robot animals located in the middle level of animal-likeness were perceived as less attractive or likeable. The authors conclude that mismatching between the realistic and natural appearance of the animal at the same time can foster an unfavorable reaction in the users.

We found that in our data, there was an uncanny valley effect on the perception of naturalness for still and moving images with expert-based ranking, but this was not the case for still and moving images with participant-based ranking.

### 5.1.5 Uncanny valley effect on interestingness, and animateness

Surprisingly, no uncanny valley effect was found for aspects of interestingness and animateness. This holds for the expert-based ranking and the participant-based ranking alike with both still and moving images. Put differently, participants considered all of the six animal images to be similarly interesting and animate. This finding suggests that despite there being a clear conceptual relation between all the uncanny valley subscales, the subscales for interestingness and animateness may behave differently. To our knowledge, there has not yet been any detailed investigation of the relationship between the perception of interestingness and animateness in the context of the uncanny valley in regard to virtual humans or virtual animals.

### 5.2 Movement

According to the original hypothesis of Mori and the hypothesis proposed by Kätsyri et al., the uncanny valley effect can be amplified by movement of the virtual character. In particular, movement can provide an artificial object with an unnatural quality and thus magnify its creepiness. Therefore, in our stimulus material, we included stimuli depicting a subtle movement of the virtual figure. In line with the expectation formulated in previous studies, the movement slightly amplified the perception responses for the less animal-like virtual characters (i.e., the robot, zombie, mechanical, and stuffed toy panda).

### 5.3 Morbidity

On the one hand, we might expect a zombie virtual character to be attractive to participants, as zombies are a common staple in popular culture. On the other hand, according to the morbidity hypothesis of Kätsyri et al., a morbid virtual character should give rise to negative affinity, in line with a human “revulsion to death.” Indeed, in our study, we found that the zombie panda was considered to be unattractive, as well as less familiar, common, and natural.

### 6 Conclusion

The current study investigated the existence of the uncanny valley effect for virtual animal characters. Considering an expert-based ranking of animal-likeness, we found uncanny valley effects for familiarity, commonality, naturalness, and attractiveness. For participant-based ranking, we found uncanny valley effects for familiarity and commonality for both still and moving images, attractiveness for still images and naturalness for moving images. In both rankings, no uncanny valley effect was found for the perception of interestingness and animateness. The results of this investigation show that the uncanny valley effect can generally be observed not just for human likeness but also for animal likeness. The findings contribute to our understanding of uncanny valley hypothesis of non-human virtual characters and provide a basis for further animal-likeness studies. Taken together, they suggest that design features of virtual animals can have a direct impact on the user experience.

The generalizability of these results is subject to certain limitations. In particular, we observed that the expert-based ranking of animal-likeness is different from that of the participants. More research is needed to fully understand these discrepancies. Also, it seems to be the case that movement has an effect on the animal-likeness, possibly leading to a new ranking. The color of the animals (in a way a property of the visualization of the animal) can influence the uncanny valley effect as well and more research into the visual appearance of the virtual animals is thus needed. Finally, it remains to be seen to what extent the results concerning virtual pandas as stimuli carry over to other virtual animals (e.g., fish, birds,
worms, beavers, insects, spiders, etc.). Future studies should concentrate on testing the uncanny valley effect on other species and their virtual visualizations.

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