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Domain-general and -specific individual difference predictors of an uncanny valley and uncanniness effects

Alexander Diel [a,b,c,*], Michael Lewis [a]

[a] Cardiff University School of Psychology, United Kingdom
[b] University of Duisburg-Essen, Clinic for Psychosomatic Medicine and Psychotherapy, LVR University Hospital Essen, 45147, Essen, Germany
[c] Center for Translational Neuro- and Behavioral Sciences (C-TNBS), University of Duisburg-Essen, 45147, Essen, Germany

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ABSTRACT

Near humanlike artificial entities can appear eerie or uncanny. This *uncanny valley* is here investigated by testing five individual difference measures as predictors of uncanniness throughout a variety of stimuli. Coulrophobia predicted uncanniness of distorted faces, bodies, and androids and clowns; disgust sensitivity predicted the uncanniness of some distorted faces; the anxiety facet of neuroticism predicted the uncanniness of some distorted faces, bodies, and voices; deviancy aversion and need for structure predicted uncanniness of distorted places and voices. Taken together, the results suggest that while uncanniness can be caused by multiple, domain-independent (e.g., deviancy aversion) and domain-specific (e.g., disease avoidance) mechanisms, the uncanniness of androids specifically may be related to a fear of clowns, potentially due to a dislike of exaggerated human proportions.

1. Introduction

Near humanlike artificial entities can appear creepy or eerie, called "uncanny valley" (Mori, 2012): Although human likeness generally increases likability (Mara, Appel, & Gnambs, 2022), realistic androids who miss to simulate humanlike appearance and behaviour are disliked (Diel, Weigelt, & MacDorman, 2022; MacDorman & Ishiguro, 2006; Mathur & Reichling, 2016). Uncanny androids may decrease trust-based interactions with humans (Mathur & Reichling, 2016), and eerie CG characters can threaten virtual reality applications (Ratajczyk, Dakowski, & Lupkowski, 2023) and lead to movie flops and studio closures (Freedman, 2012). While empirical replications and underlying mechanisms of the uncanny valley have been investigated for decades (Diel & MacDorman, 2021; Diel al., 2022; Kätsyri, Förger, Mäkäräinen, & Takala, 2015; MacDorman & Ishiguro, 2006; Wang, Lilienfeld, & Rochat, 2015), its psychological causes remain unclear.

Individual difference research may shed light on the mechanisms underlying the uncanny valley, yet relevant research remains sparse (Abubshait & Wiese, 2017; Lischetzke, Izydorczyk, Hüller, & Appel, 2017; MacDorman & Entezari, 2015; Sasaki, Ihaya, & Yamada, 2017). This work aims to extend research on individual differences on the uncanny valley by focusing on previously ignored yet theoretically relevant personality variables while accounting for more recent research on the uncanny valley that will be explored below.

1.1. Uncanny valley and distorted categories

The uncanny valley is typically conceptualized as a nonlinear, valley-like function of human likeness and uncanniness or related constructs (Bartneck, Kanda, Ishiguro, & Hagita, 2009, pp. 269–276; Diel et al., 2022; Mori, 2012; Ramey, 2005; here referred to as "proper" uncanny valley). This function may be understood as a specific instance of more general "uncanniness effects", here defined as increases in uncanniness caused by specific types stimulus manipulation across different categories (an increase of uncanniness one type of stimulus manipulation within one stimulus category would be considered one uncanniness effect). For example, some theories of the uncanny valley suggest that the presence of distortions or atypialities may increase the uncanniness of an otherwise typical stimuli (Kätsyri et al., 2015). Uncanniness effects have been observed in animal stimuli, for example when distorting or morphing animal faces (Diel & MacDorman, 2021; Yamada, Kawabe, & Ihaya, 2013) or for instances of robotic or computer-generated animals (Löffler, Dörrenbächer, & Hassenzahl, 2020, pp. 261–270; Schwind, Leicht, Jäger, Wolf, & Henze, 2018). Uncanniness effects have also been

* Corresponding author. Cardiff University School of Psychology, United Kingdom.
E-mail address: diela@cardiff.ac.uk (A. Diel).

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observed in inanimate objects, like distortions in physical places (Diel & Lewis, 2022a; Diel & MacDorman, 2021). In the same vein, distortions or deviations in human(-like) stimuli may increase uncanniness (Kätsyri et al., 2015), and especially so for more realistic stimuli (Diel & Lewis, 2022b; MacDorman, Green, Ho, & Koch, 2009; Mäkäräinen, Kätsyri, & Takala, 2014), creating a statistical uncanny valley function when plotted against human likeness or realism. Domain-independent cognitive theories of the uncanny valley that are not bound to stimulus category, like atypicality, categorical ambiguity, cognitive dissonance, perceptual mismatch, or a higher sensitivity to deviations in specialized categories, can predict uncanniness effects in stimuli beyond humanlike appearance (Diel & MacDorman, 2021; Kätsyri et al., 2015; MacDorman & Entezari, 2015; MacDorman & Ishiguro, 2006; Seyama & Nagayama, 2007; Yamada et al., 2013). Thus, such theories would explain the "proper" uncanny valley effect but also predict uncanniness effects in categories described above by expected similar cognitive mechanisms. The investigation of domain-independent uncanniness effects with similar underlying mechanisms would support theories that suggest domain-independent mechanisms to be responsible for the uncanny valley (Diel & MacDorman, 2021; Kätsyri et al., 2015; Wang et al., 2015).

In summary, the investigation of "uncanniness effects" across categories serves two purposes to enhance the understanding of the mechanisms underlying the uncanny valley:

First, if certain theories of the uncanny valley predict that a specific type of stimulus manipulation elicits uncanniness across categories (e.g., atypicality, categorical ambiguity, mismatch, higher sensitivity caused by specialized processing, etc), then observed increases of uncanniness caused by said stimulus manipulations would support said theories of the uncanny valley. On the other hand, if such uncanniness effects are not observed, said theories are not supported, and their validity in terms of the uncanny valley could also be questioned.

Second, if the same individual difference variables predict ratings in both an uncanny valley and in uncanniness effects, then the mechanisms related to said individual difference variable can be linked to domain-general mechanisms of the uncanny valley.

If similar mechanisms underlie the "proper" uncanny valley in humanlike entities and uncanniness effects in inanimate objects, then the same individual differences should sensitize uncanniness consistently across categories. Meanwhile, individual difference variables related to more domain-dependent theories (e.g., theories that expect an uncanny valley only for human or animal categories) should predict uncanniness effects in certain categories (e.g., humans or animals) while not in others (e.g., inanimate objects). Candidate variables are explored below.

1.2. Individual differences

1.2.1. Disgust sensitivity and disease avoidance

The uncanny valley may emerge due to evolved mechanisms of disease avoidance (MacDorman & Ishiguro, 2006; Moosa & Ud-Dean, 2010). As the evolutionary function of disgust is to avoid contamination (Rozin & Fallon, 1987), mechanisms of disease avoidance should be associated with disgust responses. Uncanny stimuli can indeed elicit disgust responses (Ho, Macdorman, & Pramono, 2008), and disgust sensitivity is positively associated with the uncanny valley (MacDorman & Entezari, 2015).

According to the disease avoidance theory, disgust sensitivity should be associated with the uncanniness in deviating features in organic stimuli specifically (e.g., faces, bodies, voices, including animals), while not being associated with uncanny deviations in inorganic stimuli (e.g., places, written text).

The Disgust Scale-Revised (DS-R) is a reliable measure of individual proneness to experience disgust reactions (Haidt, McCauley, & Rozin, 1994; Olatunji et al., 2007) and has been associated with the uncanny valley (MacDorman & Entezari, 2015). Thus, the DS-R is a suitable candidate to measure disgust sensitivity. The questionnaire contains statements such as "It bothers me to hear someone clear a throat full of mucous" or "You see a man with his intestines exposed after an accident".

1.2.2. Deviancy aversion

Deviations in simple patterns tend to be devalued (Gollwitzer, Marshall, Wang, & Bargh, 2017). As deviancy aversion in simple patterns is associated to negative attitudes towards individuals in statistical minorities or social deviancy, it is considered a domain-general mechanism (Gollwitzer et al., 2017, 2022). The uncanny valley has been related to deviations in familiar categories driven by a higher sensitivity to anomalies due to specialized processing (Diel & Lewis, 2022b; 2022c; MacDorman & Chattopadhyay, 2016; MacDorman et al., 2009; Matsuda, Okamoto, Ida, Okanoya, & Myowa-Yamakoshi, 2012). As deviancy aversion is domain-general, uncanniness effects driven by deviancy aversion should occur independent of stimulus categories, encompassing animate or organic stimuli (e.g., human faces and bodies) and inanimate or inorganic stimuli (e.g., physical places). Pattern deviancy is measured by showing disrupted or non-disrupted geometrical patterns which are rated on 9-scale "happy – unhappy", "comfortable – uncomfortable", and "content – discontent" scales following a "the above image makes me feel …" statement.

1.2.3. Need for structure

Multiple theories on the uncanny valley imply that it is related to violations or inconsistencies regarding experience-based cognitive structures (Jentsch, 1906/1997; Lischetzke et al., 2017; Mitchell et al., 2011; Moore, 2012; Saygin, Chaminade, Ishiguro, Driver, & Frith, 2012). Analogous to deviancy aversion, individual differences exist in the degree at which individuals need to create unambiguous cognitive structures of the world (Neuberg & Newsom, 1993). Lischetzke et al. (2017) found that personal need for structure was associated with a higher sensitivity to the uncanny valley. Individual difference in the tolerance of disrupted cognitive structure may predict people's sensitivity to eeriness of artificial entities that disrupt expectations of human appearance and behaviour. Need for structure is supposed to be domain-general and is thus expected to predict uncanniness effects across animate and inanimate object categories.

Neuberg and Newsom (1993) developed a personal need for structure questionnaire. Individuals with a high need for structure prefer to cognitively structure information in simple patterns, including the use of social stereotypes (Neuberg & Newsom, 1993). The need for structure questionnaire scores have been associated with the uncanny valley (Lischetzke et al., 2017), and is thus a viable measure for the current study. The need for structure questionnaire includes statements such as "I enjoy having a clear and structured mode of life" or "I don't like situations that are uncertain."

1.2.4. Anxiety (facet of neuroticism)

Uncanniness has been associated with fear and anxiety responses in past research (Ho et al., 2008). Neuroticism, a factor of the big five personality model, is associated with emotional instability, including sensitivity to anxiety and disgust responses and reaction towards threatening stimuli (Costa & McCrae, 1992; Digman, 1990). The anxiety facet of neuroticism (from now on referred to as *anxiety*) specifically has been found to sensitize uncanny valley reactions (MacDorman & Entezari, 2015).

Neuroticism is slightly associated with deviancy aversion (Golllwitzer et al., 2017) and could thus sensitize effects of deviancy aversion on uncanniness ratings of distorted stimuli. Furthermore, effects of anxiety are expected to be independent of stimulus category.

Anxiety can be measured using the freely available International Personality Item Pool (Goldberg, 1999). The anxiety questionnaire includes statements such as "I worry about things" and "I get stressed out easily".

1.2.5. Coulrophobia

Coulrophobia is a clinically significant fear of clowns (van Venrooij & Barnhoorn, 2017). Subclinically, 17.2% report at least being slightly afraid of clowns (vs 3.1% very afraid; Rapoport & Berta, 2019). Fear of clowns is cross-cultural affecting both children and adults (Meiri et al., 2017; Tyson, Davies, Scorey, & Greville, 2022), yet its aetiological mechanisms remain unclear. Fear of clowns may be caused by clowns falling into an uncanny valley due to their distorted humanlike appearance (Moore, 2012; Wang et al., 2015). Participants reported being distressed by clowns because they depict disturbing or odd appearance, which the authors interpreted to be analogous to the distorted appearance related to the uncanny valley (Tyson, Davies, Scorey, & Greville, 2023). However, Tyson et al. (2023) only asked participants on why they thought they were afraid of clowns; ratings of clown uncanniness and human likeness were absent. Hence, the relation between coulrophobia and the uncanny valley remains unclear.

Few measures of coulrophobia exist in the literature. A recent study developed and validated a Fear of Clowns Questionnaire (FCQ) by adapting it from a fear of spider questionnaire (Tyson et al., 2023). As the FCQ was capable of reliably measure individual differences in subclinical coulrophobia, it is a viable candidate for investigating associations between differences in fear of clowns and the uncanny valley. The FCQ uses statements includes as "I would do anything to try to avoid a clown" and "If I saw a clown, I would feel very panicky".

2. Study 1: Uncanniness effect validation

Study 1 focuses on the validation of previously found uncanniness effects.

2.1. Research question and hypotheses

First, it was tested whether the data confirm expected uncanny valley and uncanniness effects, independently of individual differences. These validations co-function as replications of previously found uncanniness effects. The uncanniness validation hypotheses are as follows:

1. Across face stimuli, a polynomial (quadratic or cubic) function of human likeness can explain uncanniness better than a linear function (uncanny valley hypothesis)
2. Incremental face distortion increases uncanniness across face types, and more so for realistic (real and cartoon-filter) compared to less realistic (sketch-filter, CG, robot) face types (face uncanniness hypothesis)
3. Incremental body distortion increases body uncanniness (body uncanniness hypothesis)
4. A) Manipulated place distortion increases place uncanniness, and B) non-manipulated deviating places are more uncanny than non-deviating places (place uncanniness hypothesis)
5. A) Artificially distorted and B) naturally pathological voices are more uncanny than typical voices (voice uncanniness hypothesis)
6. Distorted written text is more uncanny than non-distorted text, and this effect is more pronounced in more familiar languages (written text hypothesis)

2.2. Methods

2.2.1. Participants

To estimate sample size, a power analysis was conducted. The power analysis using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) with $f^2 = 0.15$ (medium effect), $\alpha = 0.05$, and $1 - \beta = 0.80$ revealed that 124 participants were sufficient. Participants were recruited from two sources: First, as Psychology undergraduate students recruited locally, and second, as US and UK citizens recruited via Prolific. Participants ($M_{\text{age}} = 28.31$, $SD_{\text{age}} = 6.81$) were 60 female, 56 male, five other, and three preferred not to say.

2.2.2. Materials

Face stimuli. Seven realism types of face stimuli were used: real, cartoon, sketch, computer-generated (CG), robot, android, and clown.

For face distortion ranges across face types, human, cartoon, sketch, CG, and robot faces were incrementally distorted in three steps. Distortions were created by increasing distance between the eyes and moving the mouth down (see Diel & Lewis, 2022a, for a detailed description).

Human stimuli were selected from the Chicago Face Database (CFD; Ma, Correll, & Wittenbrink, 2015). Cartoon and sketch faces were CFD faces rendered via cartoon character and sketch character tools of VanceAI toongineer (https://vanceai.com/toongineer-cartoonizer). The cartoon filter kept a relatively high level of detail and realism (configuration, shading, colour), while the sketch filter removed most details other than the basic facial configuration. CG faces were generated via FACSGen. Robot and android faces were selected from previous research based on their human likeness and likability ratings (Mathur & Reichling, 2016): For robot faces, the most likable low humanlike stimuli from Mathur and Reichling (2016), and for android faces, the least likable more humanlike stimuli were selected. Clown stimuli were selected using google image search, selecting for only frontal or side views of the face. Deliberately creepy clown designs were excluded to avoid confoundation. Thus, two real, cartoon, sketch, CG, and robot faces were used with three distortion levels each. Each of the five mentioned face categories thus had 6 stimuli (2 per distortion level), leading to 30 stimuli. Additionally, 16 images of androids and clowns were used, creating a total of 62 stimuli in total.

Body stimuli. Body stimuli were selected from the BEAST database (de Gelder & Van den Stock, 2011). Bodies were incrementally distorted be either extending or shrinking the length of arms and legs. Six body images were used with three levels of distortion each.

Place stimuli. Stimuli of physical places were taken from Diel and Lewis' (2022c) study on an uncanny valley of physical places. The set consisted of ten real places, five typical places that were not rated as uncanny, and five of the most uncanny places. In addition, four pairs of virtual places were created using Roomstyler®, with one stimulus per pair being distorted and the other undistorted.

Voice stimuli. Voice stimuli were taken from Diel and Lewis' (in review) study. The test stimuli are part of the Perceptual Voice Qualities Database (PVQD; Walden, 2022). The set of voices consisted of 12 stimuli: four typical human voices, four pathological voices, and four distorted voices whose fundamental frequency was multiplied by 1000 using the STRAIGHT software (Kawahara et al., 2008). All voice stimuli consisted of individuals saying "the blue spot is on the key again. How hard did he hit him?", and were 4 s in length.

Written text stimuli. Written text stimuli were taken from the study by Diel and Lewis (2022d) on the uncanniness of distorted written text in familiar and unfamiliar languages. The sentences were either in English (familiar language and script), Icelandic (unfamiliar language, familiar script), or Babylonian Cuneiform (unfamiliar language and script). Distortions were created by moving and rotating the positions of the letters without changing their sequence in the word. Sentences were taken from the *Epic of Gilgamesh* provided by the Electronic Text Corpus of Sumerian Literature (ETCSL).

A summary of all stimulus manipulations (except voices) is shown in Figs. 1 and 2.

Note. For body stimuli, three levels of distortions are shown. For place stimuli, a control and misplacement distortion is shown (see Diel & Lewis, 2022c, for more stimulus examples). For text stimuli, control and distorted example text are shown for the three languages (top to bottom: English, Icelandic, Cuneiform). Courtesy to Prof. de Gelder for allowing the use of the body stimulus from the BEAST database (de Gelder and Van den Stock, 2011).

2.2.3. Procedure

The study was conducted online. After participants completed the

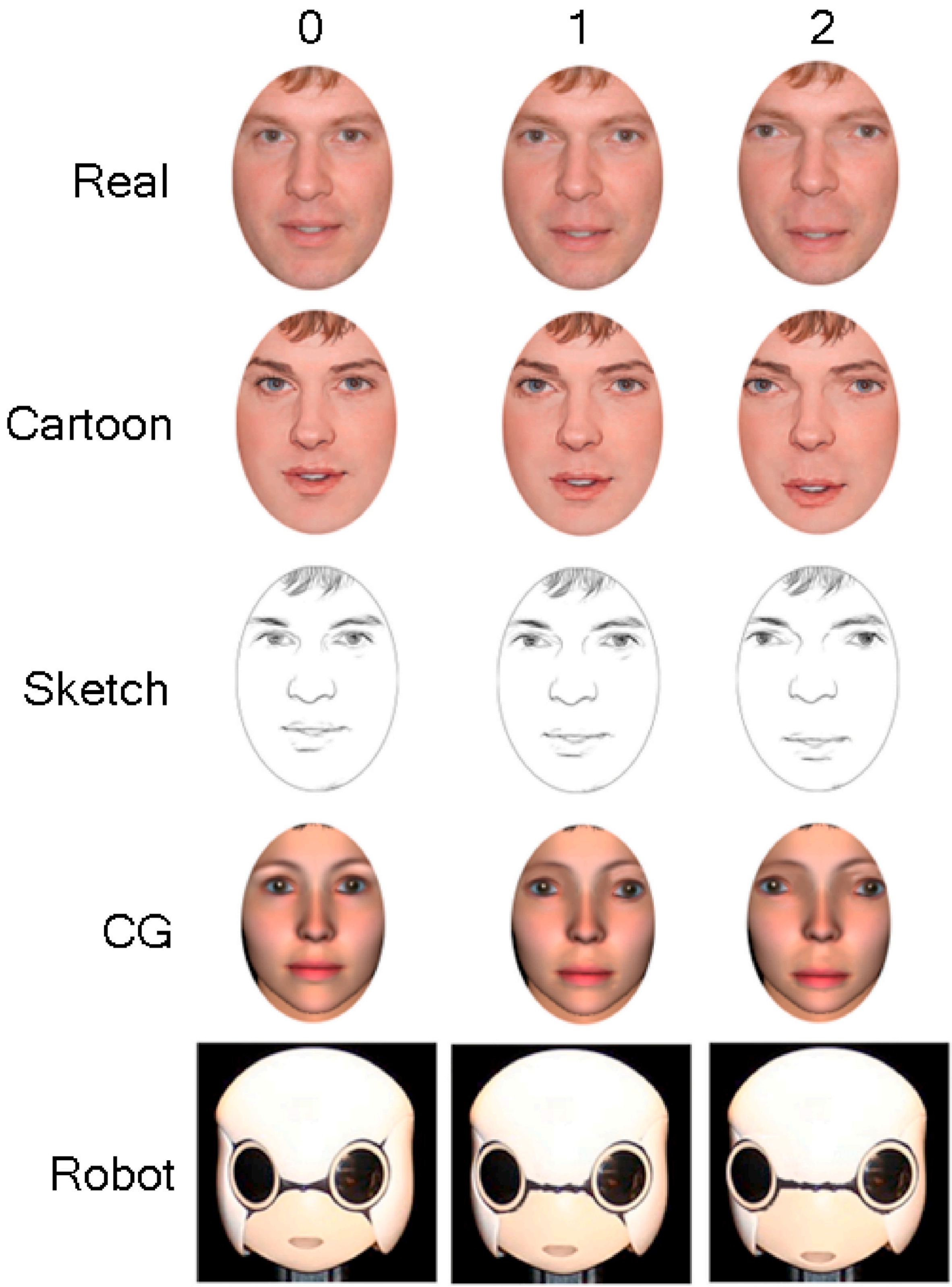

Fig. 1. Face stimulus manipulations across conditions, divided by face type (rows) and distortion levels (columns).

questionnaires after receiving study information and giving informed consent. Afterwards, participants were linked to the main experiment consisting of five sub-tasks: In the first, participants rated the face stimuli on the 0 – 100 scales on eerie, strange, and humanlike ratings. “Eerie” and “strange” items are among the most used and most effective single-item measures in uncanny valley research, and are marked by high intercorrelations indicating that they measure similar constructs (Diel et al., 2022; Ho & MacDorman, 2017). “Eerie” may capture a negative sensation characteristic to the emotional reactions towards uncanny valley specifically, linked to fear and disgust (Benjamin & Heine, 2023; Diel et al., 2022; Ho et al., 2008; Mangan, 2015). “Strange” meanwhile may relate to a cognitive perception of abnormality,

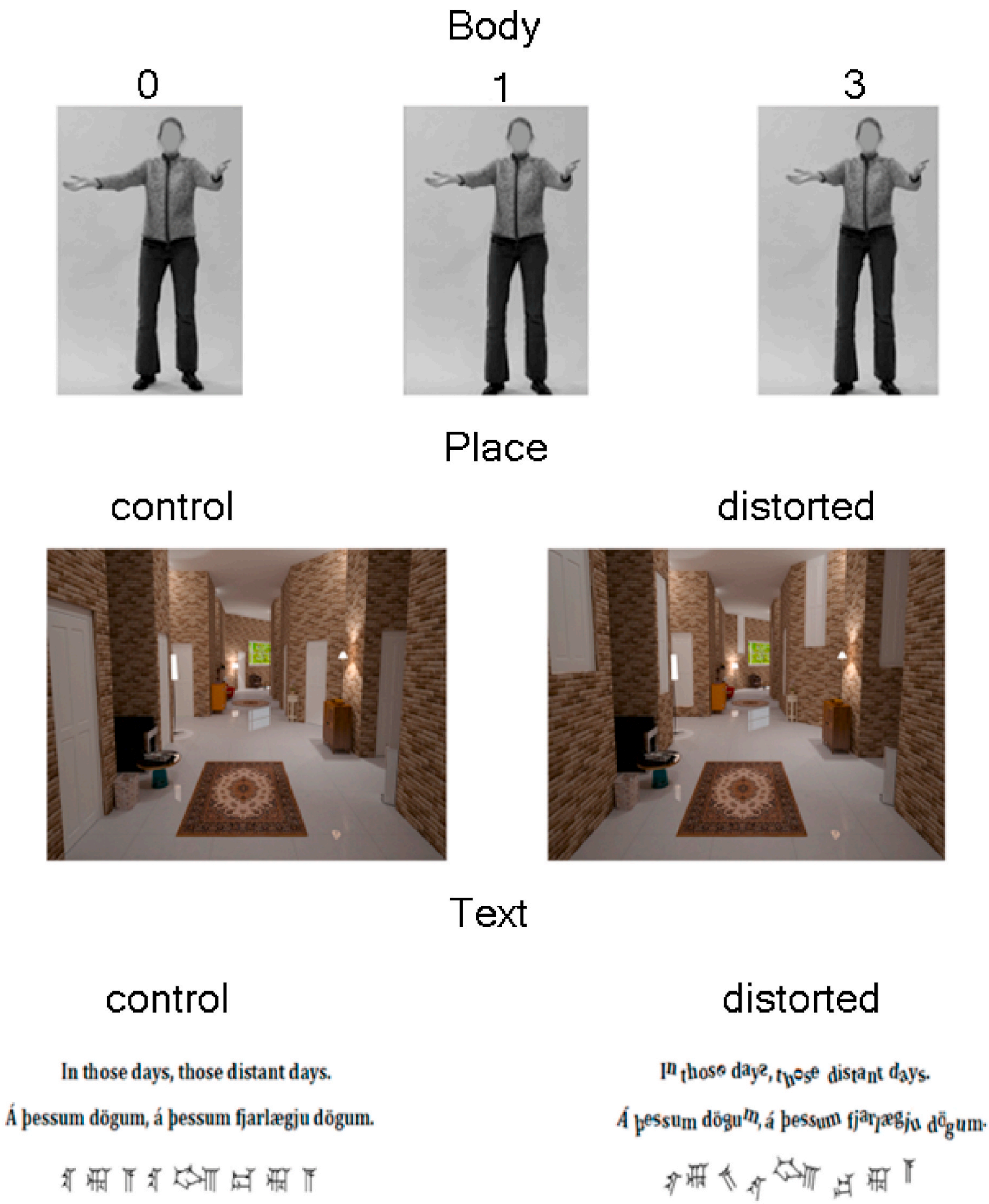

Fig. 2. Non-face visual stimuli divided by stimulus condition.

sensitivity to deviations, or a lack of familiarity that has been linked to the uncanny valley (Chattopadhyay & MacDorman, 2016; Diel & Lewis, 2022a; Diel et al., 2022; Ho et al., 2008; Mäkäräinen et al., 2014). According to recommendations, general positive items (e.g., "likable") were not used here as such items may be more susceptible to confounding effects (leading to a decrease of likability without eliciting uncanny feelings; Diel et al., 2022). Such confounding effects may be more prevalent in the current study given the wide variety of different stimuli used.

For the body, place, voice, and written text rating sub-tasks, participants rated stimuli on the same items except for human likeness. Stimuli were presented in a randomized order, and participants had unlimited time to decide on each rating scale.

2.2.4 Data analysis and availability Data analysis was conducted via RStudio. Linear mixed models were used to investigate the hypotheses. Outliers (1.5 IQR from median) were removed for each rating scale, stimulus-level. For face stimuli, 109 uncanniness scores and 267 human likeness scores have been removed. For body, place, voice and text, stimuli, 2, 45, 25, and 22 uncanniness scores have been removed. Data, analysis, and stimuli that are not protected by Creative Commons licence are available at https://osf.io/rz8d5. The study was conducted in alignment with the Declaration of Helsinki and approved by the Cardiff

University Ethics Committee Board (EC.23.01.10.6716).3.

2.3. Results

Across tasks, eerie and strange ratings were combined into an uncanniness index by calculating the means on a trial-level (see Table 1).

2.3.1. Uncanny valley

Linear mixed models with linear, quadratic, and cubic functions of human likeness as fixed factors and stimulus and participant as random factors were conducted to investigate an uncanny valley (Fig. 3). Results show that quadratic function could explain the data better than a linear function ($\chi^2 = 143.54$, $p < .001$), and a cubic function ($\chi^2 = 203.58$, $p < .001$). Thus, a quadratic function of human likeness could best explain uncanniness ($t(1136) = -12.04$ $p < .001$, $R^2_{cor} = 0.54$, AIC = 62060).

Note. The depicted plot is akin to the right part of an uncanny valley (Mori, 2012) when non-humanlike mechanical robots (e.g., a Roomba) are missing. Dots indicate stimuli, and grey areas show standard errors.

2.3.2. Uncanniness effects across stimulus conditions

Uncanniness effects were investigated using linear mixed models with participants and base stimuli as random effects, and with the relevant variables as fixed effects. Across stimulus conditions, significant main or interaction effects relevant to the hypotheses are reported, followed by post-hoc comparisons for relevant differences. Results are summarized in Table 2. Data is furthermore summarized in Figs. 4 and 5.

Note. Fig. 4A shows average uncanniness ratings across distortion levels for cartoon, CG, sketch, real, and robot faces. Fig. 4B shows average uncanniness ratings for android, clown, and undistorted human faces. Asterisks mark significant differences at a $p < .05$ level. Error bars indicate standard errors.

Note. Fig. 5A shows uncanniness ratings across body distortion levels. 5B shows uncanniness ratings across place types. 5C shows uncanniness ratings across voice types. 5D shows uncanniness ratings across text language and distortion levels. Asterisks mark significant differences at a $p < .05$ level, error bars show standard errors.

Face distortion. To test whether the effect of distortion on uncanniness was stronger for more realistic faces, post-hoc comparisons with Bonferroni-adjusted p-values were calculated between undistorted and max-distorted stimuli for each face type. Distortion significantly increased uncanniness in real ($t(3546) = -9.15$, $p_{adj} < .001$, $d = 0.86$) and CG faces ($t(3546) = -3.08$, $p_{adj} = .005$, $d = 0.28$), but did not affect cartoon ($t(3546) = -1.42$, $p_{adj} < .39$), sketch ($t(3546) = -0.35$, $p_{adj} = 1$), and robot faces ($t(3546) = 0.3$, $p_{adj} = 1$). Thus, the effect of distortion on uncanniness was present for real and CG faces, but not for (less realistic) sketch, cartoon, and robot faces.

Android and clown stimuli. Post-hoc tests with Bonferroni-adjusted p-values furthermore revealed that android ($t(3987) = 31.89$, $p_{adj} < .001$, $d = 1.61$) and clown stimuli ($t(3987) = 21.75$, $p_{adj} < .001$, $d = 1.09$) were more uncanny than human stimuli.

Body distortion. Post-hoc comparisons with Bonferroni-adjusted p-values showed that distortions increased uncanniness from level 0 to 1 ($t(1442) = -8.01$, $p_{adj} < .001$, $d = 0.77$), 0 to 2 ($t(1442) = -16.98$, $p_{adj} < .001$, $d = 1.54$), and 1 to 2 ($t(1442) = -8.96$, $p_{adj} < .001$, $d = 0.85$).

Place distortion. Bonferroni-adjusted post-hoc tests showed that distorted places were more uncanny than their non-distorted paired counterparts ($t(2115) = -9.349$, $p_{adj} < .001$, $d = 0.6$), and natural distorted places were more uncanny than natural real places ($t(2115) = 41.278$, $p_{adj} < .001$, $d = 2.42$).

Voice distortion. Bonferroni-adjusted post-hoc tests revealed that distorted voices ($t(1054) = 40.76$, $p_{adj} < .001$, $d = 2.17$) and pathological voices ($t(1054) = 30.341$, $p_{adj} < .001$, $d = 2.28$) were more uncanny than typical voices.

Text distortion. Bonferroni-adjusted post-hoc tests revealed that for English ($t(1421) = 15.21$, $p_{adj} < .001$, $d = 1.42$) and Icelandic sentences ($t(1421) = 8.24$, $p_{adj} < .001$, $d = 0.74$), distortion increased uncanniness, while it did not affect Babylonian sentences ($t(1421) = 2.73$, $p_{adj} = .069$).

In summary, consistently across stimulus domains, incremental distortions increased uncanniness. Furthermore, non-manipulated deviating stimuli were more uncanny than non-deviating counterparts across categories (clowns, androids, creepy physical places, pathological voices). Distortion effects were furthermore moderated by realism level in faces and language/script familiarity in written text stimuli, indicating that specialization with a stimulus category increases distortion sensitivity. In total, the results confirm that distortions can cause uncanniness across stimulus categories, and that this effect is more pronounced with higher specialization. Validation hypotheses are thus confirmed.

Table 1
Correlations of eerie and strange scales and Cronbach's alphas of the combined uncanniness ratings across sub-tasks.

Sub-task	Eerie-strange correlation	Cronbach's alpha
Face stimulus rating	0.74	0.85
Body stimulus rating	0.74	0.85
Place stimulus rating	0.74	0.85
Voice stimulus rating	0.82	0.9
Text stimulus rating	0.63	0.77

2.4. Discussion

2.4.1. Uncanny valley

A quadratic relation of human likeness of different face types could best explain uncanniness ratings, akin to an uncanny valley (Mori, 2012). Incremental facial distortions increased uncanniness more in more realistic faces (e.g., real human versus robot faces), and android and clown stimuli were more uncanny than normal human stimuli. Results confirm the uncanny valley effect (Mori, 2012) and the moderating role of face realism on distortions (Diel & Lewis, 2022a). Furthermore, clowns were rated as more uncanny than humans, indicating that they may fall into an uncanny valley (Tyson et al., 2023). Thus, the validation hypothesis on the uncanny valley is confirmed (*uncanny valley hypothesis*), just as the hypothesis predicting an increase of uncanniness across face distortions moderated by face realism (*face uncanniness hypothesis*).

2.4.2. Uncanniness effects

Across stimulus conditions, distortions increased uncanniness ratings: Incremental distortion of body part lengths increased uncanniness; manipulated or naturally distorted physical places were more uncanny than controls; artificially distorted or naturally pathological voices were more uncanny than healthy undistorted voices; Finally, language familiarity moderated the effect of orthographic configural distortion of written text on uncanniness, with the effect of distortions being stronger in familiar versus unfamiliar languages. Thus, uncanniness effects were confirmed across stimulus categories, and all further validation hypotheses are confirmed (namely *body uncanniness hypothesis*, *place uncanniness hypothesis*, *voice uncanniness hypothesis*, *written text uncanniness hypothesis*). In addition, as clown stimuli were more uncanny than human stimuli, the first coulrophobia hypothesis was confirmed.

3. Study 2: Individual difference analysis

The goal of Study 2 is to test five individual difference measures as predictors for uncanniness effects across stimulus categories.

3.1. Research questions and hypotheses

Hypotheses are formulated for each individual difference variable investigated:

For coulrophobia, it is expected that some clown stimuli fall into an

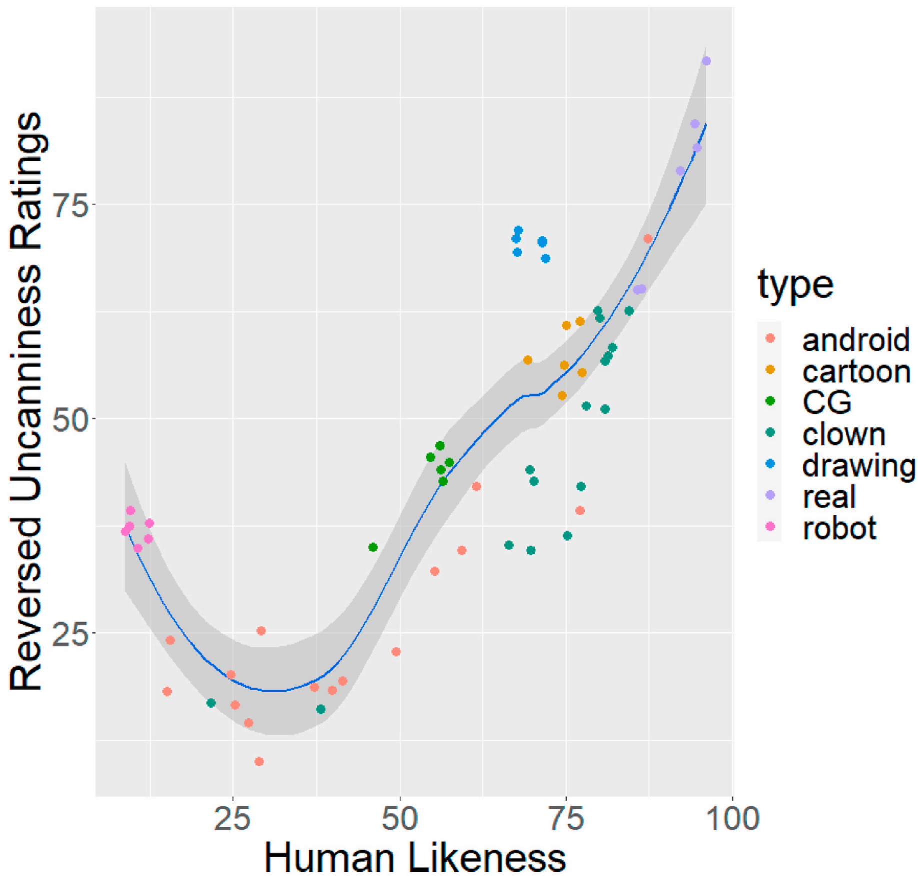

Fig. 3. Human likeness ratings plotted against reversed uncanniness ratings across all face stimuli.

Table 2
Test statistics across stimulus condition. For each stimulus condition, linear mixed models were conducted with participant and base stimulus as random effects. Relevant significant fixed effects and interactions are shown.

Stimulus condition	Effect	*F*/*t*-values	*p*-values	Coefficients
Face distortion	*Type * distortion*	$F(4, 5.46) = 6.929$	.0241	$R_c^2 = 0.52$
Android and clown	*Type*	$F(2,34) = 17.75$	<.001	$R_c^2 = 0.63$
Body distortion	*Distortion*	$t(1319) = 22.31$	<.001	$R_c^2 = 0.53$
Place distortion	*Type*	$F(3,4.84) = 17.75$	<.001	$R_c^2 = 0.62$
Voice distortion	*Type*	$F(2,2.8) = 266.8$	.002	$R_c^2 = 0.74$
Text distortion	*Language * distortion*	$F(2,7.7) = 54.62$	<.001	$R_c^2 = 0.6$

uncanny valley (more uncanny and less humanlike compared to human stimuli), and that this effect is associated with coulrophobia disposition. In addition, exploratory analyses on coulrophobia will be performed.

1. Clown stimuli are more uncanny compared to typical human stimuli
2. Coulrophobia disposition predicts a polynomial function of human likeness and uncanniness for clown stimuli
3. Coulrophobia predicts uncanniness ratings for distorted face, body, and voice stimuli, but not place and text stimuli

Disgust sensitivity is expected to increase sensitivity to the uncanny valley (measured via a polynomial function of human likeness and uncanniness), and to increase uncanniness ratings for distorted organic (face, body, voice) stimuli, but not inorganic ones (place, text).

1. Disgust sensitivity predicts a polynomial function of human likeness and uncanniness across face stimuli
2. Disgust sensitivity predicts uncanniness ratings for distorted face, body, and voice stimuli, but not place and text stimuli

Deviancy aversion is expected to increase sensitivity to the uncanny valley and to increase uncanniness ratings of distorted stimuli across all investigated stimulus categories.

1. Deviancy aversion predicts a polynomial function of human likeness and uncanniness across face stimuli
2. Deviancy aversion predicts uncanniness ratings for distorted face, body, voice, place, and text stimuli

Need for structure is expected to increase sensitivity to the uncanny valley and to increase uncanniness ratings of distorted stimuli across all investigated stimulus categories.

1. Need for structure predicts a polynomial function of human likeness and uncanniness across face stimuli
2. Need for structure predicts uncanniness ratings for distorted face, body, voice, place, and text stimuli

Anxiety is expected to increase sensitivity to the uncanny valley and to increase uncanniness ratings of distorted stimuli across all investigated stimulus categories.

1. Anxiety predicts a polynomial function of human likeness and uncanniness across face stimuli

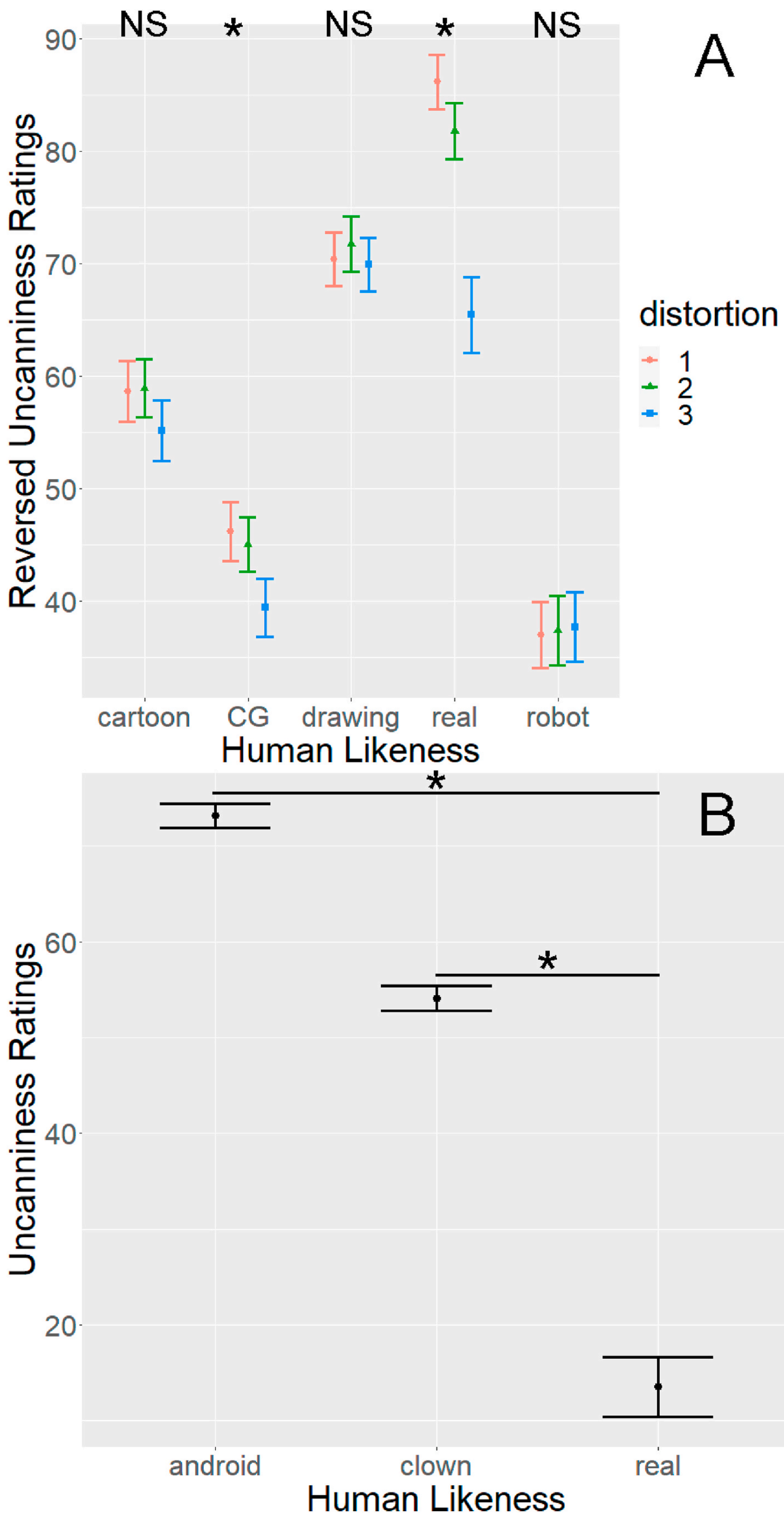

Fig. 4. Differences between face type conditions and distortions.

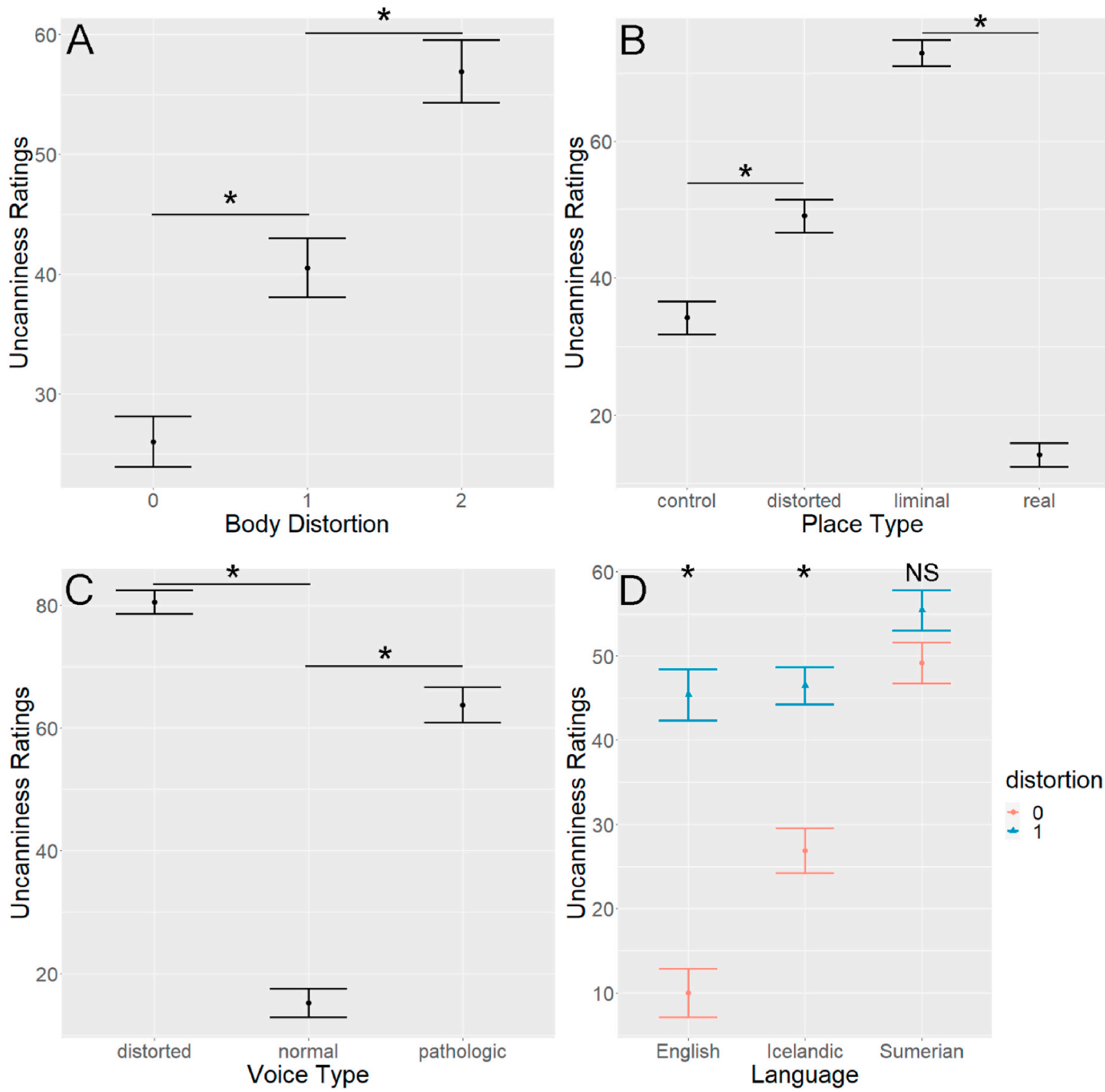

Fig. 5. Average uncanniness ratings across stimulus domains and conditions.

2. Anxiety predicts uncanniness ratings for distorted face, body, voice, place, and text stimuli

3.2. Methods

Methods are identical to those in Study 1. Questionnaires were used in addition to measure individual differences. Questionnaires were the deviancy aversion measure (Gollwitzer et al., 2017), DS-R (Haidt et al., 1994; Olatunji et al., 2007), need for structure questionnaire (Neuberg & Newsom, 1993), anxiety facet of neuroticism (Goldberg, 1999), and the FCQ (Tyson et al., 2022). Deviancy aversion measure was taken directly from Gollwitzer et al. (2017). For the other questionnaires, scales from 0 to 100 on a “fully disagree – fully agree” scale for the questionnaire statements were used. Questionnaire statements were presented in a randomized order.

3.3. Results

Individual differences were for each construct were calculated via means of item responses. Each questionnaire’s Cronbach’s alpha and intercorrelations between individual differences (including significance marks) are shown in Table 3.

Within-participant within-stimulus ANOVAs have been conducted for each relevant analysis. For face stimuli, stimuli were divided by stimulus condition including all distortion levels and effects of individual difference measures on uncanniness ratings were analysed for each type separately. For body stimuli, interactions between distortion level and individual differences were investigated. For place data, interaction between place type and individual difference measures were investigated. For voice data, distorted and pathological voices were separated

Table 3
Cronbach’s alphas and intercorrelations of individual difference measures.

Measure	Cronbach’s alpha	FCQ	DS-R	PDM	PNS	AN
FCQ	0.98	1				
DS-R	0.79	0.42	1			
PDA		0.09	0.27	1		
PNS	0.85	0.12	0.33	0.31	1	
AN	0.91	0.31	0.37	0.2	0.53	1

Note: FCQ = Fear of Clowns Questionnaire; DS-R = Disgust Scale-Revised; PDA = Pattern deviancy aversion; PNS = Personal Need for Structure; AN = Anxiety (neuroticism facet).

and interactions between voice type and individual difference measures were investigated. For word data, interaction effects between distortion and individual difference measures were investigated across languages. The results are summarized in Table 4, and coefficients and confidence intervals of the significant predictors are furthermore depicted in Fig. 6.

Note. AN = anxiety facet of neuroticism. DSR = disgust sensitivity revised. FCQ = Fear of clown questionnaire. PDM = Pattern deviancy aversion. PNS = personal need for structure.

3.4. Discussion

Throughout multiple tasks involving stimuli of different domains, the role of individual differences on uncanniness effects caused by deviations were investigated.

3.4.1. Anxiety facet

Anxiety predicted uncanniness of distortions in cartoon, sketch, and CG faces, as well as distorted human bodies and voices. Contrary to the research by MacDorman and Entezari (2015) there was no evidence that anxiety predicted the uncanniness of androids.

3.4.2. Coulrophobia

Individual differences in self-reported courlophobia predicted uncanniness of distorted human, cartoon, sketch, and robot faces, in addition to the uncanniness of clowns and androids. Furthermore, coulrophobia predicted the uncanniness of distorted text stimuli.

Tyson et al. (2023) observed that participants who reported higher levels of coulrophobia also reported that clowns look disturbing or out of place. As coulrophobia predicted uncanniness of distorted faces and bodies, coulrophobia may be associated with the dislike of exaggerated features in human appearances. Furthermore, coulrophobia predicted the uncanniness of androids, suggesting a common link between the fear of clowns and the uncanny valley, potentially related to a dislike of distorted or exaggerated human features. Given that clowns tend to wear costumes exaggerating body proportions (e.g., big red noses, make-up, or long clown shoes) dislike of such features may link coulrophobia to the uncanniness of distorted faces and bodies, which may also be present in android faces.

3.4.3. Deviancy aversion

Deviancy aversion describes an individual's tendency to dislike deviations in simple patterns, and can be generalized onto the dislike of more complex deviancy such as statistical minorities (Gollwitzer et al., 2017). In this study, deviancy aversion predicted the uncanninessdistorted voice and place stimuli. For some stimulus categories, uncanniness may stem from aversion to deviations from the expected appearance. Just as simple pattern deviancy aversion can predict the dislike of social pattern deviancy (e.g., statistical minorities; Gollwitzer et al., 2017; Gollwitzer, Marshall, & Bargh, 2020) it may also predict the uncanniness of deviations in more complex patterns, such as the expected structure of physical environments. However, deviancy aversion did not predict the uncanniness of organic visual stimuli like faces or bodies, suggesting that the dislike of deviations in organic (e.g., faces) and inorganic (e.g., places) stimuli have different underlying mechanisms. As deviancy aversion also did not predict android uncanniness, it is questionable whether it is a relevant mechanisms of the uncanny valley.

Interstingly, deviancy aversion predicted the uncanniness of distorted voices. As deviancy aversion was measured using a visual task yet predicted the uncanniness of distorted auditory stimuli, the present study is the first to show a cross-modal transferability of deviancy aversion.

3.4.4. Disgust sensitivity

Disgust responses as warnings against contamination may contribute to the dislike of individuals deviating from typical biological appearance (Park, Faulkner, & Schaller, 2003), and androids may be uncanny because they activate such processes (MacDorman & Ishiguro, 2006; Moosa & Ud-Dean, 2010). The emotion of disgust has been associated with the uncanny valley in the past (Ho et al., 2008), and disgust sensitivity has been found to sensitize uncanniness in androids (MacDorman & Entezari, 2015). In this study, disgust sensitivity has been found to predict the uncanniness of distorted cartoon, sketch, and CG faces, but not the uncanniness of androids.

As disgust sensitivity tended to predict the uncanniness of distortions in humanlike faces with realistic facial structures (sketch, cartoon, CG), it may be linked to anomalies in facial appearance of faces with typical configurations. Deviations in facial configurations may be indicators of disease, and hence, higher disgust sensitivity would predict their dislike. Analogously, disgust sensitivity predicts the sensitivity to naturally distorted (disfigured) faces (Stone, 2021).

Contrary to the results of MacDorman and Entezari (2015), disgust sensitivity did not predict the uncanniness of androids. MacDorman and Entezari used an uncanniness questionnaire developed by Ho and MacDorman (2010), which included an item related to disgust ("repulsive"). Such measures may be more sensitive to disgust-related reactions, increasing the predictive power of disgust sensitivity. As no disgust-related rating scales were used in this study, disgust sensitivity may not have sufficiently predicted the uncanniness of androids.

Table 4
Test statistics of significant predictors across stimulus conditions.

Stimulus	Predictor	*t*/*F*-values	*p*-values	R^2 Coefficients and confidence intervals
Human faces	Fear of clowns	$t(105) = 2.51$	.014	0.35 [0.27, 0.40]
Cartoon faces	Fear of clowns	$t(114) = 2.11$	.037	0.54 [0.46, 0.59]
	Anxiety	$t(109) = 2.2$	.03	0.53 [0.46, 0.58]
	Disgust sensitivity	$t(116) = 2.26$	.026	0.53 [0.46, 0.58]
Sketch faces	Fear of clowns	$t(115) = 2.94$	.004	0.56 [0.54, 0.60]
	Disgust sensitivity	$t(115) = 2.11$	.038	0.54 [0.51, 0.59]
CG faces	Disgust sensitivity	$t(113) = 2.59$	.027	0.63 [0.60, 0.68]
Robot faces	Fear of clowns	$t(114) = 2.48$	.015	0.57 [0.57, 0.67]
Clowns	Fear of clowns	$t(114) = 7.38$	<.001	0.61 [0.56, 0.67]
Androids	Fear of clowns	$t(111) = 2.28$	.025	0.58 [0.52, 0.64]
Human bodies	Fear of clowns	$t(114) = 2.11$	.037	0.34 [0.28, 0.37]
	Anxiety	$t(113) = 2.05$	.009	0.33 [0.25, 0.36]
Places	Deviancy aversion	$F(3,1924) = 5.63$	<.001	0.49 [0.43, 0.56]
	Need for structure	$F(3,1924) = 3.49$	.015	0.49 [0.43, 0.56]
Voices	Anxiety	$F(2,893) = 4.70$	.008	0.18 [0.07, 0.28]
	Deviancy aversion	$F(2,896) = 4.43$	.012	0.18 [0.07, 0.28]
	Need for structure	$F(2,896) = 8.2$	<.001	0.18 [0.07, 0.28]
Text	Fear of clowns	$F(2,1260) = 3.36$	.035	0.30 [0.27, 0.38]
	Need for structure	$F(2,1260) = 3.47$	.032	0.30 [0.27, 0.38]

Note. For each analysis, linear mixed models were conducted with individual differences as fixed effects and participant and base stimulus as random factors. Because place, voice, and text stimuli also contained categorical variables, significant interactions between the categorical variables and individual difference values were used for these conditions.

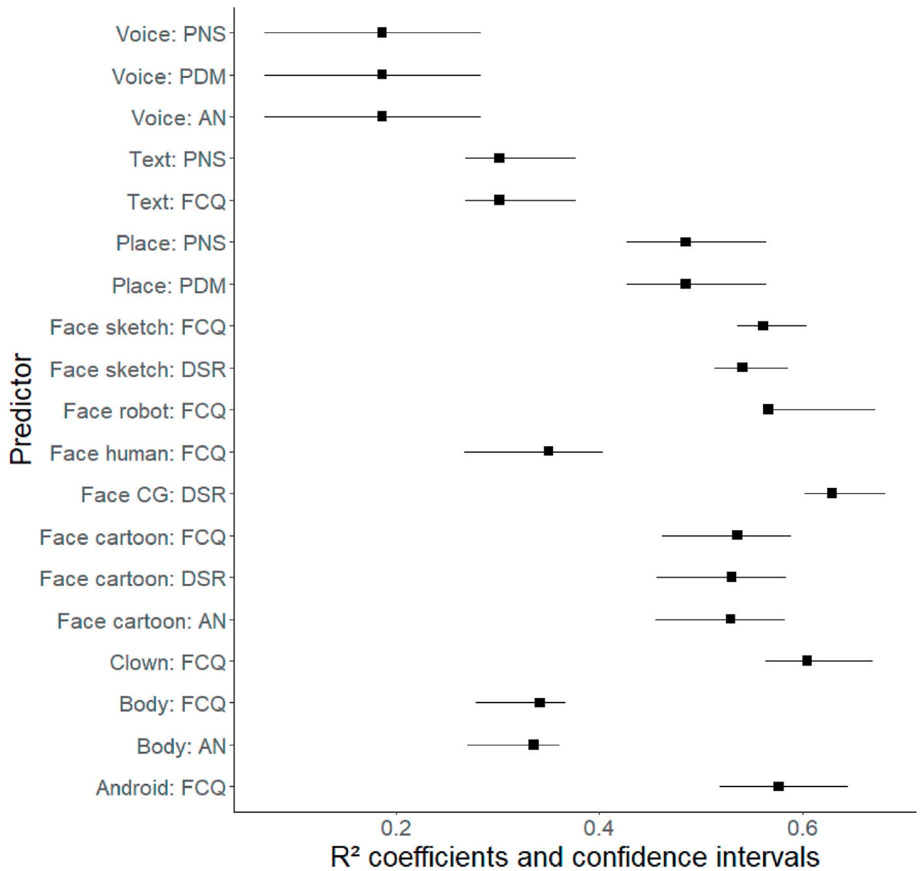

Fig. 6. R^2 coefficients of significant individual difference predictors across stimulus conditions. Black bars indicate confidence intervals.

3.4.5. Need for structure

Individual differences in the personal need for cognitive structures have been associated with the uncanny valley in past research (Lischetzke et al., 2017). However, these results were not replicated in this study. Instead, need for structure only predicted uncanniness of distorted places and voices, which are not typically associated with the uncanny valley.

Need for structure may be more associated with violations of inorganic schemata, such as expectations of the appearance of physical environments, whereas the dislike of distortions in organic visual categories (e.g., faces and bodies) are caused by different mechanisms.

4. General discussion

This work aimed to investigate the role of individual difference in uncanniness effects across categories. In Study 1, previously found uncanniness effects were replicated in five stimulus categories. In Study 2, individual difference measures were used to predict uncanniness effects. In general, the results indicate that individual differences can act as both domain-specific and domain-general contributors to uncanniness, and that uncanniness can be caused by multiple mechanisms.

4.1. Individual difference predictors of the uncanny valley

In the present study, coulrophobia was the only significant predictor of the uncanniness of androids. While coulrophobia was suggested to be associated with the uncanny valley in past research (Tyson et al., 2023), this is the first empirical evidence of a statistical link. In addition, coulrophobia predicted the uncanniness of distorted faces across various categories. Coulrophobia, the uncanny valley, and the uncanniness of distorted faces may be associated through a general mechanism increasing the sensitivity to and dislike of exaggerated or unusual human appearance. If that were the case, then individuals with clinically significant fear of clowns should also express a strong fear or dislike towards uncanny androids. Future research may investigate the link between the uncanny valley and clinical coulrophobia.

While anxiety and disgust sensitivity predicted the uncanniness of some distorted faces, contrary to previous research (MacDorman & Entezari, 2015), they did not predict android uncanniness. Discrepancies from previous research may result from the use of rating scales (some may be more sensitive to disgust reactions than others) or the choice of stimuli: While MacDorman and Entezari (2015) also included uncanny CG animations, only uncanny androids were used in this study. Distortions in CG faces were predicted by disgust sensitivity in this study, indicating that uncanniness in CG stimuli may be related to disgust. Furthermore, the stimuli by MacDorman and Entezari (2015) were animated whereas the stimuli used in this study consisted only of still images. It is possible that unusual or abnormal biological motion, or a mismatch between appearance and motion, may additional different mechanisms that lead to uncanniness related to anxiety and disgust, which were not relevant in the stimuli used in this research.

The observation that two individual difference measures (deviancy aversion and need for structure) only predicted uncanniness ratings in stimulus categories that do not typically fall into an uncanny valley, indicates that uncanniness caused by deviancy aversion and need for structure is not the same as uncanniness caused by the typical stimulus associated with the uncanny valley, like androids or distorted faces. Hence, the uncanny valley can likely not be explained by a general process like deviancy aversion or need for structure.

4.2. Heterogeneity of the uncanny valley

The results indicate that stimuli may be uncanny for different reasons. While some individual difference variables showed surprisingly consistent effects on uncanniness across stimulus categories and modalities (e.g., fear of clowns), no variable could consistently explain uncanniness across all stimulus conditions.

Different predictors for different stimulus categories may underlie different processing mechanisms. Coulrophobia may relate to exaggerated humanlike stimuli, disgust sensitivity to indicators of disease and social norm violations, and need for structure and deviancy aversion to domain-independent pattern violations. Anxiety may furthermore moderate the intensity to negative emotional experiences. Stimuli relevant to the uncanny valley, like distorted faces, CG characters, and androids, may elicit multiple mechanisms that cumulate to strong negative responses, leading to a singular "uncanny valley" effect observed in research.

4.3. Limitations and future research

The fear of clown questionnaire measures individual expressions of coulrophobia within the normal population and is not suitable to diagnose clinical levels of coulrophobia. Generalizations of the results or interpretations onto individuals with clinically significant expressions of coulrophobia are thus not warranted.

Even when only using humanlike stimuli, a wide range of different methods have been observed (Diel et al., 2022). According to the classification by Diel et al. (2022), only *distinct entities, realism render*, and *face distortion* practices have been used here, not other commonly used methods like morphing. In addition, the uncanny valley is most relevant in real-life interactions with artificial entities. Hence, the generalizability of the findings onto other instances and contexts of the uncanny valley remains unclear and can be investigated in the future. A similar concern can also be raised for uncanniness effects in non-human stimulus categories.

5. Conclusions

Investigating individual differences in the uncanny valley may provide insight into its underlying processes. In this study, coulrophobia predicted the uncanniness of androids and distorted faces of various categories. Deviancy aversion and need for structure predicted uncanniness in place and voice stimuli. Disgust sensitivity predicted the uncanniness of some distorted faces. Anxiety predicted the uncanniness of some distorted faces, bodies, and voices. Taken together, the results suggest that while uncanniness may be caused by multiple mechanisms, coulrophobia plays an important role in the uncanny valley effect specifically. A link between fear of clowns and the uncanny valley is thus indicated. While distortions or atypicalities tend to elicit uncanniness across categories, the underlying cognitive mechanisms seem to differ between categories (e.g., for organic and inorganic ones).

CRediT authorship contribution statement

Alexander Diel: Conceptualization, Data curation, Formal analysis, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing. **Michael Lewis:** Funding acquisition, Project administration, Resources, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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