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Structural deviations drive an uncanny valley of physical places

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ABSTRACT

Certain built environments can decrease aesthetic appeal. For humans and objects, deviation from typical appearances leads to nonlinear appraisal characterized as the uncanny valley. The first time, it was explored whether an uncanny valley can be found for built environments. In Experiment 1, a cubic *N*-shaped function of uncanniness plotted against realism of built environments was found, indicating an uncanny valley. Quantitative and qualitative data indicate an association between uncanniness and structural anomalies. Experiment 2 explored distortions leading to uncanniness of indoor places. In Experiment 3, human presence decreased uncanniness of distorted indoor public places but increased uncanniness of private rooms. Taken together, the evidence indicates that deviations from familiar configural patterns drive uncanniness of built physical places. Thus, strong deviations from a built environment's predictable pattern decreases its aesthetic appeal.

1. Structural deviations drive an uncanny valley of physical places

Everyday life consists of navigating physical environments. Environmental variables can influence mental health (Gifford, 2014; Kaplan, 1987): An aesthetically pleasant environment enhances enjoyment, security, and well-being (Brager, Paliaga, & de Dear, 2004; Dosen & Ostwald, 2013), while certain architectural features of buildings, like window size and lighting, can worsen mental or physical health (Almomani & Hikmat, 2008; Jafari et al., 2015; see also Spence, 2020; Parsons, 1991). Multiple literature reviews have shown that poor aesthetics of the environment negatively impact health and well-being (Gardener & de Oliveira, 2020; Kim & Yoo, 2019; Krefis, Augustin, Schlünzen, Oßenbrügge, & Augustin, 2018). Understanding the variables influencing environmental aesthetics can help with the construction of healthy environments. This work will focus on atypicality in the appearance of built environments as a cause of negative environmental aesthetics, specifically creepiness or eeriness. It begins with a review of the *uncanny valley*, a phenomenon describing the negative appeal (usually eeriness or creepiness) of stimuli that deviate from familiar categories. The concept is then applied to the creepiness or eeriness of deviating physical environments, such as haunted houses or ambiguous "liminal space" environments described further below. These insights lead to the motivation to investigate an uncanny valley of built environments based on deviations from familiar patterns of physical places.

1.1. Uncanny valley and norm deviation

The term *uncanny valley* describes negative emotional appraisal of near humanlike entities compared with less humanlike entities or humans (Mori, 2012). In uncanny valley research, the effect of manipulating a stimulus' human likeness or realism (which is often measured on rating scales) is plotted against affective responses towards the stimulus (Diel, Weigelt, & MacDorman, 2022). Affinity increases with human likeness until it dips into the negative and increases back to the positive at fully human likeness, producing a *N*-shaped function. The negative emotional experience has been described as *eeriness*, *creepiness*, or *uncanniness* (Diel et al., 2022; Ho & MacDorman, 2010, 2017; Mangan, 2015). The effect is not specific to human entities: artificial animals (Löffler, Dörrenbächer, & Hassenzahl, 2020; Schwind, Leicht, Jäger, Wolf, & Henze, 2018) and manipulations of realistic animals (Diel & MacDorman, 2021; Yamada, Kawabe, & Ihaya, 2012) elicit observable uncanny valleys. Finally, distorted houses are rated as more uncanny than normal houses (Diel & MacDorman, 2021), indicating that the uncanny valley transcends animate categories and is applicable to built physical environments.

Various theories on the uncanny valley exist (see Diel & MacDorman, 2021; Wang, Lilienfeld, & Rochat, 2015). This work will differentiate theories based on being domain-dependent (an uncanny valley occurs only for specific domains like humanoids or entities appearing animate) or domain-independent (an uncanny valley occurs regardless of domain) theories. domain-dependent explanations explain uncanniness through

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mechanisms specific to human or animal processing, and include avoidance of disease indicators (MacDorman & Ishiguro, 2006), avoidance of genetically unfit mates (MacDorman & Ishiguro, 2006), avoidance of potentially psychopathic traits (Tinwell, Nabi, & Charlton, 2014), and dehumanization (Wang, Cheong, Dilks, & Rochat, 2020; Wang et al., 2015). While not specific to humanlike stimuli, the theory that animacy or mind attributed onto inanimate entities also incorporates a human-specific dimension (Gray & Wegner, 2012; Stein & Ohler, 2017). Meanwhile, domain-independent theories explain uncanniness as resulting from more general cognitive or neural mechanisms, and include unease elicited by processing disfluency through categorically ambiguous stimuli (Carr, Hofree, Sheldon, Saygin, & Winkielman, 2017; Cheetham, Wu, Pauli, & Jancke, 2015) deviations from familiar norms (Diel & Lewis, 2022), or expectation violation in predictive coding (MacDorman & Ishiguro, 2006; Saygin et al., 2012). The observation of an uncanny valley function in stimulus domains beyond human or biological stimuli would contradict predictions of domain-restrictive theories in favor of more domain-independent theories. Specifically, this work will focus the effect of deviation from familiar configural patterns on uncanniness as a domain-independent theory.

Based on the deviation from familiarity theory (Diel & Lewis, 2022), uncanniness is elicited by stimuli deviating from familiar patterns or norms. Familiarity, in this sense, refers to the sense of typicality developed through prolonged perceptual experience. In that sense, the relation between realism and uncanniness is not causal but mediated by increased distortion sensitivity for stimuli that are closer to fully realistic appearance. Similarly, Koch, Bolderdijk, and van Ittersum (2021) recently found that norm deviation increases observers' disgust ratings of food, further indicating that norm- or familiarity deviation drives negative judgment of stimuli. In the context of built environments, architectural structures or places deviating from familiar patterns would elicit negative judgments, potentially related to anxiety and disgust. Similarly, recent evidence finds an increase in uncanniness for distorted houses (inverted windows and doors; Diel & MacDorman, 2021), indicating that configural deviations of buildings appear creepy or eerie. No research has yet investigated an uncanny valley of architecture and built environments. The successful reproduction of such an uncanny valley would indicate that uncanniness is a general response elicited by detecting deviations from predictable patterns. For physical places, unusually designed, distorted, or otherwise structurally deviating environments, are then predicted to elicit negative experiences of creepiness, eeriness, or strangeness and should, unless intended, be avoided in building design. This work will be the first to investigate an uncanny valley of physical places, and whether the effect of deviation from familiar patterns on uncanniness can be applied to physical places to explain the uncanny valley function.

1.2. Creepy environments, deviating architecture, and "liminal spaces"

Some built environments, like abandoned buildings, can elicit feelings of horror, dread, or creepiness (McAndrew, 2020). According to Kaplan's (1987) model, a high degree of mystery (defined as hidden, but "promised" information about an environment) may be elicited by surroundings not allowing inference of sufficient information, motivating further exploration. Stamps (2007) found that dim light and visual occlusion increased the mystery of physical places, which the researcher interpreted as increased informational entropy or lack of environmental information. McAndrew (2020) argued that certain physical places can be perceived as creepy if they trigger agent detection mechanisms sensitive to indicators of the presence of harmful entities. Similarly, McAndrew and Koehnke (2016) proposed that creepiness is generally elicited by *threat ambiguity*: indicators of potential danger, independent of the stimulus' category. Furthermore, absence of light may contribute to agent detection mechanisms as darkness increases the intensity of startle responses (Grillon, Pellewoski, Merikangas, & Davies, 1997; Mühlberger, Wieser, & Pauli, 2008) and enhances detection of potential threat of ethnic outgroups (Schaller, Park, & Faulkner, 2003). Thus, lack of (visual) information about the presence of threat can increase environmental creepiness.

One source of information can be schema-based typicality (Widmayer, 2002). Built environments follow predictable patterns. Houses are expected to have roofs, doors, and windows. Rooms should have entrances connected to the floor. Furniture or other features are of certain sizes, positions, and number. Certain combinations of features are predictable, like a work desk and an office chair, while others are not expected, like a toilet in a kitchen. Thus, typical physical places seem to have predictable configural patterns and can potentially deviate from those.

Visual complexity of an environment, defined as information richness, affects likability of an environment in an inverted U-shaped manner (Güçlütürk, Jacobs, & Liew, 2016; Imamoglu, 2000; Kaplan, 1987). As recognizable patterns allow the organization of information to decrease complexity (Anderson, 1991), the inability to recognize learnt patterns in structurally deviating physical places may lead to a decrease of likability due to its complexity. Similarly, inconsistent scenes are less likable (Shir, Abudarham, & Mudrik, 2021), just as built and natural environments lacking in coherence, i.e., how easily an environment can be mentally organized (Coburn et al., 2020; Vartanian, Navarrete, Palumbo, & Chatterjee, 2021; Weinberger, Christensen, Coburn, & Chatterjee, 2021). Consistent or coherent places may ease recognition of typical environmental structures, allowing the identification of the specific environment, Furthermore, personally familiar spaces and spatial configurations allow for an easier wayfinding (Hölscher & Brösamle, 2007; Iftikhar, Shash, & Luximon, 2020; Wiener, Büchner, & Hölscher, 2009), and environments deviating from typical configurations may be disliked because they are more difficult to reliably traverse. In general, inconsistent or configurally deviating environments may appear less comprehensible, predictable, safe, and generally less pleasant.

One source of such configurally deviating physical places is provided through an Internet phenomenon called *liminal spaces*: a concept of real or artificial physical places judged as ambiguous or eerie (Wikimedia, 2021).

Previous research has mostly focussed on the concept of spatial *liminality* in the context of transitional places (e.g., airports) or those allowing transformative experiences (Huang, Xiao, & Wang, 2018; Neuhofer, Egger, Yu, & Celuch, 2021; Zhang & Xu, 2019). Such definitions however would be unable to explain why many of these *liminal spaces* would elicit distinct eerie or strange experiences. Hence, the term *liminal space* will here refer exclusively to such ambiguous, distressing, or "off" physical places, distinct from other definitions of liminal spaces or liminality.

While a proper academic investigation of *liminal spaces* is yet lacking, the description of *liminal spaces* as ambiguous, strange, or eerie places fits the prediction of physical places which are eerie because they deviate from the norm. Simultaneously, this study will be the first to investigate potential causes of why those specific *liminal spaces* may appear eerie or strange. . Potential explanations can be based on discussed models of environmental and perceptual theories, such as a lack of place coherence (Coburn et al., 2020) inconsistent features (Shir et al., 2021), or as deviation from familiar place configurations. All in all, *liminal spaces* will here be used for the study of the perception of uncanny or creepy deviating physical places, and the uncanny valley of architecture. Hence, such stimuli will be used in the first experiment.

1.3. Research question

The present study is the first empirical investigation focussing on the uncanniness of built environments explained by the effect of configural deviation. Using the uncanny valley paradigm, an uncanny valley curve of photos of physical places is investigated by plotting place realism against uncanniness. Furthermore, the study's goal is to test variables that may make physical places, especially those labelled as *liminal spaces*, appear uncanny. In a second experiment, the effect of direct manipulation of a physical place's configuration on uncanniness is tested, analogous to how a disruption of face configuration creates uncanny faces (Diel & MacDorman, 2021; Diel & Lewis, in review). Finally, a third experiment was conducted to test how human presence interacts with the uncanniness of normal and distorted private and public places.

1.3.1. Predicted influences on place aesthetics

Various previous influences on place aesthetic have been suggested, with different underlying theoretical presumptions. The following variables will be investigated in the three experiments of this work:

Deviation from typical configurations. The deviation from familiarity hypothesis predicts that stimuli deviating from expected configural patterns elicit uncanniness (Diel & Lewis, 2022), in this case applied to deviations in built environments. Four obvious types of configural (i.e., feature-relational) deviations are 1) changes of sizes of some features compared to others, 2) the absence of expected features, 3) placement of features in unexpected positions, and 4) excessive repetition of certain features. Places containing these features should be perceived as more uncanny and abnormal.

Disgust. Disgust has been linked with uncanniness in past research (Ho & MacDorman, 2010; MacDorman & Entezari, 2015). Furthermore, atypical food variants elicit stronger disgust reactions (Koch et al., 2021). Although disgust is generally associated with organic material, distorted places may appear more unsettling for individuals with a higher disgust sensitivity.

Ambiguity. Categorical ambiguity of a stimulus has been proposed to elicit uncanniness (Cheetham et al., 2015). As places deviating from expected configurations may be more difficult to categorize and comprehend, the lack of information available on an ambiguous place may increase a sense of uncertainty.

Lighting and occlusion. Both lack of lighting and occlusion (presence of objects blocking the view of the space) contribute to a sense of mystery understood as information entropy (Stamps, 2007). Furthermore, lack of light increases anxiety responses (Grillon, Pellowski, Merikangas, & Davis, 1997; Mühlberger et al., 2008) and may thus contribute to anxiety induced in unusual places.

Social presence. The presence (or absence) of humans may influence the effects of deviating architecture. Social presence or support can act as a buffer for fear and stress responses (DeVries, Glasper, & Detilion, 2003). Social stimuli are salient (Theeuwes & Van der Stigchel, 2006) and may distract from uncanny features, or humans unreactive to unusual surroundings may normalize the subject's reactions, for example due to conformity (Cialdini & Goldstein, 2004). Human presence may also indicate safety in an environment otherwise perceived as hostile. Finally, when human presence is expected (e.g., in a public place like a mall), human absence would be a deviation from an expected configural pattern. In that sense, human presence should increase uncanniness when the presence is not expected. These explanations are investigated later.

2. Experiment 1: An uncanny valley of physical places

2.1. Hypotheses

Experiment 1 is designed to investigate an uncanny valley curve of real and unreal physical places, including those colloquially labelled *liminal spaces*, and whether certain environmental variables can explain the effect. Hypotheses follow.

First, plotting uncanniness against place realism should create a quadratic (*U*-shaped) or cubic (*N*-shaped) function (*uncanny valley hypothesis*) akin to previous uncanny valley research (Diel et al., 2022).

Second and third, if the uncanny valley is related to *threat avoidance* (MacDorman & Ishiguro, 2006), disgust sensitivity should predict uncanniness (*disgust hypothesis*). Disgust sensitivity was measured by the revised Disgust Scale (Haidt, McCauby, & Rozin, 1994; modified by Olatunji et al., 2007), a questionnaire used in previous research linking disgust sensitivity to uncanniness (MacDorman & Entezari, 2015).

Similarly, *ambiguity tolerance* should predict uncanniness if stimuli are uncanny because of their ambiguity (e.g., Cheetham et al., 2015; *ambiguity hypothesis*). Ambiguity tolerance was measured by the ambiguity tolerance questionnaire (MacDonald, 1970), a questionnaire developed to assess individuals' differences in reaction towards ambiguous situations.

Fourth and fifth, if *threat ambiguity* underlies the uncanniness of places, threat should predict uncanniness of physical places (McAndrew & Koehnke, 2016; *threat hypothesis*). On the other hand, abnormality should predict uncanniness ratings according to the hypothesis that deviation from familiarity underlies the effect (Diel & Lewis, 2022; *deviation hypothesis A*).

Sixth, as previous research shows that deviations from familiar patterns may underlie the uncanny valley, distortions of the structure of places should predict uncanniness and abnormality ratings. Specifically, the level of configural deviation (feature, displacement, lack of features, repetition of features, unusual sizes) predicts uncanniness and abnormality ratings (*deviation hypothesis B*).

Lighting (*lighting hypothesis*) and visual occlusion (*occlusion hypothesis*) can increase perception of eeriness and mystery in physical places (Stamps, 2007). Each place stimulus' lighting level has been coded as *none* (major parts of the depicted place are not visible due to lack of light), *artificial* (the place is not obscured by lack of lighting and lit with only artificial lighting), and *natural* (the place is not obscured by lack of lighting and lit with natural lighting, or both natural or artificial lighting). Occlusion was coded by whether major parts of the depicted places were not visible due to objects or architecture blocking the view.

Finally, an explorative analysis investigates why *liminal spaces* appear uncanny or abnormal to participants by focussing on qualitative responses on the most uncanny and abnormal physical places.

2.2. Materials and methods

2.2.1. Participants

Participants were 104 students recruited via the Cardiff University School of Psychology's Experimental Management System (EMS) and other adults recruited via Prolific®. Participants' average age was $M_{age} = 29.41$, $SD_{age} = 9.8$, and 66.67% were female. Because the motivation of *Experiment 1* was exploratory and because effect size estimation was not possible for the fitted polynomial model, selection of sample size was not based on power analysis and instead based on previous research aiming to replicate an uncanny valley function (e.g., Löffler et al., 2020; Mathur & Reichling, 2016; Pütten & Krämer, 2014). Individuals with UK residence aged 18 and above with normal or corrected vision could participate. The study was approved by the Cardiff University School of Psychology Ethics Committee in May 2021 (reference number: EC.21.04.20.6342 GA).

2.2.2. Materials

One hundred images of real or artificial physical places were collected from various sources on the Internet. Fifty were taken from websites dedicated to the *liminal space* phenomenon[1], labelled "liminal" spaces. Twenty-five were artificial representations of places such as architectural sketches or drawings, labelled "unreal." Finally, a set of 25 natural photographs of places were selected, labelled "real." Latter were randomly selected from the CNN place image database (Zhou, Lapedriza, Khosla, Oliva, & Torralba, 2018). Fifty instead of 25 "liminal" space stimuli were selected because these places were expected to be

[1] https://commons.wikimedia.org/wiki/Category:Liminal_spaces, https://aesthetics.fandom.com/wiki/Liminal_Space.

more heterogenous in their variables compared to real or artistic renditions of typical places.

Images were coded based on the following features: feature displacement, lack of features, lighting, occlusion, repetition of features, type (e.g., hallway), and unusual sizes. Coding was based on the hypotheses. All stimuli are available at https://osf.io/d9s36/.

Two questionnaires were used. First, the ambiguity tolerance questionnaire (MacDonald, 1970), consisting of 13 items (example item: "I don't tolerate ambiguous situations well"), meant to measure of how accepting or not uncomfortable a person is concerning complex issues or situations with alternate interpretations or outcomes. Second, thedisgust index (Haidt, McCauley, & Rozin, 1994; modified by Olatunji et al., 2007) consisting of 14 items (example item: "If I see someone vomit, it makes me sick in my stomach"), meant to measure the degree of disgust sensitivity. In both questionnaires, items ranged from an interval of 0 (fully disagree/not at all) to 100 (fully agree/completely).

2.2.3. Procedure

The experiment was conducted online on the platform *pavlovia* (https://pavlovia.org). After giving informed consent, participants completed the ambiguity tolerance and disgust index questionnaires. Then participants were presented with the rating task. One hundred stimuli were presented randomly, accompanied by the four composite rating scales presented in the following order: *not eerie/creepy/uncanny – eerie/creepy/uncanny*, *strange/weird/abnormal – not strange/weird/abnormal* (reversed), *not hostile/threatening/unsafe – hostile/threatening/unsafe*, *not real/authentic – real/authentic*, ranging in an interval from 1 to 100. The first scale was selected to represent a specific negative experience related to uncanniness, the second a sense of abnormality, and the third scale threat, all constructs that were related to the uncanny valley in previous research, while the final variable was meant to represent the independent variable of human likeness, sometimes realism, of the uncanny valley plot (see Diel et al., 2022). Definitions of eerie ("strange in a frightening or mysterious way") and uncanny ("beyond the normal or extraordinary, strangely familiar or uncomfortably strange") were provided with the experimental instructions, as well as an explanation for the real/authentic scale ("this question refers to how realistic, or close to a real-life building or place you perceive the depicted place to be"). For the other two scales, participants' subjective understanding of the terms was of interest, thus no definitions were provided. Rating scales were presented sequentially, together with each stimulus. Participants could select any point of the scales and had an unlimited time to view the image and select their response. Single scale ratings were used for the analyses, as the calculation of indices would have needed a higher number of scales which could have overtrained the participants given the high number of stimuli.

After completing the rating, participants were again presented with the 50 *liminal space* stimuli with the question if the participants thought the depicted place was strange or eerie and if so, why. Participants could type a response and confirm by pressing any arrow key. The whole procedure lasted $M = 43.69$ min ($SD = 26.31$).

2.2.4. Analysis, ethics statement, and data availability

Data preparation and statistical analysis was conducted via *R*. Linear mixed models were used because they handle both fixed effects and random effects (McLean, Sanders, & Stroup, 1991), which are expected given the within-subject and within-stimulus design. This type of analysis produces the large degrees of freedom (see also Kuznetsova, Brockhoff, & Christensen, 2017; Luke, 2017). The R packages *lme4* (for linear mixed models, using the function *lmer()*) and *lmerTest* (for complete depiction of the results) were used (see Bates, Mächler, Bolker, & Walker, 2015). The data, stimuli, and R code for the analysis are available at https://osf.io/d9s36/.

2.3. Results

2.3.1. Uncanny valley hypothesis

Corrected coefficients of determination (R^2_{adj}) and 95% confidence intervals (CI) of regression coefficients are reported. A linear mixed model with realism (fixed effect) and stimulus and participants (random effects) was calculated to predict uncanniness. The square and cubic terms of realism were included as predictors to test the cubic and quadratic relationship akin to an uncanny valley. The results show that a linear ($t(9495) = -2.683$, $p = .007$, CI [−0.14, −0.10]), a quadratic ($t(9527) = -7.448$, $p < .001$, CI [−0.004, −0.002]), and a cubic function of realism ($t(9471) = -2.277$, $p = .023$, CI [−0.00005, −0.000004]) could all predict uncanniness. A quadratic model was a better fit than a linear model ($\chi^2 = 63.882$, $p < .001$), as was the cubic model ($\chi^2 = 69.07$, $p < .001$). The cubic was also a better fit than the quadratic model ($\chi^2 = 5.188$, $p = .022$). The adjusted coefficient of determination was $R^2_{adj} = 0.48$ for the cubic model. The data by stimulus are plotted in Fig. 1. The confidence range at the highest point of uncanniness (at approx. 5 realism) falls entirely outside the confidence range for uncanniness both at lower levels of realism (e.g., 30) and higher levels of realism (e.g., 85) indicating a clear valley shape to the data. Thus, a cubic function of uncanniness and realism akin to an "uncanny valley" could best explain the data (*uncanny valley hypothesis*).

2.3.2. Ambiguity tolerance and disgust sensitivity

The ambiguity tolerance questionnaire's Cronbach's alpha was .862 ($M = 29.86$, $SD = 10.16$), indicating good consistency. The disgust questionnaire meanwhile had a Cronbach's alpha of .779 ($M = 26.91$, $SD = 17.2$), indicating acceptable consistency. Because both questionnaires showed a high correlation ($r = -0.88$), analyses were conducted independently to avoid multicollinearity.

Adjusted coefficients of determinations (R^2_{adj}) and 95% confidence intervals of regression coefficients are reported. Linear mixed model analyses with either ambiguity tolerance or disgust sensitivity (fixed effects) and stimulus and participants (random effects) showed that neither ambiguity tolerance ($t(84) = -0.807$, $p = .422$, $R^2_{adj} = 0.15$, CI [−0.13, 0.06]) nor disgust sensitivity ($t(84) = 0.02$, $p = .74$, $R^2_{adj} = 0.15$, CI [−0.08, 0.12]) predicted uncanniness. Thus, uncanniness was neither associated with disgust sensitivity (*disgust hypothesis*) nor

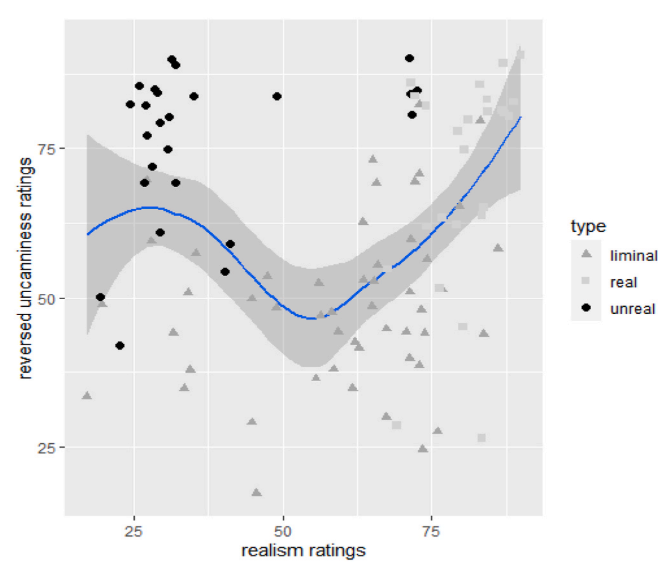

Fig. 1. Uncanniness ratings of physical place stimuli plotted against their realism ratings, divided into the type of physical place (unreal, liminal, real). Each point in the graph corresponds to one of 100 stimuli. The line is the weighted average line of best fit and the grey shaded area is the 95% confidence range over this weighted average.

ambiguity tolerance (*ambiguity hypothesis*).

2.3.3. Abnormality and threat

Adjusted coefficients of determinations (R^2_{adj}) and 95% confidence intervals of regression coefficients are reported. A linear mixed model with abnormality and threat as fixed effects and participant and stimulus as random effects showed that abnormality ($t(9353) = 27.828$, $p < .001$, CI [0.22, 0.27]), threat ($t(9599) = 33.297$, $p < .001$, CI [−0.53, 0.50]), and an interaction (t(9576) = 4.186, p < .001, CI [0.001, 0.001]) significantly predicted uncanniness. The model's determination coefficient was $R^2_{adj} = 0.58$. The interaction between abnormality and threat, as seen in Figure A1, however did not seem to indicate a clearly interpretable relationship between the variables. In total, uncanniness of physical places was associated was associated with both abnormality (*deviation hypothesis*) and threat (*threat hypothesis*).

2.3.4. Anomaly, lighting, and visual occlusion

Anomaly number, lighting, and occlusion have been tested as fixed effect predictors of uncanniness, and stimulus and participant as random effects. Anomaly number ($t(96) = 5.11$, $p < .001$, CI [7.48, 16.65]) and lighting ($t(96) = -2.63$, $p = .010$, CI [−13.63, −2.04]) significantly predicted uncanniness. Visual occlusion did not ($t(96) = 0.299$, $p = .766$, CI [−5.42, 7.39]). Uncanniness of different numbers of anomalies are seen in Fig. 2. The determination coefficient was $R^2_{adj} = 0.48$. Thus, while both lighting type (*lighting hypothesis*) and number of anomalies (deviation hypothesis) predicted uncanniness, visual occlusion did not (occlusion hypothesis).

2.3.5. Effect of place type: hallways

Forty percent of the most uncanny stimuli in this experiment were hallway-type places, which motivated a post-hoc investigation on whether hallway-type physical places are more uncanny than other types. *T*-tests were conducted for uncanniness across all stimuli. Hallways were more uncanny than non-hallway places across all stimuli ($t(25.8) = -3.4$, $p = .001$, $d = 0.82$). Significance persisted within only *liminal space* stimuli ($t(14.99) = -1.8$, $p = .046$, $d = 0.66$). Thus, hallways are more uncanny than both typical and specifically eerie, ambiguous places.

2.3.6. Qualitative analysis

After excluding or shortening general responses like "it's strange" or "uncomfortable," summarizing very similar responses (e.g., "no windows" and "windowless"), and correcting spelling errors, participant responses for the ten most uncanny stimuli are summarized in Table A1.

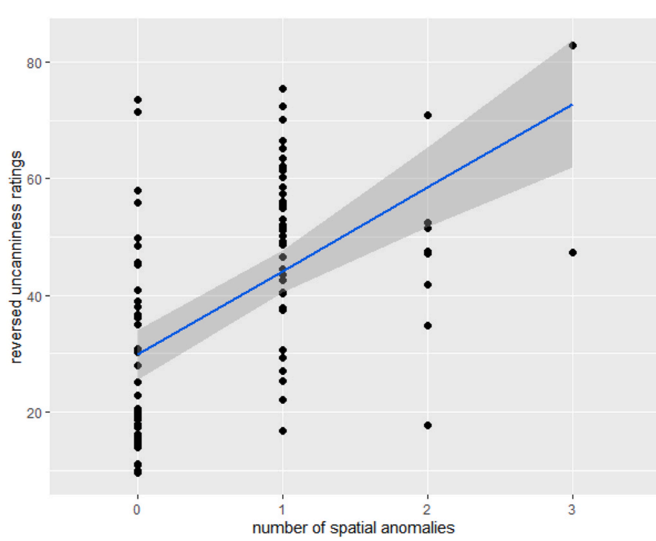

Fig. 2. Uncanniness ratings of stimuli divided into their number of anomalies.

Table 1
Number of responses categorized for each content category, for both raters.

Response content	Rater 1	Rater 2
Lack of features or emptiness	49	43
Lighting or lack of lighting/darkness	39	42
Distorted sizes or proportions	30	35
Lack of safety, hostility, threat	21	20
Displacement of features	20	27
Unknown, uncertainty, lack of purpose	16	14
Repetition of patterns or features, monotony	13	16
Water	14	12
Entrapment, closed space	10	7
Dirtiness, wornness, decay	9	5
Abandonment, desolation	7	10
Visual occlusion	7	7
Lack of people[2]	6	2

For analysis, 210 qualitative responses were categorized by content. Responses were taken of the ten most uncanny stimulus, and responses merely repeating the adjectives in the question (e.g., "the place is strange/weird/eerie/creepy") without elaborating on the reasons were excluded. Participants' responses were coded by two raters (authors) on whether the responses fitted one or multiple content categories via binominal yes-no responses(see Table 1), and interrater agreement was measured by calculating interclass correlations of the amounts for each content category (ICC = 0.985). Content categories were selected before coding, based on participants' responses. Data is summarized in Table 1. In total, a place's uncanniness has been most often attributed to indicators of spatial deviation like a lack of features or emptiness, distorted sizes or proportions, feature displacement, and repetition of features or patterns. In addition, uncanniness has been most often attributed to lighting or lack thereof, lack of safety, hostility, or threat, and unknown, uncertainty, or a lack of purpose. Visual occlusion or lack of people was mentioned relatively rarely.

2.4. Discussion

Results show that uncanniness plotted against realism creates a cubic function equivalent to an uncanny valley curve. Thus, the generality of the uncanny valley encompasses built environments. Furthermore, uncanniness could be predicted by both threat and abnormality and the number of anomalies. Abnormality and threat interacted, however not in a clear pattern (Figure A1). In the qualitative analysis participants majorly reported structural anomalies like displaced, distorted, missing, or repeating features as the sources of uncanniness. This indicates that uncanniness is driven by deviations from typical built structure. Similar to Stamps' (2007) findings, lighting predicted the uncanniness of places and was a cause of uncanniness according to qualitative ratings; visual occlusion, however, was not associated with uncanniness in the quantitative and qualitative analyses. The difference may be due to the binominal coding of visual occlusion in this study, or discrepancies in the understanding of mystery and uncanniness. Finally, neither ambiguity tolerance nor disgust sensitivity predicted uncanniness, showing that the uncanny valley of physical places is not associated with a place's ambiguity or a sense of disgust. However, it is yet unclear whether spatial distortions elicit uncanniness or whether these variables were merely correlated in the pre-selected stimuli.

3. Experiment 2: Spatial distortion

Despite interesting results on the effect of deviation on uncanniness in Experiment 1, the interpretation of the results is hindered by the unstructured collection of stimulus material and the heterogeneity of places depicted. *Liminal space* stimuli are heterogenous and vary in multiple different variables, hence the causal link between structural distortion and eeriness remains unclear. Qualitative responses however indicate that structural anomalies (specifically distorted size/

proportion, lack of features, displacements, and repetition) increase uncanniness of built environments. In addition, the effect of social presence was investigated, as the presence of humans can buffer fear and stress responses (DeVries et al., 2003), and social absence make a place appear more unusual when other humans are expected (e.g., public places like malls, offices, or restaurants).

Thus, a second experiment was conducted to test the effect between manipulation of configural deviation and uncanniness of built environments.

3.1. Hypotheses

To further explore the deviation from familiarity prediction that configural anomalies elicit uncanniness, the effect of spatial anomalies on uncanniness were investigated. Based on the findings in Experiment 1 that four kinds of structural anomalies were predominantly reported by participants (distorted size, lack, displacement, repetition), the following hypotheses were tested:

First, presence of spatial anomalies in a room increases uncanniness ratings.

Second, uncanniness increases with the number of distortions in a room.

Finally, the effect of social presence manipulation is investigated as social presence may have buffering effects on fear or stress (DeVries, Glasper, & Detillion, 2003). Thus, social absence should increase the uncanniness of built interiors compared to social presence.

3.2. Methods

3.2.1. Participants

A total of 52 participants were recruited via Prolific®. Participants' average age was $M_{age} = 28.89$, $SD_{age} = 7.44$, and 73.21% were female. Given a typical small effect size of $d = 0.25$ and a 2×6 within-subject design with five stimuli per condition (see below), a sample size of $n = 52$ would move the power up over .8 ($1\text{-}\beta = 0.812$). Because no previous research on the effect of deviation on place evaluation exists, a standard small effect size was chosen (Cohen, 1988, 1992; see also Albers & Lakens, 2018; Perugini, Galluci, & Constantini, 2014) to reduce the chance of a false negative for small effects. Individuals with UK residence aged 18 and above with normal or corrected vision could participate.

3.2.2. Stimuli

Seventy-five images of virtual physical places were used. Stimuli were created using Roomstyler®. Five pairs of either typical or distorted versions of the same rooms were created for each of the following manipulations: *Lack* (either typical rooms or rooms lacking expected or essential features like specific furniture, doors/windows, or completely empty rooms), *repetition* (either typical rooms or rooms where certain features like furniture, patterns of furniture, doors/windows are excessively repeated to the point of being unusual or unexpected for a typical room), *displacement* (either typical rooms or rooms where certain features like furniture or doors/windows are placed in unusual or unexpected positions), and *size* (either typical rooms or rooms where certain features like furniture, doors/windows, or walls have been distorted to unusual or unexpected sizes). Because such manipulations could lead to various changes of informational value in a room, pairs of either typical or rooms with controlled distortions were created with other potential variables (lighting, escape routes, visual occlusion, visual information density) being controlled to control *configural* room distortion specifically. The effect of the presence of humans (*social presence*) in big, open places has been investigated by creating 2×5 stimuli depicting either big spaces filled with human models, or without them. Human models were placed in the first and/or second plane, depending on image. One stimulus pair per distortion type, including *social presence*, is depicted in Fig. 3. Stimulus design (feature manipulation) check was done by a-priori consideration. Agreement between two raters (authors) on condition-based stimulus categorization (correct nominal assignment of the stimuli to each of the 10 (2×5) conditions) was $\kappa = 0.74$, indicating moderate agreement.

Finally, to investigate whether increasing deviation also increases uncanniness, 3×5 *hybrid* stimuli with either 2, 3, or 4 combined distortion types were created. Examples of hybrid stimuli including descriptions of distortions are depicted in Fig. 4.

3.2.3. Measures and procedure

Participants rated each stimulus on the scales *not eerie – eerie*, *creepy – not creepy*, *not uncanny – uncanny*, *strange – not strange*, and *not weird – weird*, ranging in an interval from 1 to 100, allowing participants to select any point on the scales.

The experiment was conducted online. After giving informed consent, participants rated all stimuli based on the rating scales mentioned above. Stimuli were presented in a random order and simultaneously with each scale which were presented sequentially. Participants had unlimited time to view the images and select their response. The procedure lasted for about 20 min. The scales *creepy* and *strange* were reversed. The procedure took $M = 27.69$ min ($SD = 12.04$).

3.3. Results

3.3.1. Uncanniness ratings

Rating scales were combined into an *uncanniness* index by calculating the means of the five scales. The index' Cronbach's alpha was .89, indicating good reliability.

Because effects of the base room pair on uncanniness were expected, linear mixed models were conducted to test the effect of distortion (control vs distortion) on uncanniness ratings for each type of distortion, with participants and base rooms as within-subject variables. Main effects of distortion for the *lack* ($t(428) = 17.728$, $p < .001$, $R^2_{adj} = 0.58$, CI [25.67, 32.06]), *repetition* ($t(425) = 16.705$, $p < .001$, $R^2_{adj} = 0.53$, CI [25.10, 32.27]), *displacement* ($t(433) = 13.44$, $p < .001$, $R^2_{adj} = 0.45$, CI [20.15, 27.04]), *size distortion* ($t(434) = 12.691$, $p < .001$, $R^2_{adj} = 0.57$, CI [20.15, 27.04]). *controlled distortion* ($t(426) = 13.87$, $p < .001$, $R^2_{adj} = 0.50$, CI [20.31, 27.01]), and *social presence* ($t(431) = 10.572$, $p < .001$, $R^2_{adj} = 0.57$, CI [13.63, 19.85]) conditions were found. Thus, all types of distortion increased uncanniness, as well as social absence. Results are summarized in Fig. 5. Descriptive data for each condition are summarized in Table A2.

Finally, number of anomalies predicted uncanniness ($t(2616) = 38.28$, $p < .001$, $R^2_{corr} = 0.47$, CI [11.86, 13.14]), summarized in Fig. 6. Thus, uncanniness of a physical place increases with the number of structural anomalies present. Descriptive data across number of anomalies are summarized in Table A3.

3.4. Discussion

Experiment 2 showed that the uncanniness of physical places is driven by the presence and number of spatial anomalies like lack of, repeating, displaced, or proportionally distorted features. Effects were present even if other variables were controlled, indicating that configural distortion of a place elicits uncanniness. Finally, social presence in places decreases uncanniness. However, the reason behind the effect of social presence is unclear and other objects could potentially play the role as other humans. This is explored further in Experiment 3.

4. Experiment 3: Social presence

Experiment 2. showed that social presence decreases uncanniness of big, open interiors. Multiple explanations are possible: that humans act as distractors from unusual features (*distraction*), that a lack of humans does not fit the configuration of wide places (*deviation*), that humans

Fig. 3. Example stimulus pairs per distortion type. Lack = lacking features or furniture. Repetition = repeating patterns of features or furniture. Placement = displaced features or furniture. Size distortion = distorted sizes of features or furniture. Controlled distortion = distortion with other variables (lighting, escape routes, cleanness/hygiene, visual information density) controlled. Social presence = presence of human models in big, open places.

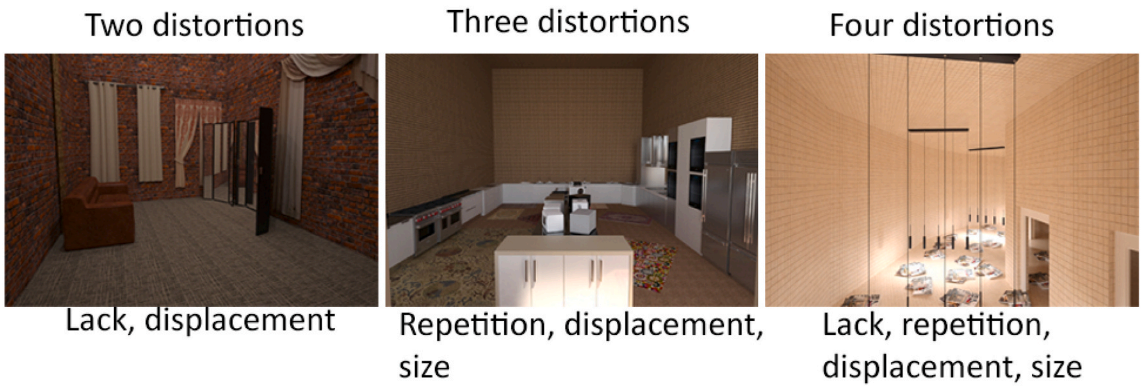

Fig. 4. One hybrid stimulus example per number of distortion types. Types of distortions are listed below the images.

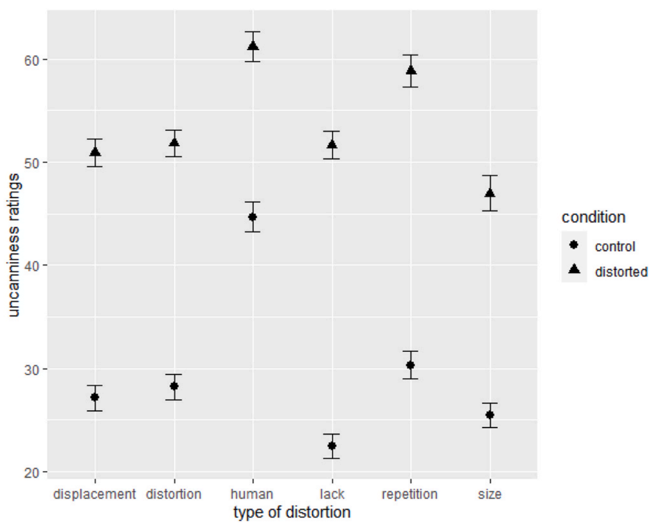

Fig. 5. Uncanniness ratings for each type of distortion. Error bars depict standard errors.
Note. Displacement = features or furniture not fitting the type of room; *distortion* = controlled configural distortion; *human* = presence (control) or absence (distorted) of humans in spatially distorted places; *lack* = lack of features or furniture; *repetition* = excessively repetitive features or furniture; *size* = unusual or distorted sizes.

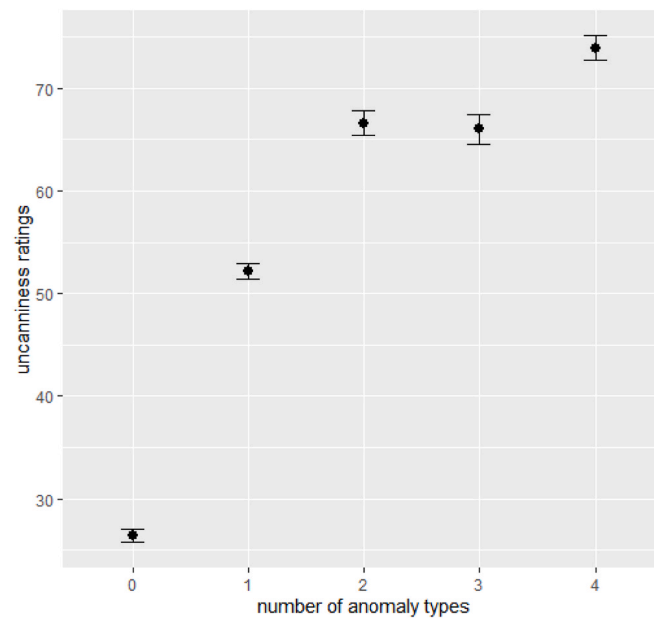

Fig. 6. Uncanniness ratings averaged across number of anomaly types in a room. Error bars depict standard errors.

normalize the oddity of a distorted physical place (*normalization*), and that social presence decreases potential threat (*threat*). Finally, results from Experiment 1 and 2 both indicate that emptiness can increase uncanniness of physical places, the social presence stimuli in Experiment 2 did not control for physical emptiness. Thus, a third experiment has been conducted to test the hypotheses mentioned above.

4.1. Hypotheses

According to the *distraction hypothesis*, human presence decreases uncanniness of a place because social stimuli distract from spatial anomalies due to their salience. As a short display of a stimulus would shift the attentional bottleneck towards more salient stimuli (Itti, 2005; Theeuwes & Van der Stigchel, 2006), social presence should decrease the viewers' ability to detect spatial anomalies in quickly displayed stimuli. Thus, when a place is briefly presented (500 ms), participants should be less able to detect architectural anomalies or oddities when humans are present in the image, regardless of whether the place is private or public (*distraction hypothesis*).

According to the *deviation hypothesis*, social presence would decrease uncanniness of places when humans are expected in those places Diel & MacDorman, 2021; Shir et al., 2021), like malls, restaurants, or busy streets. If deviation from expectation would predict uncanniness, the presence of humans would however also *increase* uncanniness of places where presence is unexpected, such as toilets or bedrooms. Thus, and interaction between the type of place (social presence expected vs unexpected) and social presence is expected. As social presence would generally be expected in public places and unexpected in private places, human presence should decrease uncanniness of public places (malls, fitness studios, offices, etc.) and increase the uncanniness of private places (e.g., home rooms; *deviation hypothesis*).

The *normalization hypothesis* predicts that social presence normalizes abnormality and thus uncanniness in general, for example due to the calm and friendly demeanours of human models that could elicit similar reactions in viewers through conformity (Cialdini & Goldstein, 2004). Social presence should thus decrease abnormality and uncanniness of distorted places, regardless of whether the place is private or public (*normalization hypothesis*).

Finally, the *threat hypothesis*, built upon the *threat ambiguity* (McAndrew & Koehnke, 2016), predicts that social presence generally decreases threat as the presence of other humans decreases the chance of potential danger like hiding predators or hazards in abandoned places. Social presence should thus decrease both threat and uncanniness, regardless of whether the place is distorted, or a public or private place (*threat hypothesis*).

4.2. Methods

4.2.1. Participants

Thirty-seven participants were recruited via Prolific®. Participants' average age was $M_{age} = 24.19$, $SD_{age} = 4.88$, and 74.19% were female. Given an effect size of $d = 0.25$, a $n = 37$ sample and a 2×2×2 within-subject design with five stimuli per condition (see below), power would exceed 0.8 ($1\text{-}\beta = 0.841$). Because no previous research on the effect of deviation on place evaluation exists, and because finding the existence of an effect, even a small one, was the goal of the experiment, a standard small effect size was chosen (Cohen, 1988, 1992; see also Albers & Lakens, 2018; Perugini, Gallucci, & Costantini, 2014) to reduce the chance of a false negative for small effects. Individuals with UK residence aged 18 and above with normal or corrected vision could participate.

4.2.2. Stimuli

Quadruplets of rooms were created as stimuli using Roomstyler®. The same base room was used to manipulate social presence (human models or furniture) and distortion (typical rooms or distorted versions based on distortion types in Experiment 2). Finally, rooms were either private (bathroom, kitchen, living room, bedroom, hallway) or public (fitness studio, underground hallway, office, supermarket, lecture hall). Thus, stimuli were divided based on a 2×2×2 design with social presence, distortion, and room type as independent variables, with five stimuli per condition, adding up to a total of 40 stimuli. Human models were selected matched to the place (e.g., models wearing gym clothes for a gym) and placed to indicate meaningful actions or interactions. To control for the effect of emptiness, human models were replaced with place-typical furniture of around the same size as the models. Human models were placed in the first and/or second plane, depending on image. Fig. 7 depicts example stimuli for each condition. Stimulus design (feature manipulation) check was done by a-priori consideration. Agreement between two raters (authors) on condition-based stimulus categorization (a series of three binominal yes-no assignments per

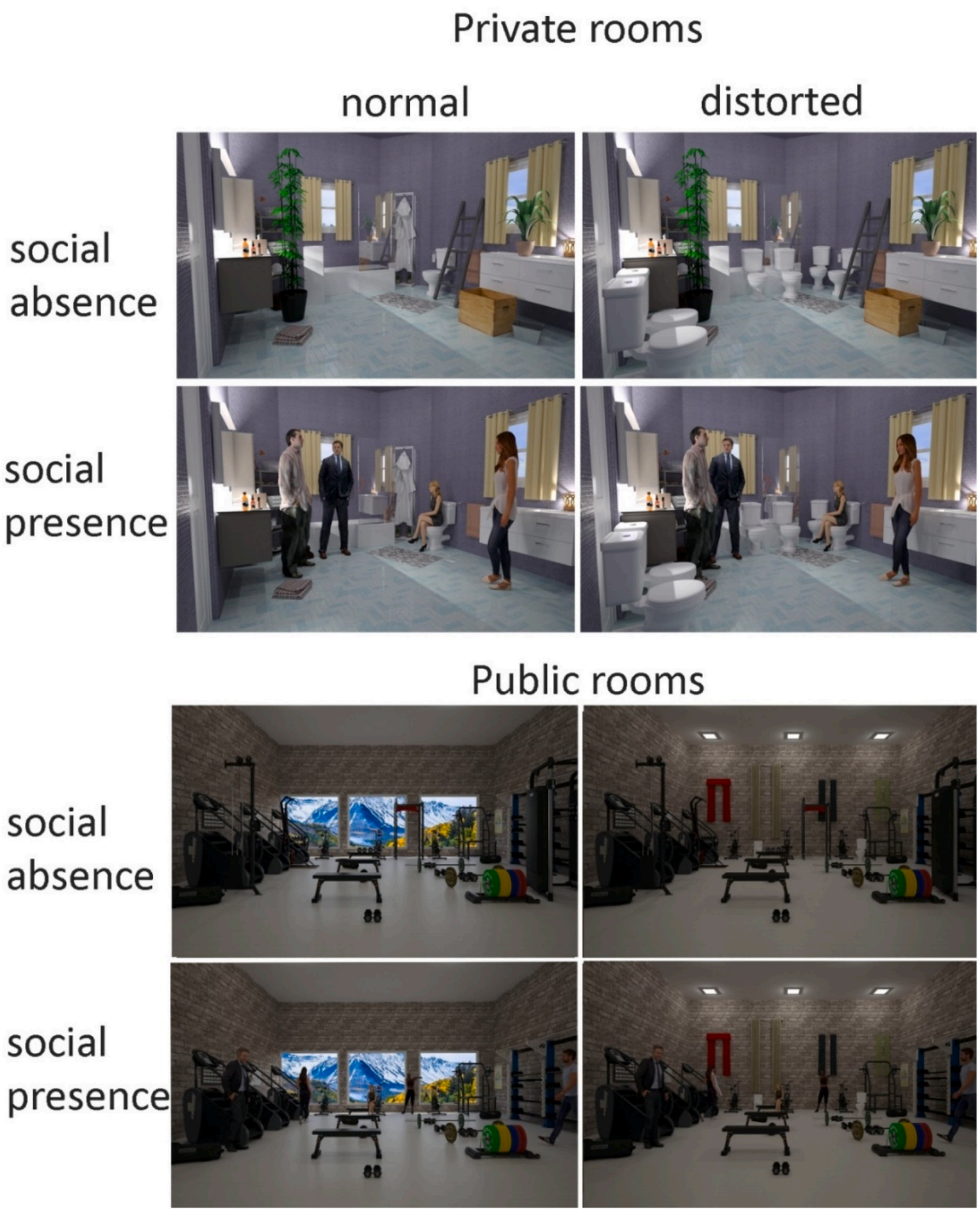

Fig. 7. Example images for each condition. The type of distortion for both the private and public room is repetition (of toilets or windows).

stimulus: private/public, social presence/absence, and distorted/normal) was κ = 0.83, indicating strong agreement.

4.2.3. Procedure

The experiment was conducted online and consisted of two parts. After giving informed consent, participants viewed each of the 40 stimuli randomly for 500 ms, preceded and followed by grey noise of 500 ms. After each stimulus, participants were asked two questions with scales ranging from *totally disagree* (1) to *totally agree* (100): “The room’s architecture or design was unusual or strange.” and “I saw some oddities in the room.”

For the second part, participants again viewed all 40 images presented in a random order and were asked to rate the places on 7 scales, each ranging as intervals from (1) to (100): *not eerie – eerie*, *not creepy – creepy*, *uncanny – not uncanny*, *not strange – strange*, *not weird – weird*, *not threatening – threatening*, and *unsafe – not unsafe*. Participants were allowed to select any point on the scales. The procedure lasted for M = 18.23 min (SD = 9.20).

4.3. Results

4.3.1. Rating scales

For the first part of the experiment, the two questions on the rooms’ strangeness or oddities were combined into a single *perception of oddities* variable (Cronbach’s alpha $\alpha = .84$). For the second part, rating scales were combined into the indices uncanny (*eerie, creepy, uncanny*), abnormal (*strange, weird*), and threatening (*threatening, unsafe*). Cronbach’s alphas were .87, .97, and 0.81, respectively.

Uncanniness ratings across all measures and conditions are summarized in Table A4.

4.3.2. Distraction hypothesis

A within-subject ANOVA was conducted for the perception of oddities during 500 ms presentation, with social presence, distortion, and room type as within-subject variables. The data are presented in Fig. 8. Results show main effects of both social presence ($F(1, 36) = 12.27$, $p = .001$, $\eta_p^2 = .25$, 95% CI [0.05, 0.47]) and distortion ($F(1, 36) = 161.49$, $p < .001$, $\eta_p^2 = .82$, 95% CI [0.7, 0.88]), and interaction effects between social presence and distortion ($F(1, 36) = 9.1$, $p = .005$, $\eta^2_p = .2$, 95% CI [0.02, 0.42]) and social presence and room type ($F(1, 36) = 10.5$, $p = .003$, $\eta_p^2 = .23$, 95% CI [0.03, 0.44]). No other terms were significant.

Post-hoc Tukey tests were conducted to test whether social presence decreased the detection of oddities. Results show that distortion increased perception of oddities in all social presence × room type conditions ($t(120) = 9.7$, $p_{adj} < .001$, $d = 1.77$, 95% CI [1.35, 2.19], for control private; $t(120) = 6.47$, $p_{adj} < .001$, $d = 1.18$, 95% CI [0.79, 1.57], for human private; $t(120) = 9.41$, $p_{adj} < .001$, $d = 1.72$, 95% CI [1.3, 2.13], for control public; $t(120) = 7.1$, $p_{adj} < .001$, $d = 1.3$, 95% CI [0.9, 1.69], for human public). However, social presence did not decrease perception of oddities in any condition ($t(101) = -2.49$, $p_{adj} = 1.000$, for distorted private; $t(101) = -5.51$, $p_{adj} = 1.000$, for normal private; $t(101) = 0.02$, $p_{adj} = 1.000$, for distorted public; $t(101) = -2.14$, $p_{adj} = 1.000$, for normal public). Additional exploratory post-hoc test were conducted: social presence increased oddity perception in distorted private ($t(101) = -2.49$, $p_{adj} = .029$, $d = -0.5$, 95% CI [−0.89, −0.10]) and normal private ($t(101) = -5.51$, $p_{adj} < .001$, $d = -1.1$, 95% CI [−1.51, −0.68]) places, but not in distorted public ($t(101) = 0.02$, $p_{adj} = 1.000$) or normal public places ($t(101) = -2.14$, $p_{adj} = .07$). As social presence did not decrease the detection of oddities in any place condition, hypothesis 1 was not supported.

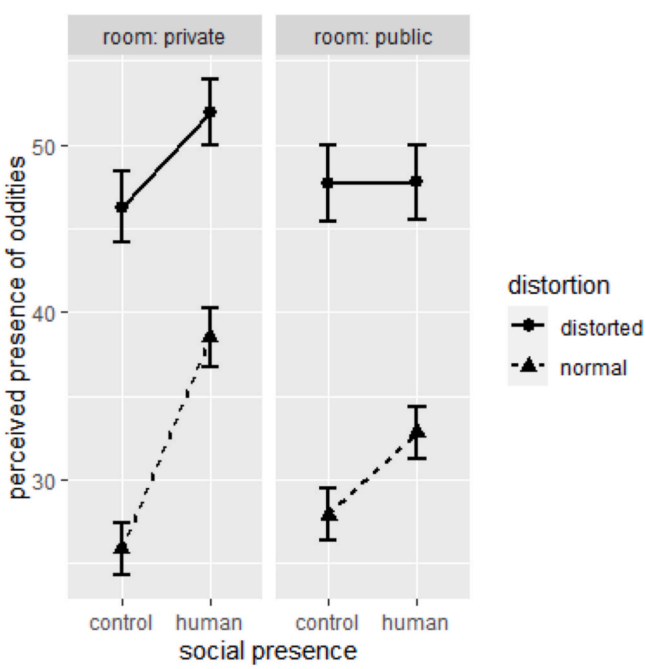

Fig. 8. Mean perceived oddities ratings across conditions. Error bars indicate standard errors.

4.3.3. Deviation hypothesis

A within-subject ANOVA was conducted for *uncanny* ratings, with social presence, distortion, and room type as within-subject variables. Data are summarized in Fig. 9. Results show a main effect of distortion ($F(1, 36) = 179.18$, $p < .001$, η2p = .83, 95% CI [0.72, 0.89]), and interaction effects between social presence and distortion ($F(1, 36) = 15.82$, $p < .001$, η2p = .31, 95% CI [0.08, 0.51]), and between social

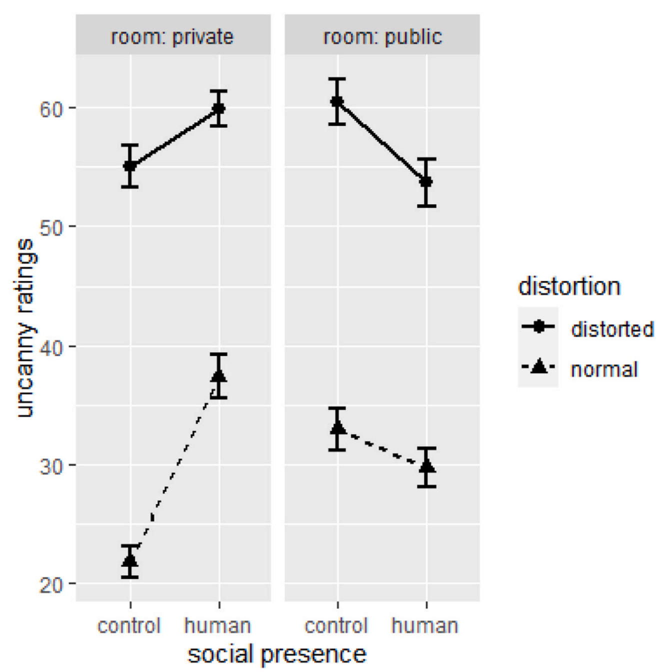

Fig. 9. Mean uncanniness ratings across conditions. Error bars indicate standard errors.

[2] Inconsistent ratings for *lack of people* were present for the following four participant descriptions: “desolate”; “very hollow/dead”; “no windows/empty”; “looks very empty and too repetitive”. Discrepancies in this item seemed mostly due to interpretations of words like *empty* and *hollow*.

presence and room type ($F(1, 36) = 62.61$, $p < .001$, $\eta 2p = .63$, 95% CI [0.43, 0.76]).

Post-hoc Tukey tests show that distortion increased uncanniness regardless of social presence or room type ($t(85) = 8.51$, padj <.001, $d = 1.85$, 95% CI [1.33, 2.35], for control private; $t(85) = 12.95$, padj <.001, $d = 2.81$, 95% CI [2.21, 3.4], for human private; $t(85) = 10.59$, padj <.001, $d = 2.3$, 95% CI [1.75, 2.84], for control public; $t(85) = 9.58$, padj <.001, $d = 2.08$, 95% CI [1.55, 2.6], for human public). Furthermore, social presence decreased uncanniness of distorted public places ($t(133) = 2.95$, padj $= .01$, $d = 0.51$, 95% CI [0.17, 0.86]), but not normal public places ($t(133) = 1.72$, padj $= .265$), and increased the uncanniness of both distorted private ($t(133) = -2.04$, padj $= .043$, $d = -0.35$, 95% CI [−0.7, −0.01]) and normal private ($t(133) = -7.41$, padj <.001, $d = -1.29$, 95% CI [−1.66, −0.91]) places. As social presence increased the uncanniness of private places but decreased the uncanniness of distorted (but not normal) public places, hypothesis 2 was mostly supported.

4.3.4. Normalization hypothesis

A within-subject ANOVA with social presence, distortion, and room type as within-subject variables was used to investigate the effect of these variables on abnormality ratings. The data are summarized in Fig. 10. Main effects were observed for social presence ($F(1, 36) = 17.16$, $p < .001$, $\eta 2p = .32$, 95% CI [0.13, 0.5]) and distortion ($F(1, 36) = 191.71$, $p < .001$, $\eta 2p = .84$, 95% CI [0.76, 0.89]), and interactions between social presence and distortion ($F(1, 36) = 31.22$, $p < .001$, $\eta 2p = .46$, 95% CI [0.26, 0.61]), social presence and room type ($F(1, 36) = 33.31$, $p < .001$, $\eta 2p = .48$, 95% CI [0.28, 0.62]), and all factors combined ($F(1, 36) = 12.04$, $p = .001$, $\eta 2p = .25$, 95% CI [0.07, 0.43]).

Post-hoc Tukey tests were calculated to test the specific predictions. Distortion increased abnormality in all social presence × room type conditions ($t(84) = 14.47$, padj <.001, $d = 3.16$, 95% CI [2.51, 3.79], for control private; $t(84) = 8.12$, padj <.001, $d = 1.77$, 95% CI [1.26, 2.27], for human private; $t(84) = 19.66$, padj <.001, $d = 4.29$, 95% CI [3.51, 5.06], for control public; $t(84) = 10.08$, padj <.001, $d = 2.2$, 95% CI [1.65, 2.74], for human public). Social presence however did not decrease abnormality in any distortion × room type condition ($t(135) = -0.77$, padj $= 1.000$, for distorted private; $t(135) = -9.18$, padj $= 1.000$, for normal private; $t(135) = 0.67$, padj $= 1.000$; for distorted public; $t(135) = -0.22$, padj $= 1.000$, for normal public). Additional explorative post-hoc tests revealed a significant increase of abnormality ratings when humans were present in undistorted private places ($t(135) = -9.18$, padj <.001, $d = -1.58$, 95% CI [−1.96, −1.19]), but not if the same place was distorted ($t(135) = -0.77$, padj $= .445$). As social presence did not decrease abnormality ratings in any condition, hypothesis 3 was not supported.

4.3.5. Threat hypothesis

A within-subject ANOVA has been conducted to test the effect of the within-subject variables social presence, distortion, and room type on threat ratings. Data are summarized in Fig. 11. Main effects were observed for social presence ($F(1, 36) = 23.44$, $p < .001$, $\eta 2p = .39$, 95% CI [0.19, 0.56]) and distortion ($F(1, 36) = 64.08$, $p < .001$, $\eta 2p = .64$, 95% CI [0.47, 0.74]). and interactions between social presence and distortion ($F(1, 36) = 4.16$), $p = .049$, $\eta 2p = .1$, 95% CI [0.00, 0.28]) and social presence and room type ($F(1, 36) = 30.66$, $p < .001$, $\eta 2p = .46$, 95% CI [0.26, 0.61]). No other term was significant.

Post-hoc Tukey tests again show that threat was higher for distorted compared with normal places across social presence × room type ($t(95) = 7.67$, padj <.001, $d = 1.57$, 95% CI [1.11, 2.03], for control private; $t(95) = 4.98$, padj <.001, $d = 1.02$, 95% CI [0.59, 1.45], for human private; $t(95) = 5.98$, $d = 1.23$, 95% CI [0.69, 1.66], padj <.001, for control public; $t(95) = 5.35$, $d = 1.1$, 95% CI [0.66, 1.53], padj <.001, for human public). However, threat was not decreased by human presence in any distortion × room type condition ($t(144) = -3.45$, padj $= 1.000$, for distorted private; $t(144) = -6.8$, padj $= 1.000$, for normal private; $t(144) = 0.84$, padj $= 1.000$, for distorted public; $t(144) = 0.07$, padj $= 1.000$, for normal public). After examining the t values, additional exploratory post-hoc tests were conducted and showed that threat was increased by social presence in normal ($t(144) = -3.45$, padj <.001, $d = -0.58$, 95% CI [−0.91, −0.24]) and distorted ($t(144) = -6.8$, padj <.001, $d = -1.13$, 95% CI [−1.13, −0.78]) private places. As social presence did not decrease threat ratings, hypothesis 4 was not supported.

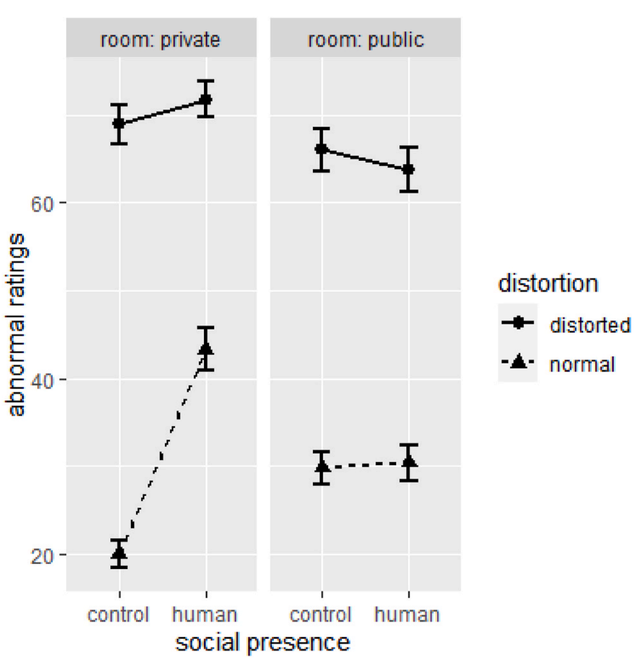

Fig. 10. Mean abnormal ratings across conditions. Error bars depict standard errors.

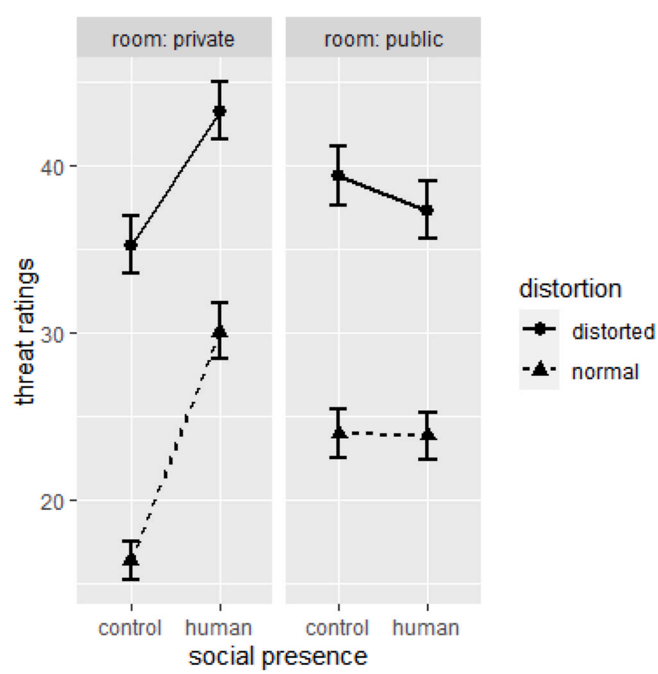

Fig. 11. Mean threat ratings across conditions. Error bars depict standard errors.

4.4. Discussion

Experiment 3 investigated explanations on the effect of social presence on environmental uncanniness. Humans neither distracted from, nor normalized spatial anomalies. However, social presence either increased or decreased the uncanniness, oddity, abnormality, and threat partially depending on whether humans would be expected. As human models were replaced with furniture in the social absence conditions, changes of uncanniness are likely not due manipulation of physical emptiness itself. Thus, the effect of social presence depends on whether humans are expected or not, fitting the deviation from familiarity prediction.

5. General discussion

This study was motivated to investigate the effect of deviation from familiarity on the evaluation of built environments. Specifically, it was the first to investigate whether an uncanny valley can be found for physical places, and whether uncanniness of places can be explained by configural deviations. Results and their implications for the uncanny valley effect and the evaluation of built environments are discussed.

5.1. Discussion of results

5.1.1. An uncanny valley of physical places

Experiment 1. found that a cubic function of realism can best explain uncanniness for naturalistic images of physical places, comparable to the uncanny valley typically observed in uncanny valley research (Mori, 2012): Physical places become more likable with increasing realism, but deviations from typical structural patterns of realistic places are rated strange or eerie.

Most most stimuli within the "valley"-range of the function are *liminal space* type places while those left to the valley are unreal places (Fig. 1). This pattern follows results of previous research on the uncanny valley: unrealistically human, mechanical robotic entities lie to the left of the valley while uncanny stimuli are characterized by highly realistic yet "off" exemplars, for example due to atypical or mismatching features (Mathur & Reichling, 2016; Mori, 2012). The eeriness or strangeness of *liminal spaces* similarly can be explained by their deviation from otherwise typical and realistic physical places.

It is not clear whether the uncanniness observed here equates the uncanniness typical for the uncanny valley, as uncanniness can be elicited by various stimuli and situations. However, the cubic *N*-shaped function and the effect of deviation from familiar patterns found here are characteristic to previous uncanny valley research (Diel & MacDorman, 2021; Mori, 2012). Similar statistical patterns indicate that the mechanisms underlying the uncanny valley of physical places are comparable to those observed in uncanny valley research. The previous emphasis on humanoid stimuli in uncanny valley research may reflect humans' high perceptual familiarity and a narrow range acceptable of human appearance, causing even slight deviations of manufactured androids to be uncanny, while such deviations would typically not occur when constructing built environments.

However, this work shows that built places deviating from typical configurations also elicit uncanniness. Thus, the uncanny valley observed for both places and biological stimuli may have the same underlying cognitive mechanisms not bound by stimulus category. The present results support the notion that the uncanny valley is not restricted to human or animal stimuli (which is assumed in some theories like disease avoidance or dehumanization), and explanations of the phenomenon should be applicable independent of stimulus categories, examples including categorization-related processes (Cheetham et al., 2015), deviation from familiarity (Diel & Lewis, in review), expectation violation (MacDorman & Ishiguro, 2006), and threat ambiguity (McAndrew & Koehnke, 2016).

5.1.2. Uncanniness and configural deviation

Configural deviation is a potential source of environmental uncanniness. In all experiments, abnormality, structural anomalies, or deviations from typical built environments (including the expected presence or absence of people) were associated with uncanniness. The results align with previous research finding that configural deviations in faces are uncanny (Diel & Lewis, 2022; Diel & MacDorman, 2021; Mäkäräinen, Kätsyri, & Takala, 2014), and that inconsistent features in scenes are weird, disturbing, and less likable (Shir et al., 2021). Uncanniness could thus result from deviations from familiar configurations.

Previous research found associations between reduced environmental likability and a lack of coherence (Coburn et al., 2020; Kaplan, 1987; Vartanian et al., 2021; Weinberger et al., 2021). Configural deviation could decrease a place's perceived coherence understood as a disagreement between a place's elements and in turn likability.

Social presence decreased uncanniness ratings of wide, deviating placesin Experiments 2 and 3. The effect of human presence on uncanniness was however not general and interacted with the type of rooms: Human presence decreased uncanniness in wide places, yet increased uncanniness in private rooms. Humans neither distract from, nor normalize spatial anomalies. Furthermore, the effect of physical emptiness observed in *Experiment 2* was controlled as human models were replaced with furniture in the social absence conditions. Instead, the uncanniness-decreasing effect of social presence on distorted public places may reflect eased recognition of a place based on typicality, making it less deviating, while increasing deviation (and threat) of private places. Alternatively, human presence may decrease an ambiguous or unfamiliar place's threat since a threatening place is less likely to be inhabited.

If the deviation from familiarity explanation were correct, the number of human models present should further moderate the effect of social presence on uncanniness depending on place: A fewer humans (e.g., one or two) may be acceptable in some private places like living rooms or kitchens, however social presence should become unacceptable when a certain threshold is reached. The effect may be further moderated by the familiarity of individuals (and places) depicted, as seeing a familiar person in an unusual location, or an unfamiliar person in a personal location may further estrange a scene. Future research can look into how the number and familiarity of people influences uncanniness ratings of places.

5.1.3. Threat and lack of information

Threat significantly predicted uncanniness in Experiment 1. Participants furthermore reported lighting, lack of safety and threat, and visual occlusions as reasons for a place's eeriness. However, only lighting, not occlusion, significantly predicted uncanniness. Lack of light has been associated with perceived lack of safety in past research (Boomsma & Steg, 2014). These results align with McAndrew and Koehnke's (2016) theory of *threat ambiguity* and with Stamps (2007) observations that lighting and occlusion increase a place's sense of mystery or lack of information.

While threat ambiguity can explain the perception of threat of uncanny places, it is unclear whether the *ambiguity* of threat elicited eeriness (as proposed by McAndrew & Koehnke, 2016). Feelings of threat may have stemmed from other sources: detecting potential environmental hazards, uncleanness, and other sources of contaminations in relation to threat avoidance theories (MacDorman & Ishiguro, 2006). Alternatively, stimuli deviating from familiar patterns may be threatening because they do not fit established cognitive conceptualizations or categories (Mangan, 2015; Schoenherr & Burleigh, 2015) and are thus less predictable. Thus, while uncanniness ratings correlated with threat, it is still unclear whether threat ambiguity specifically causes uncanniness of deviating architecture.

Recognizable patterns and structures allow to infer category-based information (Widmayer, 2002): Recognizing a place as a private bathroom provides additional relevant information. Anomalous or pattern-deviating places however escape categorization and prohibit inference of useful information: as a result, such places may appear eerie, strange, less safe, and potentially mysterious (Stamps, 2007).

Because environmental safety is of value to residents and a lack of perceived safety is related to stress and poor mental and physical health (Bilotta, Ariccio, Leone, & Bonaiuto, 2019; Brosschot, Verkuil, & Thayer, 2018; Conde & Pina, 2014), Designing environments based on typicality and predictability can increase residents' comfort and protect their health. .

5.2. Configural deviation and the aesthetics of physical places

The present research shows that built environments can cause a sense of eeriness or uncanniness if they sufficiently deviate from familiar, expected patterns and structures. These results can provide insights into understanding a variety of research on the evaluation of built environments:

Bizarre or postmodern architecture has been described as not fitting typical categories of places and structures (Jencks, 1979), and buildings of such styles are judged as less typical, familiar, pleasant, and preferable (Purcell, 1995; Purcell & Nasar, 1992; Stamps & Nasar, 1997). Thus, their deviation may decrease their likability.

Previous research found that a lack of coherence may reduce the likability of built and natural environments, potentially by increasing cognitive disfluency (Coburn et al., 2020; Vartanian et al., 2021; Weinberger et al., 2021). Highly incoherent places lacking internal organization may fall in the uncanny valley of architecture observed in Experiment 1.

Images typically described as *liminal spaces* in Internet communities may appear eerie, strange, or uncanny because the depicted places deviate from typical, experience-based expectations of places, and could thus be considered place-analogies of the uncanny valley. *Liminal space* stimuli, their place typicality, and aesthetic appeal could be investigated in future research, for example in the context of coherence (Kaplan, 1987) or expected pathfinding ability related to place familiarity (Hölscher & Brösamle, 2007), but also potential positive ratings of deviating or "liminal" spaces. Finally, an recognitzing a place can support navigation (e.g., by inferring relevant information), and familiarity helps with wayfinding (Haq & Zimring, 2003; Hölscher & Brösamle, 2007). Perceived difficulties in wayfinding and walkability are associated with increased anxiety (Chang, 2013) and decreased likability(Li, 2006), and well-being (Jaskiewicz & Besta, 2014). As a deviating place configuration may reduce the amount of information one may infer about the environment and its navigation, it may also negatively affect likability and well-being. In summary, negative reactions towards distorted, changed, or otherwise unexpected built environments are found throughout literature. A deviation-from-familiarity framework can encompass these reactions towards deviations from structural patterns of places, changes in specific environments, as well as the eerie atmosphere of configurally disordered or anomalous places, such as those observed in "haunted" settings. The aesthetics of built environments could thus be improved by designing them to adhere to their expected typicality.

5.3. Limitations and open questions

Stimuli in Experiment 1 were selected based on three types: unreal places, real places, and places described as eerie or ambiguous. While an uncanny valley was observed, a selection bias cannot be excluded. Future research may investigate how controlled change of realism affects uncanniness, and whether higher realism sensitizes the effect of deviation on uncanniness.

Subjective responses were measured via self-report scales. Although self-report scales are common in uncanny valley research (see Diel et al., 2022), measuring arousal and valence as essential components of affect (Carroll, Yik, Russell, & Barrett, 1999) can improve future investigation of affective reactions towards deviating built environments.

Stimuli in Experiment 2 were exclusively virtually constructed rooms with controlled deviations. Thus, stimulus range is limited. Future research may aim to replicate the results using a wider range of place stimuli like buildings, open urban places, and landscapes.

Stimuli in Experiments 2 and 3 were virtual renditions of built environments, and evaluations of those may not completely represent reactions towards real-life environments. This transfer may be especially hindered by social presence stimuli as participants may perceive virtual representations of human differently from real humans. Future research can look into replicating the observed effects using pictures of real places including real humans.

Finally, while Experiment 3 provided insight into the effect of human presence on uncanniness of indoor scenes, further modulating effects of social presence on the uncanniness of physical places are still unclear. If consistency of the configural representation of a place is important for uncanniness, then certain human variables would also either increase or decrease the consistency of the situation, such as clothing (e.g., a business suit in an office vs in a gym), or social behavior. Future research can investigate more holistic perspectives of place consistency and how social presence affects uncanniness.

6. Conclusion

An uncanny valley of physical places has been observed and explained by configural deviations in physical places. The first two experiments found an uncanny valley of physical places associated with deviating architectural features. The third experiment's results indicates that the effect deviations of physical places on uncanniness also encompasses the presence of humans. Thus, uncanniness is a general reaction to deviations from familiar patterns. Given the impact of a rich environment and mental well-being (e.g., Gardener & de Oliveira, 2020), the design of coherent and pattern-consistent environments is of practical importance.

7. Author note

We have no conflict of interest to disclose.

Author statement

Alexander Diel: Conceptualization, methodology, software, investigation, data curation, formal analysis visualization, writing- Original draft preparation, writing-reviewing and editing.

Michael Lewis: Supervision, writing- Reviewing and editing.

Appendix

Table A.1
Participant responses to the ten most uncanny "liminal space" stimuli. Numbers in brackets indicate the specific stimulus which can be found at <u>https://osf.io/d9s36/.</u>

Stimulus description	Participant responses to why they found the image eerie or strange
A toilet at the end of a very narrow, otherwise empty hallway (image 018)	"Very intense place for a toilet." "enclosed." "strange place to put a bathroom." "very unusual," "makes me feel trapped," "very long toilet room!!," "because of these room proportions," "rather piss my trousers," "feels trapped, no window," "I would not use this toilet. It's eerie and strange that someone put it there," "extremely odd room, design choice is weird," "weird room for a toilet very strange shape," "Just why? This is creepy!!," "claustrophobic," "weird structure, single point perspective, eerie ambience," references to both room's length and toilet (3 times), just references to the room's length (4 times)
A dark, wide public hallway curving to the right (image 045)	"Feels unsafe," "dingy lights," "dark and threatening," "dark and full of unnatural light," "empty," "night time corridor with shiny (wet) looking walls," "lighting, winding," "dark" (2 times), "dim lighting," "dark and wet looking," "looks like a crime scene," "dark bend," "underground passes always have the fear of the unknown about them," "bad lighting," "fear of what could come at the end," "looks like a murder alley," "windowless it can be creepy when empty," "feels trapped," "contrast in lighting and highly reflective surfaces," "weirdly empty, eerie and empty," "dark cold and unsafe if you were alone," "underground passages are ominous," "darkness, lack of context"
A wide hallway with repeating intersecting walls (image 027)	"empty," "lots of corners/areas someone could be hiding and poorly lit," "long corridor with green light and unclean surfaces," "the lighting," "dim lights & no windows," "lights are strange," "empty warehouse type building," "anything could jump at you," "light and I can't see what's around the corners," "looks like the scene of a crime," "the area is dark but also has artificial lights and has wide spaces," "abandoned and nothing else," "sense of emptiness and green lighting does not help," "too many areas I can't see," "looks like it's abandoned and unused," "emptiness makes this feel somewhat creepy," "deep single-point perspective, emptiness"
Water beneath a bridge with repeating concrete columns which seem to go on forever (image 048)	"No surfaces/platforms around so feels unsafe," "flood water," "reminds me of a catastrophe," "flooded infrastructure," "rised water level, feels unsafe," "the water is high," "because it looks dirty," "dark water" (2 times), "lots of doorways not leading anywhere, eerie because of the unknown," "makes me feel trapped and unsafe," "is there supposed to be water or has it flooded?," "because of the water and the low ceiling, no escape in sight," "unsafe looking," "reminds me of drowning," "looks like a car park but it's flooded with water," "doesn't look like it's meant to be flooded," "the view from under a bridge in addition to the depth of the repeating patterns," "any flooded structure is weird and a bit eerie to me," "single point perspective"
A dark, small room with a single chair and wooden walls, and a path leading to the right (image 019)	"Desolate," "what's around the corner?," "just a chair in a room," "random chair and is dark," "chair looks isolated," "single chair and unknown bend," "what is the point of the chair," "can't see what's on the right side," "random chair in the corner of a corridor," "shadows make it a bit creepy looking," "abandoned chair by itself," "the single chair, draped in shadow does not look like a pleasant place to sit," "dimly lit, odd chair placement," "dark and dingy hallway with a lone chair feels very eerie," "hostility of uncertainty," not eerie or strange (2 times)
A prop front of a house viewed from the side, revealing that it is just a narrow wall (image 038)	"Very odd," "just the front of a house and it's night time," "thin house" (2 times), "where is the back of the house?," "most of the buildings are missing," "the house has no back," "the house is flat," "no back of the house," "2d houses," "the house looks like it is part of a stage set or something," "half a house," "thin building and light from the left," "only the front of the house?," "house is 2d," "the flat façade is unsettling as it appears there is nothing behind it," "evidently a fake wall, quite odd," "odd building on the right," "only the front of the building is depicted, the actual buildings are missing," "you never expect to see a house which is only a single wall," "no purpose?," "lighting, false façade, blurred background"
Empty, wide repeating rooms seemingly going on forever, with a yellowish tint (image 050)	"Bleak," "feels unsafe and unsettling because of how run down and yellow it is," "you can't see everything," "looks like a horror movie theme," "monotonous and decaying," "no windows," "can't figure out the purpose," "it seems it would be easy to get lost," "huge space," "can't see where the space ends and a lot of hidden areas behind the walls," "what is the purpose of this room??," "depressing looking, awful lighting," "what is this?," "unfinished wall partitions, worn ceiling tiles and 70s palette," "looks rundown and abandoned," "repeated worn out walls gives a sensation of games like," "mirrored room structure," "grimy walls," "emptiness, decay, repetition," References only to the lack of furniture or emptiness (3 times), lighting references only (3 times)
An outdoor desert scene containing repeating high apartment buildings made of concrete, with desert mountains in the background (023)	"Seems like the weirdest place for structures like this," "copy and paste," "very hollow/dead," "lots of monotonous buildings with no apparent population," "all the same," "no people," "all the blocks are identical," "city in a desert – not normal," "strange buildings and lots of them in a desert," "too similar," "it looks like something from a sci-fi film," "not natural," "unusual disposition of buildings," "all these high rise buildings, with HUGE mountains in the background," "just looks out of place," "buildings are all same and look miniature," "The scale of the office blocks is strange. The image almost like toys scattered across the landscape," "very unnatural, doesn't look like a normal city," "very strange landscape with lots of high rises doesn't seem believable," "buildings seems out of place with respect to the surrounding area," "these blank, monolithic buildings are almost intimidating," "lots of tall designs packed so closely," "out of place almost like an organic growth on the mountainside"
An empty, wide space with a single entrance and repeating patterns on floor and walls (image 004)	"No windows, empty," "the colours and the carved out walk way," "look very empty and too repetitive," "both sides of the arch are the same. The strange camera angle makes it weird," "lighting," "small door," "there are no windows," "not much light," "emptiness," "door is way too small," "it looks like a prison or other secure compound," "there's some sort of mystery," "brutalist looking," "emptiness of the hall and unfinished nature of the door feels odd," "very unnatural, not life-like," hard to tell what it's part of looks like some sort of old asylum, doesn't look real," "the patterns on the floor and walls give off a creepy sensation," "creepy dark room," "surrealistic looking structure, emptiness, vague lighting"
A building without windows, the walls are covered by white tile (image 017)	"Look like bathroom floor," "no windows and old camera image quality," "the tiling doesn't work outside," "plain building locked door," "no windows, makes me feel trapped," "a lot of geometric

(*continued on next page*)

Table A.1 (*continued*)

Stimulus description	Participant responses to why they found the image eerie or strange
	shapes going on," "not great looking, looks like a bathroom wall," "this building looks like it should have windows but there are none shown," "imposing," "no windows but has doors very odd," "ominous building, like an asylum/prison from a horror movie," "eerie structure, windowless," references only to lack of windows (11 times)

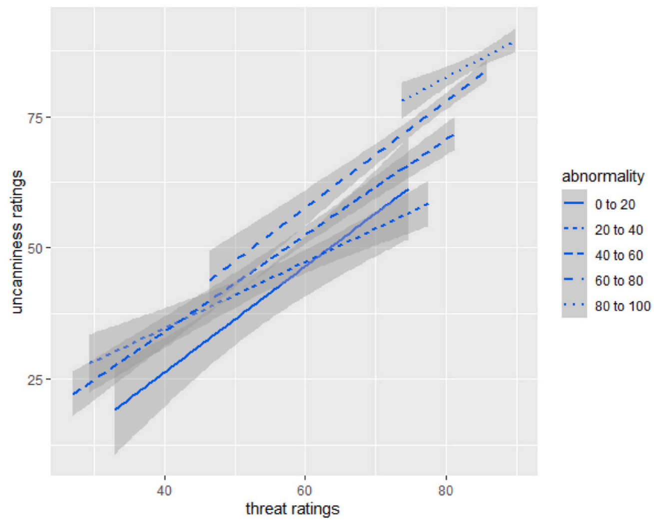

Fig. A.1. Uncanniness ratings plotted against threat ratings, divided into discretized abnormality ratings.

Table A.2
Uncanniness means and standard deviations (SD) across conditions (Experiment 2). Given the within-subject design, sample size was n = 52 across conditions.

No distortion			Distortion	
Distortion type	Uncanniness mean	Uncanniness SD	Uncanniness mean	Uncanniness SD
Lack	22.43	21.6	51.68	24.42
Repetition	30.32	25.19	58.88	25.37
Displacement	27.13	22.76	50.89	23.63
Size	25.4	22.72	46.98	29.35
Controlled	28.19	22.61	51.83	24.3
Social	44.69	24.8	61.24	25.31

Table A.3
Uncanniness means and standard deviations (SD) across number of anomalies (Experiment 2). Given the within-subject design, sample size was n = 52 across conditions.

Anomaly number	0	1	2	3	4
Uncanniness mean	26.45	52.14	66.75	65.92	73.85
Uncanniness SD	23.09	26.02	21.15	23.21	19.47

Table A.4
Measure means and standard deviations (SD) across conditions (Experiment 3; Distortion = control or distorted; type = private or public place; social = social absence or presence). Given the within-subject design, sample size was n = 37 across conditions.

Condition (Distortion/type/social)	Oddity		Uncanniness		Abnormality		Threatening	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Control/private/absence	25.88	21.47	21.78	17.88	19.91	20.72	16.32	15.56
Control/private/presence	38.5	23.16	37.39	23.92	43.33	32.09	30.03	21.96
Control/public/absence	27.91	20.95	32.96	23.21	29.79	24.5	23.91	19.17
Control/public/presence	32.82	20.87	29.71	21.38	30.36	26.9	23.8	18.71
Distorted/private/absence	46.28	28.01	55.02	23.23	68.05	32.45	35.18	22.88
Distorted/private/presence	51.88	26.7	59.9	20.02	71.81	26.27	43.21	22.42
Distorted/public/absence	47.65	30.98	60.43	25.57	66.05	32.45	39.34	24.12
Distorted/public/presence	47.23	29.92	53.69	26.11	63.72	33.45	37.29	22.48

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