The Role of the Eyes in the Uncanny Valley Effect: Does Incongruence between Eyes and Face Influence Uncanniness?

Isa Dollée

Faculty of Behavioural, Management and Social Sciences (BMS), University of Twente

Human Factors & Engineering Psychology

1st Supervisor: Martin Schmettow

2nd Supervisor: Marlise Westerhof

July 7, 2022

Abstract

This aim of this study is to investigate the impact of the eyes and their human likeness in relation to the human likeness of the overall face structure on the uncanny valley effect. The uncanny valley effect describes the relationship between the human likeness and likeability of entities. Generally, entities are seen as more likeable as they resemble humans more closely until a certain point of moderate-to-high human likeness, at which the emotional response rapidly becomes negative. Entities that cross this point and are seen as extremely human-like are again rated favorably. This pattern has been replicated using biological primate faces and has been shown to occur universally in all humans, suggesting an evolutionary origin. Previous research and informal observations indicate that the sclera color may influence this effect and that incongruence between human and non-human features on a face may cause it.

Thus, an eye-tracking study about encounters between 30 participants and 8 primate face stimuli which vary in human likeness and are manipulated to have either white or dark sclerae was conducted. Findings support the hypothesis that incongruence causes an uncanny valley response. Further, differential effects for two types of incongruence were identified. Specifically, faces with human skulls and dark, ape-like sclerae were rated as uncannier than vice versa and had stronger effect on eye movement variables, including reduced restlessness in visual exploration and a tendency of participants to look away.

Table of Contents

Introduction

Description and Relevance of the Uncanny Valley Effect

The uncanny valley effect is a phenomenon that affects many interactions in our contemporary world. The effect describes the non-linear relationship of an agent's human likeness and a human's emotional response to the agent (Mori et al., 2012). Specifically, the human typically feels more positively about an agent with greater human likeness up to a certain point. Once the agent crosses this point and resembles humans too closely, the human's emotional response quickly changes and turns into an aversion. In this case, the agent is said to be in the "uncanny valley" (Mori et al., 2012). Commonly, this effect is discussed in the context of technological agents, such as robots. In fact, human-robot interactions can be expected to become more frequent in the future. Today, robots are already employed in elderly care (Chu et al., 2017) and health care (Oborn et al., 2011) and their numbers may increase to accommodate aging populations and staff shortages in these fields (Chu et al., 2017). Furthermore, robots are currently implemented and researched in the service industry (Kim et al., 2021) and education (Belpaeme et al., 2018), as well as developed for search and rescue of persons in need (Priandana et al., 2018). As such, encounters and interactions with robots will likely become more common in different areas of life. In these encounters, a robot's perceived uncanniness can have consequences beyond mere disliking. For instance, work by Laakasuo et al. (2021) suggests that there is a "moral uncanny valley effect", in which people judge a robot's moral decisions less favorably when the robot looks uncanny. In addition, Destephe et al. (2015) demonstrate that people are less likely to accept uncanny robots as working partners. Consequently, the uncanny valley effect significantly influences the success of human-robot interactions.

Moreover, the effect can also influence perceptions of other humans. In particular, advancements in prosthetic design and production allow modern facial prosthetics to look almost fully human, potentially placing those that wear them in the uncanny valley (Mori et al., 2012). Indeed, Snykers et al. (2019) show that people with a prosthetic eye may be perceived as uncanny. Likely, this effect would cause problems in the lives of people with facial disfigurements. In line with this, De Sousa (2010) emphasize the importance of how others react to the appearance of people with facial trauma. According to the authors, learning to cope with these reactions is "the greatest psychosocial challenge" for patients. In many cases, difficulties to cope with this challenge lead people to withdraw from social contact (De Sousa, 2010) . As such, the uncanny valley effect can profoundly impact the social life and psychological recovery of people with facial prosthetics or disfigurements. Following this, it is important to not only investigate the uncanny valley effect in technological contexts, but also biological ones.

Evolutionary Origins of the Uncanny Valley Effect

Previous evidence points towards an evolutionary origin of the uncanny valley effect. First, Koopman and Schmettow (2019) recently demonstrated that the uncanny valley effect is universal, meaning that every person experiences it. Following this, the effect cannot merely be caused by cultural factors, as these would vary between people and thus, not everyone would display the effect. In like manner, work by Haeske and Schmettow (2016) further weakens fully cultural explanations. They showed that the uncanny valley effect occurs even when faces of varying human likeness are only displayed very shortly. Therefore, the effect must emerge in early processing before cultural factors influence the perception of the faces. Lastly, Steckenfinger and Ghazanfar (2009) showed that macaque monkeys also experience the uncanny valley effect. Hence, this suggests the effect may have evolved before humans evolved as a separate species. In all, research indicates that the uncanny valley effect is at least partially caused by an evolved biological mechanism.

To investigate the evolution of the uncanny valley response, Geue and Schmettow (2021) recently replicated the effect with primate faces. Next to this, she demonstrated that the effect occurs not just based on human likeness, but also based on the ancestral closeness of the face's species to homo sapiens (Geue & Schmettow, 2021). These findings suggest that the uncanny valley effect may have evolved when homo sapiens coexisted with other human species as a mechanism to limit closeness to those species (Geue & Schmettow, 2021). The avoidance of other human species may have been a response to specific evolutionary selection pressures, such as the prevention of cross-species reproduction or the transmission of disease (Geue & Schmettow, 2021). In short, the uncanny valley effect may be an evolved mechanism to reduce contact between homo sapiens and other human species.

The Role of Perceptual Mismatch

Despite these findings, other research suggests that close human resemblance does not fully account for a face's uncanny appearance. Rather, it appears that further conditions must be met to cause the effect (Kätsyri et al., 2015). Specifically, Kätsyri et al. (2015) found that, when comparing multiple explanations of the uncanny valley effect, the strongest support was found for the perceptual mismatch hypothesis. According to this hypothesis, faces cause a negative emotional response when their various features do not resemble humans to the same degree. As an example, Kätsyri et al. (2015) argue that a human face with artificial eyes or the reverse, an artificial face with human eyes, would be perceived as uncanny. In summary, a face is most likely seen as uncanny when it has both nearly human and less human features.

Processing of Human and Non-Human Faces

In fact, people process human faces differently than other faces. Evidence suggests that this difference is both developmentally acquired and facilitated through an inborn preparedness for facial stimuli. According to De Haan et al. (2002), new-born infants display a preference for visual stimuli with face-like configurations. Likely, this bias originates from subcortical brain areas (De Haan et al., 2002) . As such, the attention of human infants is oriented to faces, ensuring that the infants will gain experience with facial stimuli (De Haan et al., 2002). This, in turn, supports the development of specialized cortical brain areas for face processing and expertise in recognition of human faces (De Haan et al., 2002). Concretely, infants begin to develop a “face space” at three months old. This means that they start to see faces as a category, in which some faces are more typical than others (De Haan et al., 2002). In line with this, infants also begin to prefer human over monkey faces at the age of three months (Di Giorgio et al., 2013), suggesting that they have developed a model for human faces. Hence, an innate bias for face-like configurations promotes the development of a face space for conspecifics in human infants.

Due to the face space, humans employ different processing strategies for conspecific and other-species faces. Generally, faces can be assessed analytically or intuitively (Mega & Volz, 2017). When using an analytical strategy, people use many short fixations to look at the face and mainly focus on the eyes (Mega & Volz, 2017) . In contrast, intuitive processing is characterized by fewer, longer fixations that are more focused on the center of the (Mega & Volz, 2017). Further, intuitive viewing indicates a larger reliance on expertise with similar faces and is a more holistic perceptual strategy, focusing on the center of the face and using configural information more than specific facial features (Mega & Volz, 2017). In accordance with this, processing of human faces aligns more with intuitive, configural perception, whereas processing of monkey faces appears to be more analytic and feature based. Dahl et al. (2014) investigated the source of the own-species effect, the phenomenon that people are quicker at discriminating faces of their own species than other species, while maintaining accuracy. Their results indicate that humans are more sensitive to the facial configuration of same-species faces, which allows them to process the faces more quickly (Dahl et al., 2014). When the reliance on configural information was inhibited by inverting the faces, participants relied on facial features to discriminate faces of both humans and other species, and the own-species effect disappeared (Dahl et al., 2014). Thus, it appears that people are able to use more holistic, intuitive processing for conspecific faces, allowing them to recognize human faces more quickly. Interestingly, the own-species effect becomes stronger the more evolutionarily distant the other species is (Dahl et al., 2014). Therefore, differences in facial processing are tied to a face's degree of humanness, suggesting that they may be involved in the uncanny valley effect.

The Potential Role of Eyes in the Uncanny Valley Effect

Following this, the question remains which specific facial features or configurations cause a face's placement in the uncanny valley. Two lines of reasoning suggest that the eyes are involved in the creation of this effect.

For one, this is because the eyes are important in facial perception in general. Despite an increased reliance on configural information for human faces, (Dahl et al., 2014) observe that featural information about the eyes is used to recognize all faces, including human ones. This observation is confirmed by eye-tracking studies, which consistently report that when seeing a human face, people first fixate on the eyes (Bagepally, 2015; Di Giorgio et al., 2013). Thus, people pay special attention to the eyes of a face. As a result, people may be more likely to notice a perceptual mismatch between nearly human and less human characteristics when this mismatch involves the eyes.

Secondly, there are concrete observations linking the eyes to the uncanny valley effect. For example, Snykers et al. (2019) reported that orbital epithesis are often perceived as uncanny from a close distance. Similarly, Geue and Schmettow (2021) observed post-hoc that non-human primate faces with big, white sclerae may be most likely to fall into the uncanny valley. Both observations indicate that the eyes are somehow involved in causing the uncanny valley effect. Moreover, Geue and Schmettow's (2021) finding indicates a specific characteristic of the eyes that may relate to the uncanny valley: the sclerae. Given that humans have bigger sclerae than other primates (Kobayashi & Koshima, 2008), they may be considered a uniquely human feature. This means that Geue and Schmettow's (2021) observation constitutes a perceptual mismatch between human-looking eyes and a non-human face, further substantiating the potential role of the sclerae in causing the uncanny valley effect. Further, the sclerae may be important to the uncanny valley effect because they are useful in interactions with other humans. In fact, according to the cooperative eye hypothesis, humans evolved bigger sclerae so others could see where a person directs their gaze or focuses their attention, improving cooperation with other humans (Kobayashi & Koshima, 2008; Tomasello et al., 2007).

Additionally, human sclerae are an indicator of age, health, and attractiveness (Provine et al., 2013; Tomasello et al., 2007), hence, they are a useful cue in mate selection. Therefore, it is possible that humans pay special attention to eyes with sclerae. As a result, a perceptual mismatch involving this feature may be detected more easily and lead to an uncanny valley response. In all, it may be hypothesized that the uncanny valley effect occurs for non-human faces with eyes that have big, white sclerae.

Potential Eye Movement Patterns Associated with the Uncanny Valley Effect

Supposing the uncanny valley effect indeed occurs for such faces, it would likely be associated with particular eye movement patterns that relate to how these faces are processed. While, to our knowledge, no study has investigated this possibility for non-human faces with big, white sclerae specifically, other research can inform a plausible hypothesis. First, consider the order in which people might fixate on parts of the face: In general, people first direct their gaze to the eyes (Bagepally, 2015; Di Giorgio et al., 2013). Finding human-looking eyes with white sclerae, this may set the expectation that the rest of the face is also human-like. Thus, the gaze may be directed to the center of the face, so it can be viewed holistically. In this moment, the perceptual mismatch is detected, as the expectation of a human facial configuration is not met.

Then, the question remains how facial processing continues after the mismatch is detected. A hypothesis can be found by drawing a parallel to the perception of malformed faces. Studies on people with a unilateral cleft or palate show that people focus on the malformed area for a longer duration (Meyer-Marcotty et al., 2010; Meyer-Marcotty et al., 2011). This might be interpreted as the viewer's attempt to figure out what seems "wrong" or "off" about the face, given that the gaze appears to fixate on the element that disrupts the expected facial configuration. If the same principle applies to uncanny faces, the gaze should also try to locate the source of disruption. Since the entire facial configuration is unexpected, eye fixations should encompass the entire face and focus on the center. Indeed, da Fonseca Grebot et al. (2022) found that participants spent more time fixating on the nasal area of categorically ambiguous faces than of clearly human or clearly artificial faces. Thus, their results align with this interpretation.

However, it is unlikely that the viewer's eyes will remain fixated on the center of the face. For one, as the face is not human, the viewer will likely not be able to rely on a previously established face space for an intuitive, holistic perceptual strategy. Rather, an analytic strategy, using many short fixations to gain information about individual features, is more probable.

Furthermore, short fixations also match findings about perception of ambiguous figures. Van Leeuwen et al. (2002) report that when participants switch from one interpretation of an ambiguous figure to another, this is associated with short fixation durations. If an uncanny face causes uncertainty about whether to interpret it as human or non-human, this may be associated with the same quick eye movements found to relate to ambiguous figures. Further, it may be speculated that as the viewer attempts to resolve this ambiguity, the main points of fixation will be those that cause the ambiguity: the eyes and the center of the face, representing the facial configuration. Therefore, viewers of an uncanny face will likely switch between fixating on the eyes and the center of the face.

In summary, this study will investigate the following hypotheses:

H1: Incongruent faces, in which either the face configuration or eye type is human while the other is ape-like, will be perceived as uncannier than congruent faces.

H2: When perceiving incongruent faces, participants will display more restless visual exploration behavior, characterized by more frequent fixations.

H3: When perceiving incongruent faces, participants will spend more time fixating on the nasal and central areas than when perceiving congruent faces.

Methods

This is an eye-tracking study about an encounter between participants and primate face stimuli. The face stimuli vary in human likeness and are manipulated to have either white or dark sclerae, resulting in four categories of stimuli: (a) congruent: ape eyes and ape skull, (b) congruent: human eyes and human skull, (c) incongruent: ape eyes and human skull, and (d) incongruent: human eyes and ape skull. Participants rated the uncanniness of each face stimulus and their visual search behaviour and the time spent on different areas of the face were analysed.

Participants

30 people participated in the study. They were acquaintances that the researchers recruited by personal requests. Since no demographic differences were not expected to influence the results, no demographic data was collected to protect the participants' privacy.

Stimuli

Selection

This study used a subset of eight faces from a previous study on the uncanny valley effect by Geue and Schmettow (2021). Their stimulus set consisted of 89 primate faces and 11 robot or android faces, which were compiled to include a broad array of primate species with varying levels of human likeness (Geue & Schmettow, 2021). Geue and Schmettow (2021) retrieved stimuli from multiple sources, including John Gurche's catalogue of hominid busts (https://gurche.com/), which they had permission to use, and the open access databases Global Biodiversity Information Facility (https://www.gbif.org/) and PrimFace (https://visiome.neuroinf.jp/primface/). For each face, Geue and Schmettow (2021) determined human likeness rating and an eeriness score, which the researchers of the current study used to determine each face's position in the uncanny valley curve. For human likeness, Geue and Schmettow (2021) obtained the average of four independent expert ratings for each face, while only including stimuli with high inter-rater reliability on these ratings in their study. For eeriness, they used the average of responses to a one-item visual analogue scale by Mathur and Reichling (2016) and to the "spine-tingling" subscale of the eeriness index by Ho and MacDorman (2016) (Geue &Schmettow, 2021).

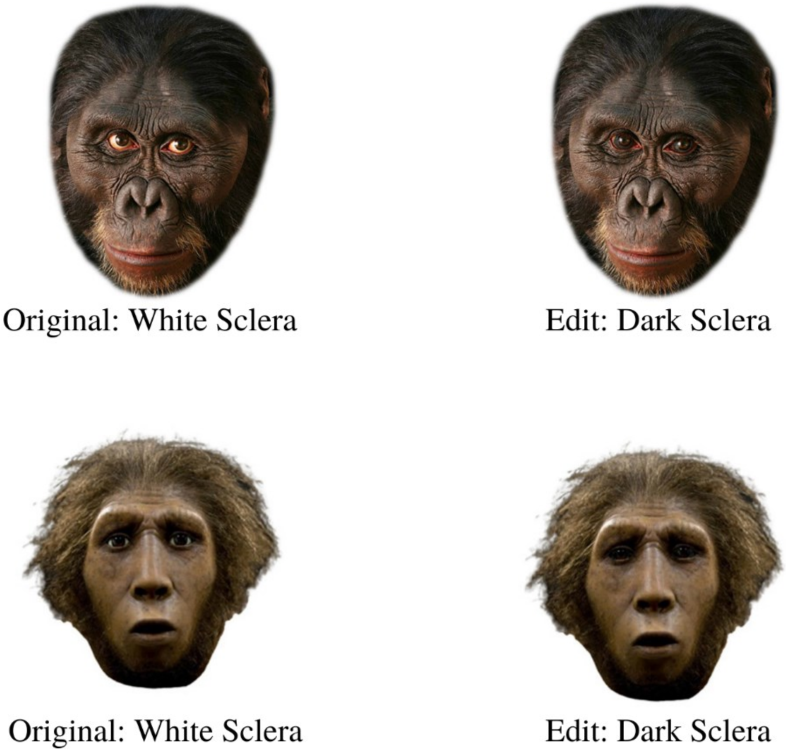
Based on the human likeness ratings and eeriness scores, we selected nine faces that covered three points in the uncanny valley curve: the shoulder, the lowest point of the valley, and the upwards slope. Further, selected faces had to meet these criteria: the picture (a) showed a primate face, (b) showed the entire face from the top of the head to the chin, and (c) showed the face in frontal or ¾ view, so that both eyes were visible. However, due to a mistake in the manipulation, one stimulus at the shoulder was excluded from the analysis, resulting in a total of 8 faces.

Manipulation

The set of stimuli contained two versions of each selected face: one with white sclerae and one with dark sclerae (for examples, see Figure 1). For this, the faces were manipulated in Clip Studio Paint, a software for image editing and digital painting. First, the new sclera colour was drawn on top of the image. Then, the new colour was made somewhat transparent so the shadows of the eye could still be seen. Finally, a slight blur was applied to the new sclera colour, so its edges would look more natural and match the picture's resolution. The final set of stimuli can be seen in Appendix A.

Figure 1

Example Stimuli with White and Dark Sclerae



Area of Interest Coding

To prepare the stimuli for data analysis, areas of interest (AOI) were coded for the eyes, nose, mouth, and rest of each face. Specifically, rectangles were defined that touched the outermost points of each facial feature. The decision to limit the AOIs to the edges of the feature was based on recommendations by Orquin et al. (2016), who recommend adjusting the size of AOIs to the accuracy of the eye tracking equipment. In the case of this study, the eye tracker was considered not very accurate. Therefore, small AOIs were used to avoid false positives, such as interpreting a fixation as looking on the eyes when the participant was looking somewhere else.

Eye Tracker

Device and Setup

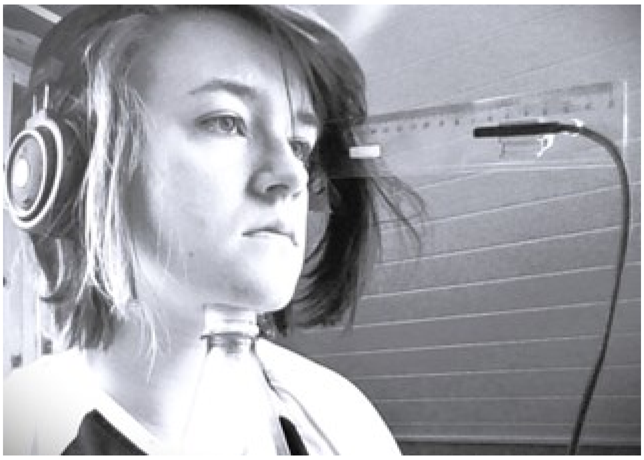
To collect eye movement data, an eye tracker was built according to the instructions by Schmettow (n.d.). This way, the researchers had access to a cheap and portable eye tracking device to conduct the study outside of the laboratory. The device is depicted in Figure 2. It consisted of an endoscopic camera with a resolution of 640x480, which was lit up by white

LEDs. The camera pointed at the participant's eye and was placed into a clip, which was stuck to a ruler and held behind the participant's ear. The ruler was stabilized by a pair of over-ear headphones, which the participant wore on top of the ruler.

Several additional procedures were used to improve the accuracy of measures. To minimize head movements, the participants placed their chin on a roll of paper towels, a foam roller, or a bottle and put on arm on the table. In addition, participants were asked to take of their glasses if their vision allowed it and a desk lamp shone at the participants face, improving the sharpness of the camera recording.

Figure 2

Eye Tracking Setup



Eye Tracking Software

The raw eye tracking data was collected using a Python program, which was developed by researchers of the University of Twente for the self-built eye tracker. The program was able to calibrate the eye tracker, display images and measure the x- and y-coordinates of the participant's gaze at each time of measurement with a 30Hz sampling rate.

One-Item Likeability Scale

The one-item likeability scale (Mathur & Reichling, 2016) was used to rate the faces' level of uncanniness. This measure is a visual analogue scale from -100 to 100, in which the low end stands for "unfriendly, unpleasant, creepy" and the high end stands for "friendly and pleasant, not creepy".

Procedure

The researchers met the participants in their homes to conduct the study. First, the participant received and read an information sheet (Appendix B) about the study and signed the informed consent form (Appendix C), both in paper format. During this time, the researcher set up the laptop and software for the study. Once the participant had signed the informed consent form, he or she sat down in front of the laptop and the researcher setup the eye tracker and items to improve measurements according to the description above. Next, the researcher started the eye tracking software. The study began with a calibration of the eye tracker. Then, each face stimulus was shown for 5 seconds, followed by a quick calibration before the next face. The face stimuli were displayed in the same order for each participant, with no two versions of the same face shown immediately after each other. After this, researcher removed the eye tracker and the participant proceeded with rating all stimuli on the one-item likeability scale (Mathur & Reichling, 2016) on paper (Appendix D). For this, the researcher instructed the participant to go through a slideshow presenting all stimuli one by one and simultaneously marking his or her ratings on paper. After the participant had seen and rated all face stimuli, the and the study ended.

Data Analysis

The full R script for the data analysis can be seen in Appendix E.

Deriving Fixations Time and Saccade Distance

The raw data was categorized into two distinct events based on the distance between observations. First, the distance between consecutive observations was computed and compared to a threshold value to determine candidates for fixations. For this, a threshold value of 50 pixels was chosen based on an exploratory analysis of data from a small-scale pilot, in which the researchers recorded their eye movements while the stimuli were presented to them. This approach is in line with Salvucci and Goldberg (2000), who recommend exploratory data analysis to determine a threshold value for distinguishing fixations and saccades. Then, the Euclidian distance between consecutive observations was computed. If this distance fell below the threshold value, the later observation was classified as part of a fixation. Conversely, if the distance met or exceeded the threshold value, the later observation was classified as part of a fixation. Next, successive observations that shared the same classification were merged into groups. Thus, observations were grouped into either a candidate fixation or a saccade at the end of this phase.

After identifying fixations and saccades, basic measures describing them were computed. For fixations, their duration was computed by subtracting the time of the first observation from the time of the last observation. In addition, fixations were described in terms of their location, which was operationalized as the average coordinates of all observations within the fixation. On the other hand, saccades were described in terms of their distance, which was computed by applying the Pythagorean theorem to their first and last observation.

Eye Tracking Measures

To interpret the eye tracking data, two categories of metrics were computed. For one, the researchers wanted to quantify the restlessness in visual exploration. This was assessed using two metrics: the total distance that the gaze had travelled and the number of fixations. Total distance travelled was calculated by summing the distance of all saccades that occurred for one face stimulus and participant. The number of fixations was defined the number of fixations per face stimulus and participant.

Secondly, the researchers wanted to measure the relative interest in each AOI. For this, the total dwell time in each AOI was computed by summing the duration of all fixations that were located within the AOI.

Design and Statistical Model

This study employed a 2-factor (congruence) within-subjects design. The congruence variable was based on the variables sclera type and skull type, which both had the two levels "ape-like" and "human-like". If both sclera and skull type had the same level, the congruence variable had the level "congruent". If sclera and skull type did not match, congruence had the level "incongruent".

Due to the repeated measures design, observations of the same participant were not dependent. Therefore, a multi-level factorial model was used to analyse the data in R. This was a 2-factor (congruence) model with a participant level slope and intercept. In addition, a 2 (sclera type) by 2 (skull type) model with participant level slopes and intercept was run to distinguish between types of incongruence.

Using this model, a beta regression was performed on the variable uncanniness rating. For total distance travelled and AOI dwell time, a beta regression was not suitable as these variables had no upper bound, and a Gamma regression was employed instead. For the number of fixations, a binomial regression was used.

Results

H1: Uncanniness Ratings

According to the first hypothesis, it was predicted that incongruent faces would be perceived as uncannier than congruent faces. Consequently, higher ratings on the one-item likeability scale were expected for congruent faces. To test this hypothesis, multi-level beta regression with participant level intercepts and slopes were estimated using either congruence (Table 1) or sclera and skull type (Table 2) as predictors. In both cases, the random effects ranged from 0.1 to 0.38, showing substantial variation between participants.

In the first model (Table 1), the coefficient estimate of congruence was positive, suggesting that congruent faces were rated as less uncanny than incongruent faces. In line with this, a graphical representation showed that the mean rating of congruent faces was higher, i.e., less uncanny, than that of incongruent faces (Figure 3). However, the effect's coefficient was small, and its 95% confidence interval included both positive and negative values. Thus, there may have been no effect or if there was, it was likely small.

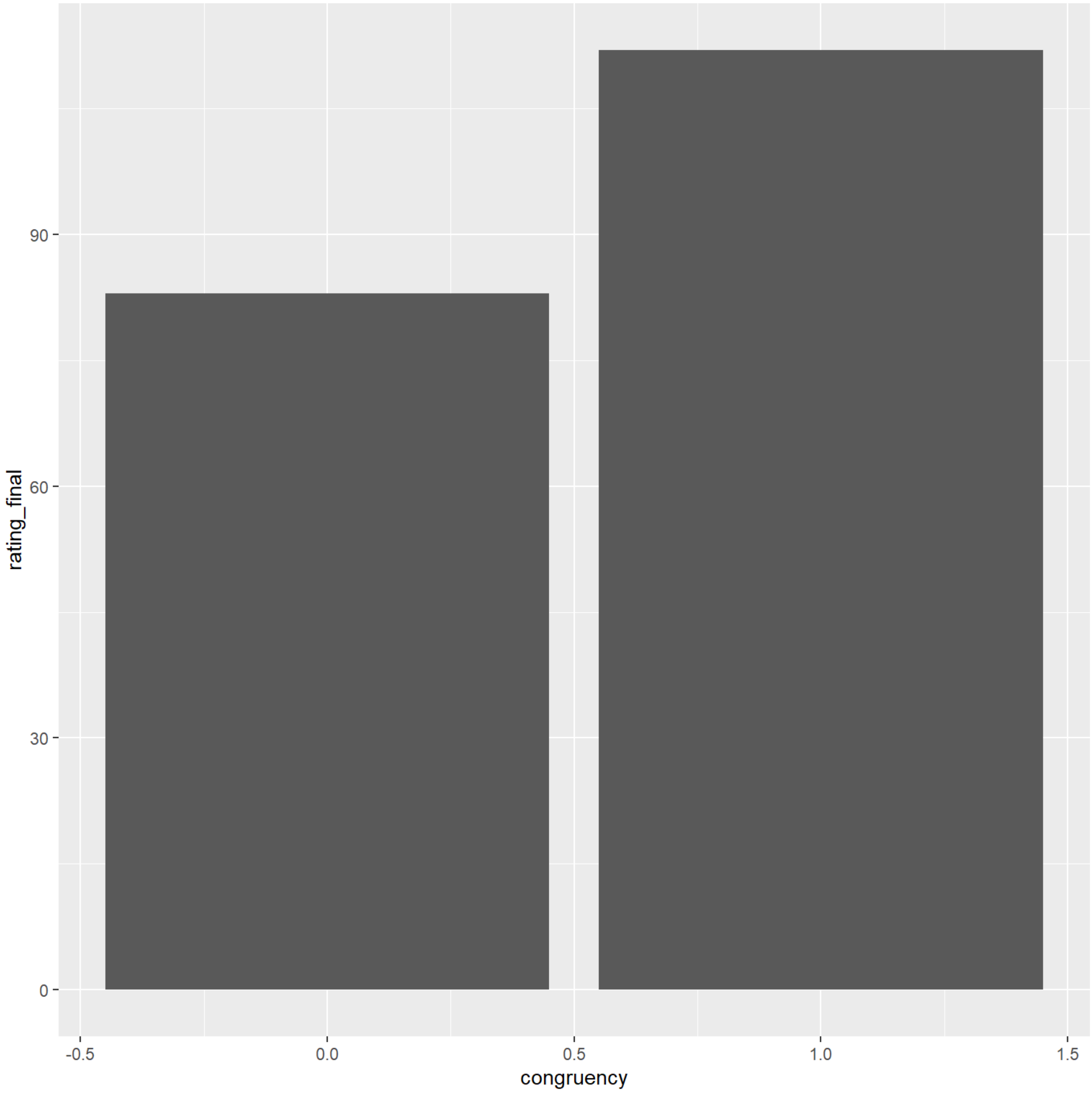
Table 1

Beta Regression Fixed Effects and Random Factor Variation of Uncanniness Ratings by Congruence

	Fixed effect estimate	CI – Lower Bound	CI – Upper Bound	Random factor variation	CI – Lower Bound	CI – Upper Bound
Intercept (incongruent)	-0.23	-0.39	-0.07	0.23	0.08	0.41
Congruence	0.15	-0.03	0.33	0.1	0.02	0.25

Figure 3

Uncanniness Ratings by Congruence



In the second model (Table 2), there were negative effects for human sclerae and human skulls, suggesting that incongruent faces were rated as uncannier than fully ape-like faces. This effect was greater for human skulls, indicating that faces with ape eyes and human skulls are perceived as uncannier than faces with human eyes and ape skulls. Hence, it appears that the type of incongruence is relevant to evoking uncanniness. For this reason, further analyses were only performed using sclera and skull type as predictors, whereas the model with congruence was omitted. In addition, fully human faces were rated as uncannier than ape-like faces, but less uncanny than incongruent faces. On the one hand, this matches the hypothesis that uncanniness is caused by incongruence. On the other hand, it is not in line with the predicted uncanny valley curve, as typically, fully human faces are considered more likeable than non-human faces.

Table 2

Beta Regression Fixed Effects and Random Factor Variation of Uncanniness Ratings by Sclera and Skull Type

	Fixed Effect Estimate	CI – Lower Bound	CI – Upper Bound	Random Factor Variation	CI – Lower Bound	CI – Upper Bound
Intercept (fully ape-like)	0.1	-0.04	0.24	0.21	0.07	0.36
Human Sclerae	-0.1	-0.29	0.09	0.19	0.04	0.41
Human Skull	-1.01	-1.33	-0.7	0.38	0.2	0.63
Human Sclerae * Human Skull	0.26	-0.16	0.66	0.37	0.16	0.64

H2: Visual Exploration

The second hypothesis was that when perceiving incongruent faces, participants would display more restless visual exploration behavior. Visual exploration was measured using two variables, namely the number of visits and total distance travelled, whereby an increase in these variables indicated increased restlessness. Thus, an increase in the number of visits and total distance travelled was expected for incongruent faces.

This hypothesis was tested using a binomial regression with the number of visits and a gamma regression for total distance travelled. To interpret the outcomes of the binomial regression, the exponent mean function was used. Consequently, the regression coefficients can be interpreted multiplicatively, meaning that to add an effect to the intercept, the intercept should be multiplied by the effect's coefficient. As such, effects above 1 are positive and effects below 1 are negative. For total distance travelled, the intended gamma regression of a multi-level model with total distance travelled did not run in R. Instead, a gaussian regression was used. Its coefficients are additive, meaning that effects above 0 show an increase in total distance travelled, whereas effects smaller than 0 represent a decrease.

Table 3 shows the regression coefficients for the number of visits and total distance travelled. The number of visits was lower in faces with human sclerae, skulls, or both than in fully ape-like faces. However, the coefficient was lowest for incongruent faces with human skulls, while the confidence intervals included positive effects for human sclerae and the combination of human sclerae and skull. From this, it can be drawn that the decrease in number of visits is most prominent for faces with human skulls and ape-like eyes. The same pattern was found for total distance travelled, which was highest in fully ape-like faces and lowest in faces with human skulls and ape-like eyes. Thus, it appears that visual exploration of ape faces is most restless. The reduction of restlessness in visual exploration is strongest for faces with human skulls while being smaller and less certain for faces with human sclerae or fully human faces.

Table 3

Fixed Effects of Number of Visits and Total Distance Travelled by Sclera and Skull Type

	Visits	CI – Lower Bound	CI – Upper Bound	Distance	CI – Lower Bound	CI – Upper Bound
Intercept (fully ape-like)	4.5	4.09	5.04	386.20	296.41	478.32
Human Sclerae	0.94	0.86	1.04	-27.85	-91.34	32.68
Human Skull	0.86	0.76	0.98	-50.32	-133.78	32.02
Human Sclerae * Human Skull	1.1	0.92	1.34	59.26	-60.31	180.56

In Table 4, the random factor variation for the regressions with number of visits and total distance travelled is displayed. For both variables, the variation in intercepts and slopes was of similar size as the fixed effects (Table 3), suggesting substantial variation between participants.

Table 4

Random Factor Variation of Number of Visits and Total Distance Travelled by Sclera and Skull Type

	Visits	CI – Lower Bound	CI – Upper Bound	Distance	CI – Lower Bound	CI – Upper Bound
Intercept (fully ape-like)	0.2	0.14	0.29	212.52	158.22	284.56
Human Sclerae	0.06	0.01	0.15	59.30	12.97	119.98
Human Skull	0.07	0.03	0.15	52.13	18.71	104.58
Human Sclerae * Human Skull	0.1	0.03	0.22	61.93	19.82	130.78

H3: Total Dwell Time per AOI

It was hypothesized that when perceiving incongruent faces, participants would spend more time fixating on the nasal and central areas than when perceiving congruent faces. To test this hypothesis, a gamma regression with AOI, sclera type and skull type are shown in Table 5. The AOI “mouth” and “nose” were merged into the AOI “snout” to simplify the model and because the effects for them were similar. The participant level intercept and slopes were omitted, as this model would not run in R. Like for the number of visits, the exponent mean function was used. Therefore, coefficients larger than one indicate an increase in dwell time, while coefficients smaller than one indicate a decrease.

Table 5

Gamma Regression Coefficient Estimates and Confidence Intervals of Dwell Time per AOI by Sclera and Skull Type

	Estimate	Confidence Interval – Lower Bound	Confidence Interval – Upper Bound
Intercept (eyes, ape sclerae, ape skull)	16.00	12.86	20.12
Outside	0.92	0.71	1.20
Snout	1.54	1.07	2.22
Human sclerae	0.82	0.61	1.14
Human skull	0.95	0.66	1.42
Outside*human sclerae	1.08	0.75	1.50
Snout*human sclerae	1.47	0.89	2.32
Outside*human skull	0.63	0.41	0.94
Snout*human skull	0.92	0.50	1.62
Human sclerae*human skull	1.57	1.14	2.16

For easier interpretation, the estimated dwell time per condition was calculated. To obtain these estimates, the coefficients of all applicable effects were multiplied. For example, the combined effect for the dwell time on the snout in faces with human sclerae and ape skulls was calculated as follows: Snout * Human sclerae * (snout*human sclerae) = 1.54 * 0.82 * 1.47 = 1.86. These combined effects represent the change in dwell time compared to the dwell time on the eyes in ape faces. Then, the combined effects were added to the intercept, which is the dwell time on the eyes in ape faces, to calculate the absolute dwell time for each condition, which are displayed in Figure 4 and 5.

Regarding the eyes, participant spent most time focusing on this area in fully human faces, followed by ape faces, faces with human sclerae and ape skulls, and faces with ape sclerae and human skulls, in order. This is in line with the hypothesis, as less time was spent on the eyes in incongruent faces, which would allow for more time spent on the nasal and central areas of the face.

Concerning the areas outside the eyes and snout, a similar pattern was observed as for previous variables. Namely, there was a reduction in dwell time on this area in incongruent faces compared to ape faces, with a bigger effect for faces with human skulls and ape sclerae.

However, this finding is unexpected, as an increase in time spent on the central areas of the face was predicted for incongruent faces.

Finally, the combined effects on dwell time on the snout mostly do not match the hypothesis. Specifically, participants spent less time on the snout of incongruent faces with human skulls compared to congruent ape and congruent human faces. Further, less time was spent on the snout of incongruent faces with human sclerae than congruent faces. Only the comparison of fully ape-like faces and incongruent faces with human sclerae matches the hypothesis, as participants fixated on the snout of the latter for more time.

Figure 4

Dwell Time per AOI in Faces with Human Skulls by Sclera Type

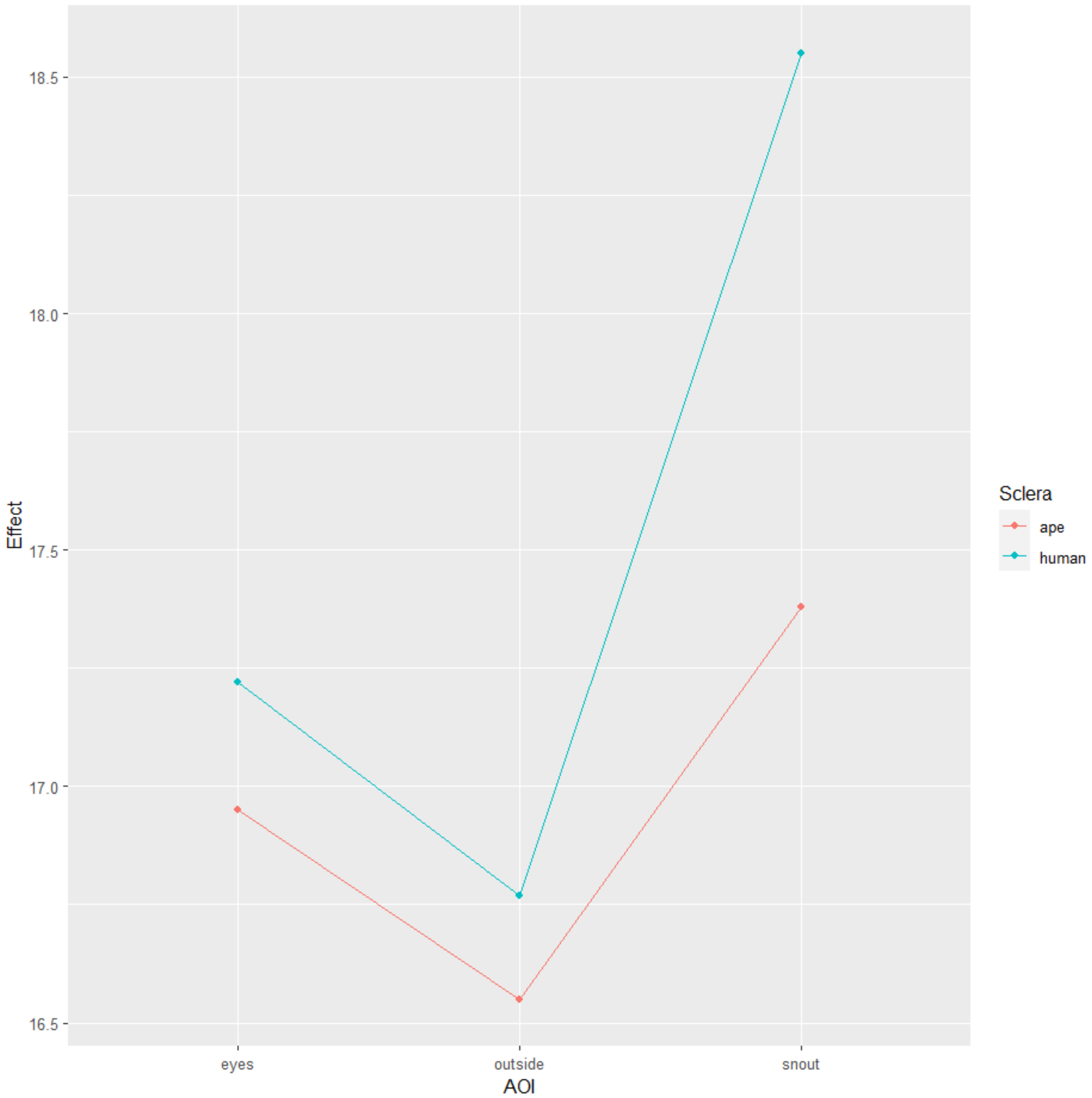
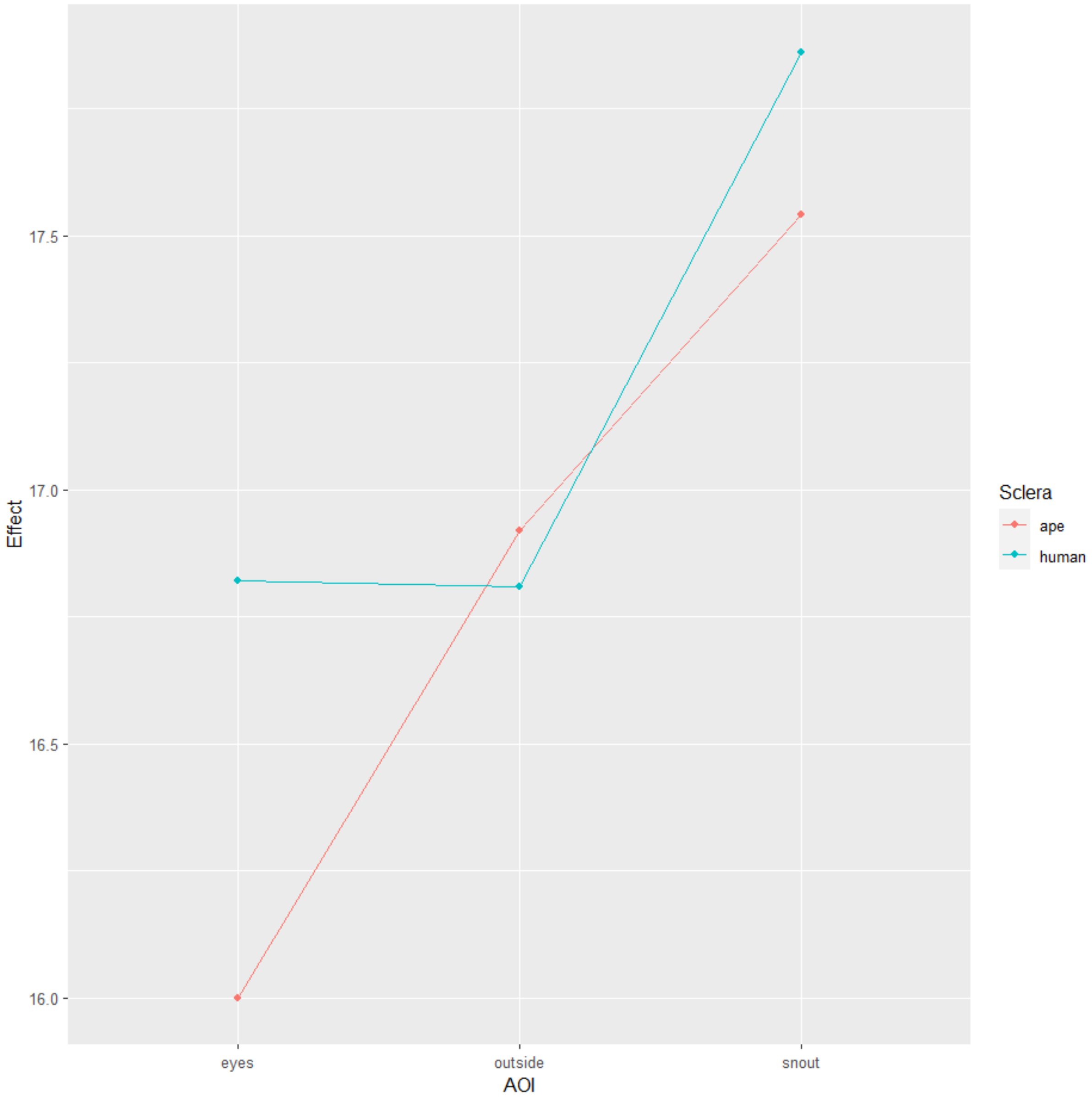


Figure 5

Dwell Time per AOI in Faces with Ape Skulls by Sclera Type



Discussion

Types of Incongruence in the Uncanny Valley Effect

The main aim of this study was to study the impact of the eyes and their human likeness in relation to the human likeness of the overall face structure on the uncanny valley effect. Following the first hypothesis, we expected that incongruent faces, which exhibit one human and one non-human characteristic, would be rated as uncannier than congruent faces. While this hypothesis was confirmed, we found an unexpected difference between the two types of incongruence in this study. Specifically, faces with human skulls and ape sclerae were rated as uncannier than faces with ape skulls and human sclerae. This pattern, in which the general effect of incongruence was amplified for incongruent faces with human skulls, was mirrored in the findings related to restlessness in visual exploration and dwell time in different areas of the face. From this, it can be drawn that the type of incongruence meaningfully mediates the uncanny valley effect and the manner of perception of the face. In short, we found that the uncanny effect and its effect on eye tracking measures was stronger for faces with human skulls and ape eyes than vice versa.

To our knowledge, the effect of this combination of facial features has not previously been observed in the scientific literature. However, it has been used in popular entertainment media to create scary-looking creatures. For instance, in the TV series "Supernatural" (Kripke et al., 2005-2020), the eyes of people possessed by demons appear fully black. The use of this design principle in media to create scary characters supports the idea of a psychological mechanism that activates fear when faced with a human face with dark eyes. In contrast, non-human faces with human eyes are routinely used to animate friendly creatures, including for example the main characters in the animated movies "Monsters, Inc." (Docter, 2001) or "Madagascar" (Darnell, E., & McGrath, T., 2005). Based on this, it appears that the difference between types of incongruence found in this study is reflected in the entertainment industry, despite not having been assessed scientifically before.

Practical Implications of the Two Types of Incongruence

The types of incongruence have implications for practical contexts in which the uncanny valley effect may occur. For instance, they may inform the design of robots to avoid giving them an uncanny appearance. In detail, robots with human facial configurations may be especially susceptible to be uncanny, if their eyes do not match their facial configuration. Therefore, designers may need to be careful about creating robots with humanlike faces and may reduce the risk of uncanniness by using a non-human facial configuration. In this way, the current findings may help to improve interactions with robots, as previous researchers found that people are less likely to accept uncanny robots as working partners (Destephe et al., 2015) or judge their moral decisions favorably (Laakasuo et al., 2021). To summarize, the finding of two types of incongruence suggests that robot faces should be designed with non-human facial configurations to avoid the uncanny valley effect and thus, improve attitudes of humans towards the robots.

In addition, the types of incongruence may relate to people with facial trauma of the eyes. Snykers et al. (2019) report that people with a prosthetic eye can be perceived as uncanny.

This may be a result of the persons intact human face being paired with an eye which deviates from typical human eyes. Thus, they have a typical human facial configuration with, to a degree, non-human eyes, possibly leading to the same type of incongruence associated with greater uncanniness in this study. In this case, avoiding the uncanny valley effect may be difficult, as simply switching to a non-human facial configuration is not possible. Instead, the development and increased availability of highly realistic, humanlike prosthetics may be necessary. This may be an important step in helping people with prosthetic eyes, as the reactions of others to facial trauma present a psychological and social challenge to people with facial disfigurement (De Sousa, 2010). To conclude, the development and availability of realistic prosthetic eyes may resolve an incongruence between a typical human face and atypical eyes, helping people with eye trauma to avoid being perceived as uncanny.

Implications for the Origins of the Uncanny Valley Effect

Given the differential effect of types of incongruence, explanations for the uncanny valley effect must consider why dark sclerae on a human face cause more discomfort than white sclerae on an ape face. One explanation may be that the latter type of face may not be perceived as incongruent. In fact, some of the ape faces used in this study originally had white sclerae which were manipulated to be more ape-like. While human sclerae are generally larger than those of other animals with white sclerae (Kobayashi & Koshima, 2008), this difference may not be enough for white sclerae to be perceived as human on animal faces. Put differently, white sclerae may be a feature that is necessary for humans but not unique to them. In this case, stimuli in this study that were intended to be incongruent due to white sclerae may have been perceived as congruent, non-human primate faces. To assess whether this interpretation is in line with participants' actual experiences, future research should extend this study by collecting separate human likeness ratings for the eyes and skulls and analyzing whether ape faces with white sclerae are seen as incongruent or not. If such faces are indeed perceived as fully ape-like, this would mean that the perceptual mismatch hypothesis might suffice to explain the uncanny valley effect based on this study's findings. However, if such faces are seen as incongruent, the perceptual mismatch hypothesis is not sufficient to explain why the uncanny valley effect occurs. To summarize, the differential effect of types of incongruence may occur because one type may not actually be incongruent but additional research is needed to test this interpretation.

Regardless of whether white sclerae are considered incongruent with ape faces or not, the increased strength of the uncanny valley effect for human faces with dark sclera may also be caused by other explanations. For one, it may relate to the role of sclerae in human interaction. According to the cooperative eye hypothesis, humans have evolved large, white sclerae so the direction of their gaze would be easier to detect, which allows other humans to understand their intentions and cooperate with them more easily (Kobayashi & Koshima, 2008). Consequently, the intentions of humans without this feature would be less clear to others, which might entice others to avoid them. Moreover, Schein and Gray (2015) found that people are less likely to attribute a soul or the capacity for emotions to faces without eyes than those with eyes. Possibly, a similar effect may have occurred when participants saw faces with dark sclerae, leading participants to expect a lack of emotional experience for the incongruent faces with dark eyes. This might result in reduced trust in the faces, as emotional expression influences the perceived trustworthiness of agents. For example, Paradeda et al. (2016) observed increased trust in robots when the robots displayed facial expressions which matched the emotion that participants expected of the robot. Likewise, Tang et al. (2018) report that children are more likely to trust adults who express more positive emotion, even when they have knowledge of the adult's previous behaviour. Thus, dark sclerae on human faces may cause discomfort because the face's intentions are less transparent and because people may question its capacity for emotion. As a result, trust in the face may be reduced, which might create the observed dislike. To test this hypothesis, future research may ask participants to rate the trustworthiness, capacity for emotion, and speculate on the intentions of human faces with white or dark sclerae. In addition, these faces should display different facial expressions to consider the effect of emotional expression on the findings.

A second explanation for the higher uncanniness of human faces with dark sclerae is based on holistic processing of faces. Holistic processing describes a manner of viewing a stimulus, such as a face, as a whole, rather than attending to its individual parts (Maurer et al., 2002). Based on their literature review, Mauer et al. (2002) conclude that this manner of face processing occurs before analyzing individual facial features. Further, holistic viewing is used more when viewing human rather than other-species faces (Mega & Volz, 2017), possibly as a result of the expertise and specialized knowledge humans have developed for conspecific faces (De Haan et al., 2002; Mega & Volz, 2017). Following this, a differential order effect may occur for human and ape faces, explaining the difference in uncanniness between the two types of incongruence. Specifically, when seeing a face with a human skull, participants may have first perceived the face holistically, recognizing it as human. As a result, they may have expected the individual facial features to be human as well, leading to a perceptual mismatch when attending to the non-human eyes. In contrast, a lesser reliance on holistic processing for ape faces may have resulted in weaker expectations for specific facial features. Consequently, eyes that are incongruent with ape faces may not have violated participants' expectations as much, leading to reduced uncanniness. To evaluate this interpretation, future research may analyze the scan paths of ape and human faces with differently colored sclerae, which may confirm whether the order of processing differs between human and ape facial configurations. Alternatively, researchers may ask participants to match different types of eyes to ape or human faces without eyes to test which expectations participants hold for the eyes based on facial configurations. In brief, early holistic processing for human, but not ape skulls, may have led participant to expect human sclerae, leading to a stronger uncanny valley response for incongruent faces with human rather than ape skulls.

Relation between Uncanniness and Eye Movements

We predicted that participants would display more restless visual exploration behavior when perceiving incongruent faces than congruent faces. Against expectations, the present findings indicate that incongruent faces are associated with lower restlessness in visual exploration, as both the number of fixations and the total distance travelled was reduced in these faces. Again, this effect was greater for incongruent faces with human skulls rather than human sclerae, supporting the notion to one type of incongruence. An explanation for these findings is that these faces have a human facial configuration, as only the color of the eyes was manipulated, while the proportions and shapes of all features remained the same. When perceiving human faces, humans tend to employ an intuitive face processing strategy, which is associated with fewer, longer fixations (Mega & Volz, 2017), matching the lower numbers of fixations and total distance travelled found in this study. Alternatively, uncanniness itself could be related to lower restlessness in visual exploration. In short, it is unclear whether the reduction of visual exploration behavior is related to the human facial configuration or the uncanniness of the stimuli.

Finally, we expected that participants would spend more time fixating on the nasal and central areas when seeing incongruent faces than when seeing congruent faces. This hypothesis was not confirmed, as participants generally spent less time on the snout and outside in incongruent faces than congruent faces, with this effect being bigger for incongruent faces with human skulls. Interestingly, participants also spent less time fixating on the eyes of incongruent faces, suggesting that they may have simply looked away from uncanny faces. This matches findings by Xu et al. (2021), who found that people spend less time looking at a fearful stimulus when they intend to avoid looking at it. Supposing the uncanny valley effect indeed evolved to avoid uncanny entities, this would explain the behaviour of the participants in this study.

Limitations

An important limitation of this study was the low accuracy of the eye tracker. Consequently, the current findings should be used to identify patterns and directions of effects, but better equipment is needed to estimate accurate effect sizes and variations. Further, only a small number of stimuli was used, which limits the ability to discern small differences between types of faces. In addition, all participants saw the stimuli in the same order. For this reason, order effects may have affected the results, such as the mere exposure effect, in which stimuli are rated more favorably when they are seen repeatedly (Yagi & Inoue, 2018).

Directions for Future Research

Future research may focus primarily on further investigating the potential origins of uncanny valley effect. Specifically, future research should extend this study by collecting separate human likeness ratings for skulls and sclerae and analyzing whether ape faces with white sclera are seen as incongruent to clarify the role of the perceptual mismatch hypothesis. To assess the role of perceived intentions, emotions, and trustworthiness, future research may ask participants to rate human faces with white or dark sclerae and different facial expressions on these variables. Third, the role of holistic processing may be clarified by future research. For this, one approach would be to analyze the scan paths of ape and human faces with differently colored sclerae, revealing whether the order of processing differs between faces with human and ape skulls. Alternatively, researchers may ask participants to match pairs of eyes to eyeless ape or human faces to investigate which expectations participants develop about eyes based on facial configurations of different species.

Conclusion

This study identified two types of incongruence with differential effects on uncanniness and eye movements. While both types were associated with increases in uncanniness and decreased restlessness in visual exploration, these effects were larger for faces with human skulls and ape eyes than vice versa. Thus, it appears that dark sclerae on human faces induce a stronger uncanny valley response. These findings may suggest that the perceptual mismatch hypothesis is insufficient to explaining the uncanny valley effect. Possibly, they may be explained by the threat avoidance theory and the effect of dark sclerae on perceived intentions, emotions, and trustworthiness of uncanny agents. However, future research is needed to verify or falsify these explanations.

References

Bagepally, B. S. (2015). Gaze pattern on spontaneous human face perception: An eye tracker study. *Journal of the Indian Academy of Applied Psychology, 41*(Special Issue 3), 127-130.

Belpaeme, T., Kennedy, J., Ramachandran, A., Scassellati, B., & Tanaka, F. (2018). Social robots for education: A review. *Science Robotics, 3*(21), Article eaat5954. https://doi.org/10.1126/scirobotics.aat5954

Chu, M.-T., Khosla, R., Khaksar, S. M. S., & Nguyen, K. (2017). Service innovation through social robot engagement to improve dementia care quality. *Assistive Technology, 29*(1), 8-18. https://doi.org/10.1080/10400435.2016.1171807

da Fonseca Grebot, I. B., Cintra, P. H. P., de Lima, E. F. F., de Castro, M. V., & de Moraes, R. (2022). Uncanny valley hypothesis and hierarchy of facial features in the human likeness continua: An eye-tracking approach. *Psychology and Neuroscience, 15*(1), 28-42. https://doi.org/10.1037/pne0000281

Dahl, C. D., Rasch, M. J., & Chen, C. C. (2014). The other-race and other-species effects in face perception - A subordinate-level analysis. *Frontiers in Psychology, 5*(SEP), Article 68. https://doi.org/10.3389/fpsyg.2014.01068

Darnell, E., & McGrath, T. (Directors). (2005) *Madagascar* [Film]. DreamWorks Animation; PDI/DreamWorks.

De Haan, M., Humphreys, K., & Johnson, M. H. (2002). Developing a brain specialized for face perception: A converging methods approach. *Developmental Psychobiology, 40*(3), 200-212. https://doi.org/10.1002/dev.10027

De Sousa, A. (2010). Psychological issues in acquired facial trauma. *Indian Journal of Plastic Surgery, 43*(2), 200-205. https://doi.org/10.4103/0970-0358.73452

Destephe, M., Brandao, M., Kishi, T., Zecca, M., Hashimoto, K., & Takanishi, A. (2015). Walking in the uncanny valley: Importance of the attractiveness on the acceptance of a robot as a working partner. *Frontiers in Psychology, 6*(FEB), Article 204. https://doi.org/10.3389/fpsyg.2015.00204

Di Giorgio, E., Méary, D., Pascalis, O., & Simion, F. (2013). The face perception system becomes species-specific at 3 months: An eye-tracking study. *International Journal of Behavioral Development, 37*(2), 95-99. https://doi.org/10.1177/0165025412465362

Docter, P. (Director). (2001). *Monsters, Inc.* [Film]. Walt Disney Pictures; Pixar Animation Studios.

Geue, L., & Schmettow, M. (2021). From robotics to primates: Tracing the uncanny valley effect to its evolutionary origin [Bachelor Thesis, University of Twente]. https://essay.utwente.nl/87564/

Haeske, A. B., & Schmettow, M. (2016). The Uncanny Valley: Involvement of fast and slow evaluation systems. [Bachelor thesis, University of Twente]. https://essay.utwente.nl/69091/

Ho, C. C., & MacDorman, K. F. (2016). Measuring the uncanny valley effect. *International Journal of Social Robotics, 9*(1), 129-139. https://doi.org/10.1007/s12369-016-0380-9

Kätsyri, J., Förger, K., Mäkäräinen, M., & Takala, T. (2015). A review of empirical evidence on different uncanny valley hypotheses: Support for perceptual mismatch as one road to the valley of eeriness. *Frontiers in Psychology, 6*(MAR), Article 390. https://doi.org/10.3389/fpsyg.2015.00390

Kim, M. G., Park, M., Kim, J., Kwon, Y. S., Sohn, D. S., Yoon, H., & Seo, K. H. (2021). On the common and different expectations on robot service in restaurant between customers and employees. In *Companion of the 2021 ACM/IEEE International Conference on Human-Robot Interaction* (262-265). Association for Computing Machinery. https://doi.org/10.1145/3434074.3447172

Kobayashi, H., & Koshima, S. (2008). Evolution of the human eye as a device for communication. In Matsuzawa, T. (Ed.). *Primate Origins of Human Cognition and Behaviour*, 383-401. Springer, Tokyo. https://doi.org/10.1007/978-4-431-09423-4_19

Koopman, R., & Schmettow, M. (2019). The uncanny valley as a universal experience: A replication study using multilevel modelling [Bachelor Thesis, University of Twente]. https://essay.utwente.nl/77172/

Kripke, E., Singer, R., McGinty Nichol, J., Nutter, D., Manners, K., Shiban, J., Sgriccia, P., Gamble, S., Edlund, B., Carver, J., Michaels, J., Aronauer, T., Glass, A., Dabb, A., Buckner, B., & Ross-Leming, E. (Executive producers). (2005-2020). *Supernatural* [TV Series]. Kripke Enterprises; Wonderland Sound and Vision; Warner Bros. Television.

Laakasuo, M., Palomäki, J., & Köbis, N. (2021). Moral uncanny valley: A robot's appearance moderates how its decisions are judged. *International Journal of Social Robotics, 13*(7), 1679-1688. https://doi.org/10.1007/s12369-020-00738-6

Mathur, M. B., & Reichling, D. B. (2016). Navigating a social world with robot partners: A quantitative cartography of the uncanny valley. *Cognition, 146*, 22-32. https://doi.org/10.1016/j.cognition.2015.09.008

Maurer, D., Le Grand, R., & Mondloch, C. J. (2002). The many faces of configural processing. *Trends in Cognitive Sciences, 6*(6), 255-260. https://doi.org/10.1016/S1364-6613(02)01903-4

Mega, L. F., & Volz, K. G. (2017). Intuitive face judgments rely on holistic eye movement pattern. *Frontiers in Psychology, 8*(JUN), Article 1005. https://doi.org/10.3389/fpsyg.2017.01005

Meyer-Marcotty, P., Gerdes, A. B. M., Reuther, T., Stellzig-Eisenhauer, A., & Alpers, G. W. (2010). Persons with cleft lip and palate are looked at differently. *Journal of Dental Research, 89*(4), 400-404. https://doi.org/10.1177/0022034509359488

Meyer-Marcotty, P., Gerdes, A. B. M., Stellzig-Eisenhauer, A., & Alpers, G. W. (2011). Visual face perception of adults with unilateral cleft lip and palate in comparison to controls - An eye-tracking study. *Cleft Palate-Craniofacial Journal, 48*(2), 210-216. https://doi.org/10.1597/08-244

Mori, M., MacDorman, K. F., & Kageki, N. (2012). The uncanny valley. *IEEE Robotics & Automation Magazine, 19*(2), 98-100. https://doi.org/10.1109/mra.2012.2192811

Oborn, E., Barrett, M., & Darzi, A. (2011). Robots and service innovation in health care. *Journal of Health Services Research and Policy, 16*(1), 46-50. https://doi.org/10.1258/jhsrp.2010.010001

Orquin, J. L., Ashby, N. J. S., & Clarke, A. D. F. (2016). Areas of interest as a signal detection problem in behavioral eye-tracking research. *Journal of Behavioral Decision Making, 29*(2-3), 103-115. https://doi.org/10.1002/bdm.1867

Paradeda, R. B., Hashemian, M., Rodrigues, R. A., & Paiva, A. (2016). How facial expressions and small talk may influence trust in a robot. In: Agah, A., Cabibihan, J. J., Howard, A., Salichs, M., He, H. (Eds.) *Social Robotics. ICSR 2016. Lecture Notes in Computer Science(), vol 9979*. Springer, Cham. https://doi.org/10.1007/978-3-319-47437-3_1

Priandana, K., Hardhienata, M., Choironi, M. I., Pawitra, R. G. D., Wulandari, Wahjuni, S., & Buono, A. (2018). Design of a task-oriented autonomous wheeled-robot for search and rescue. In *2018 International Conference on Advanced Computer Science and Information Systems (ICACSIS)* (259-263). https://doi.org/10.1109/ICACSIS.2018.8618160

Provine, R. R., Cabrera, M. O., & Nave-Blodgett, J. (2013). Red, yellow, and super-white sclera. *Human Nature, 24*(2), 126-136. https://doi.org/10.1007/s12110-013-9168-x

Salvucci, D. D., & Goldberg, J. H. (2000). Identifying fixations and saccades in eye-tracking protocols. In *Proceedings of the 2000 Symposium on Eye Tracking Research &*

Applications (71-78). Association for Computing Machinery. https://doi.org/10.1145/355017.355028

Schein, C., & Gray, K. (2015). The eyes are the window to the uncanny valley: Mind perception, autism and missing souls. *Interaction Studies, 16*(2), 173-179. https://doi.org/10.1075/is.16.2.02sch

Schmettow, M. (n.d.) *YET.* Github. https://github.com/schmettow/YET

Snykers, J., Motzkus, Y., Van Camp, M., Vaes, K. (2019). Empowering design solutions for orbital epitheses, avoiding the uncanny valley. In: Ahram, T., Falcão, C. (Eds.). *Advances in Usability, User Experience and Assistive Technology. AHFE 2018. Advances in Intelligent Systems and Computing, vol 794.* Springer, Cham. https://doi.org/10.1007/978-3-319-94947-5_94

Steckenfinger, S. A., & Ghazanfar, A. A. (2009). Monkey visual behavior falls into the uncanny valley. *Proceedings of the National Academy of Sciences of the United States of America, 106*(43), 18362-18366. https://doi.org/10.1073/pnas.0910063106

Tang, Y., Harris, P. L., Zou, H., & Xu, Q. (2018). The impact of emotional expressions on children’s trust judgments. *Cognition and Emotion, 33*(2), 318-331. https://doi.org/10.1080/02699931.2018.1449735

Tomasello, M., Hare, B., Lehmann, H., & Call, J. (2007). Reliance on head versus eyes in the gaze following of great apes and human infants: The cooperative eye hypothesis. *Journal of Human Evolution, 52*(3), 314-320. https://doi.org/10.1016/j.jhevol.2006.10.001

Van Leeuwen, C., Aukes, M., & Luman, M. (2002). Ambiguous figures, fixation durations, and the bus-paradox. In Wang, L., Rajapakse, J. C., Fukushima, K., Lee, S. Y., & Yao, X. (Eds.). *Proceedings of the 9th International Conference on Neural Information Processing (ICONIP’OZ), Vol. 3* (1164-1168). https://doi.org/10.1109/ICONIP.2002.1202804

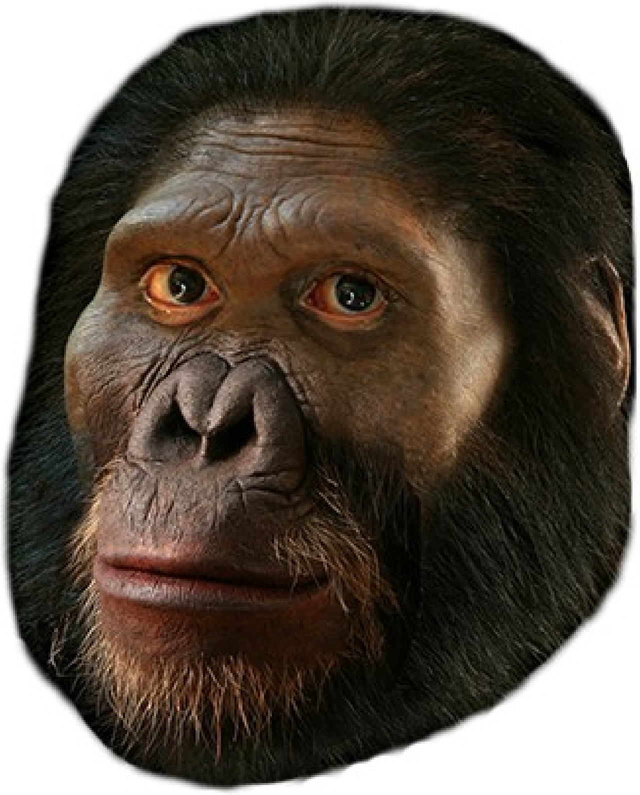
Xu, M., Rowe, K., & Purdon, C. (2021). To approach or to avoid: The role of ambivalent motivation in attentional biases to threat and spider fear. *Cognitive Therapy and Research, 45*, 767-782. https://doi.org/10.1007/s10608-020-10193-2

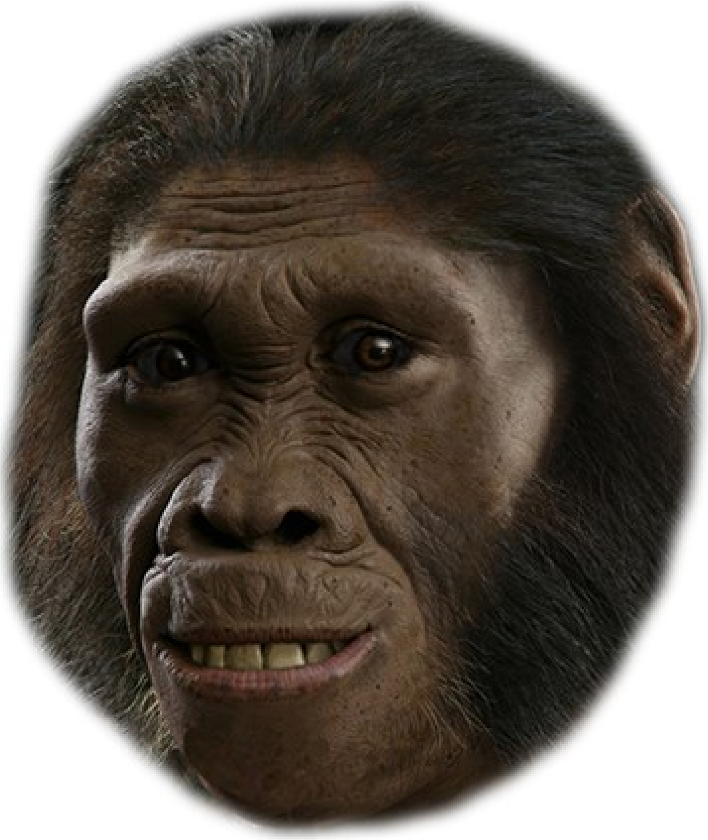
Yagi, Y., & Inoue, K. (2018). The contribution of attention to the mere exposure effect for parts of advertising images. *Frontiers in Psychology, 9*(SEP), Article 1635. https://doi.org/10.3389/fpsyg.2018.01635

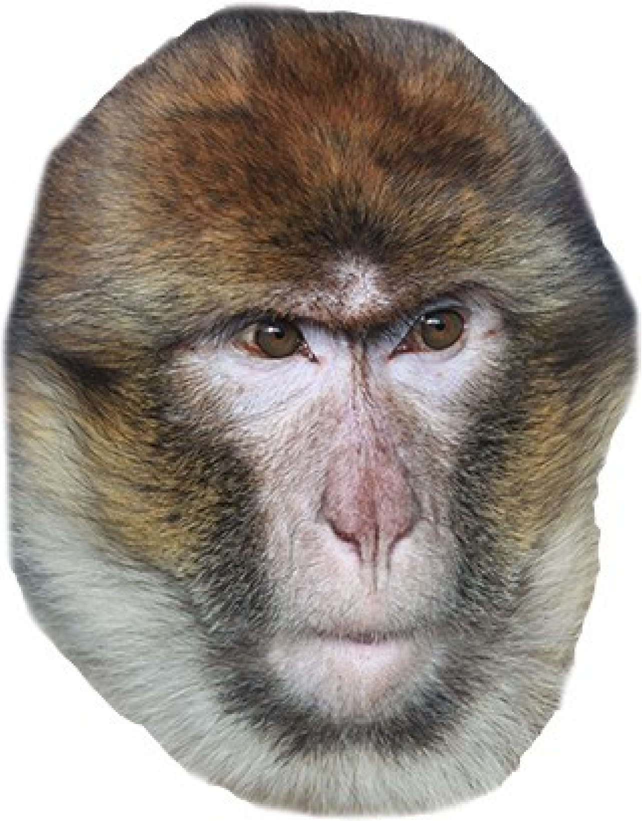
Appendix A
Final Set of Images in Order of Presentation

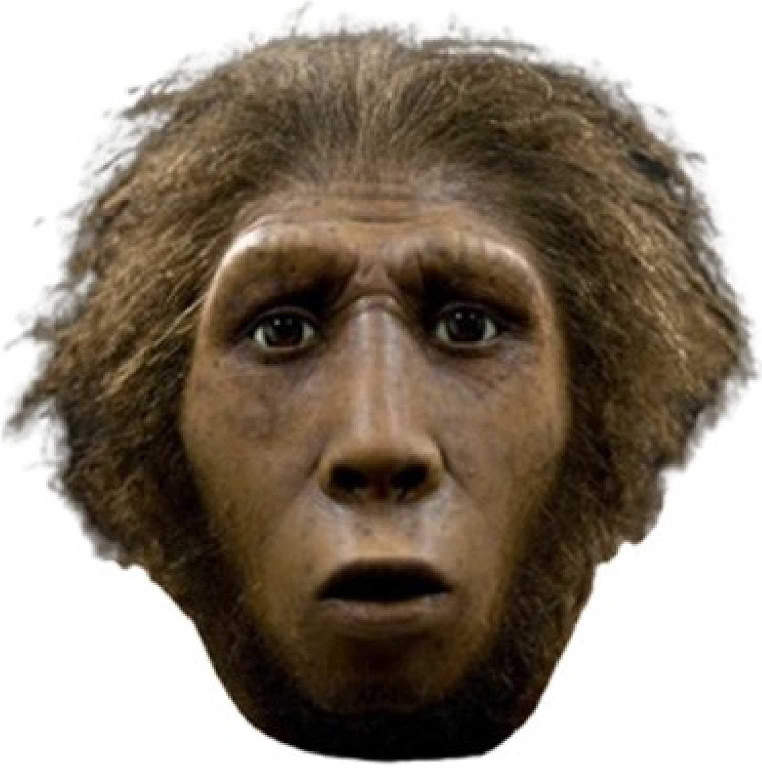
Dummy Pictures

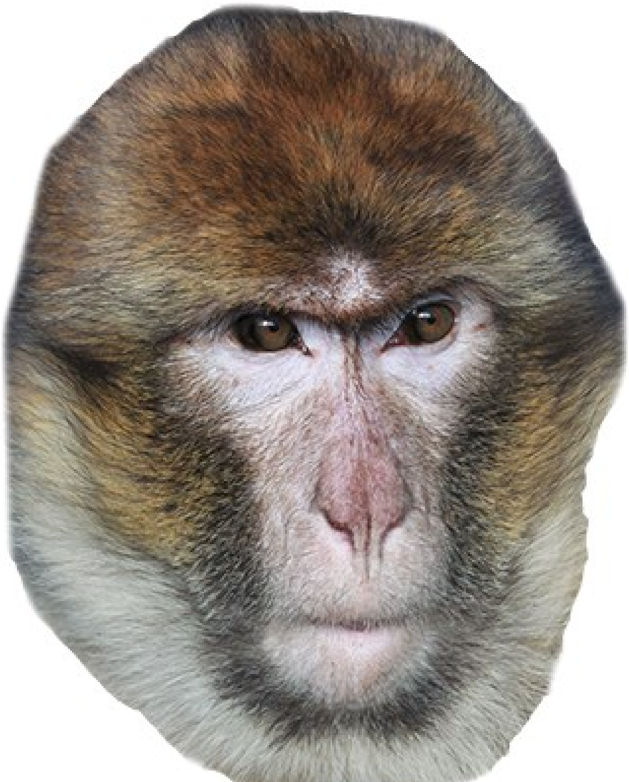
Face Stimuli

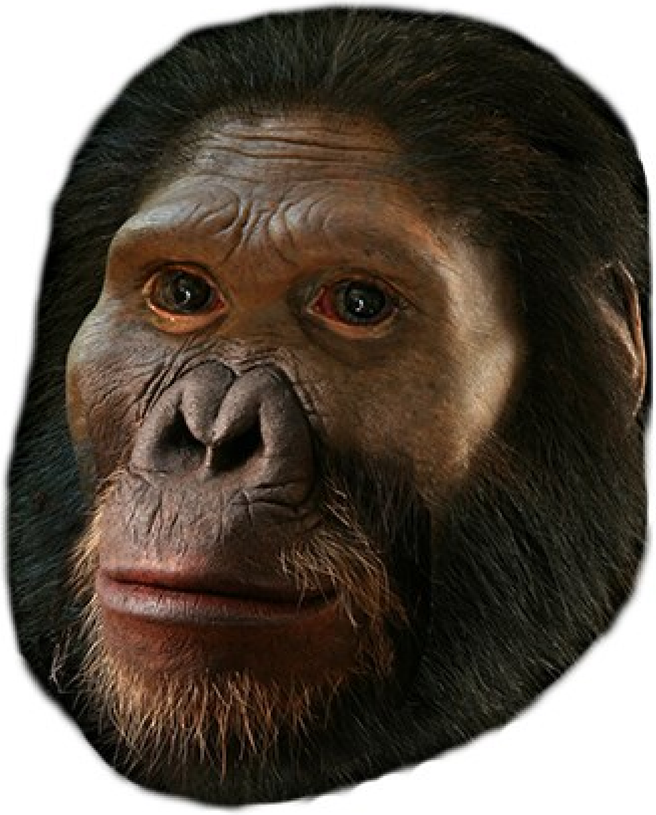


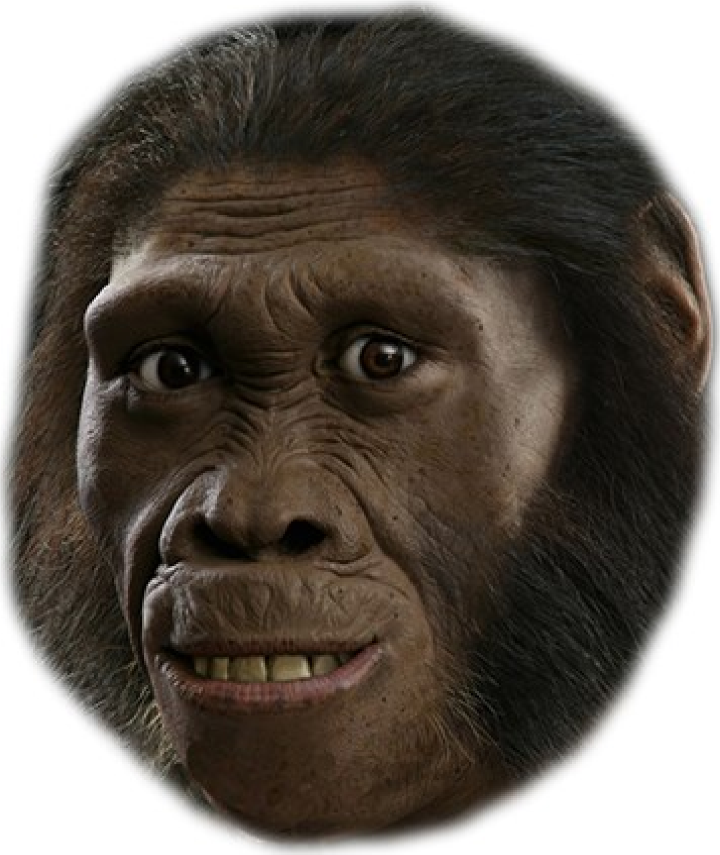


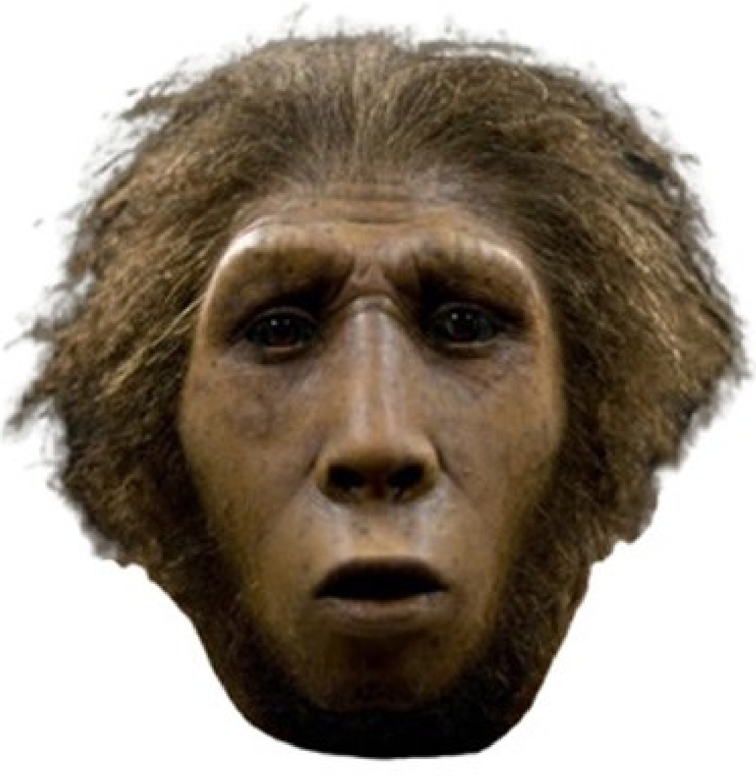












Appendix B

Study Information Sheet

Information Sheet

The Significance of Sclera Colour in the Uncanny Valley Effect: An Eye Tracking Study

Purpose

The Uncanny Valley Effect describes a drop in how likable a face (or character) is at a moderate-to-high human likeness. Therefore, people may feel slight discomfort or eeriness in response to faces (or characters) that have some human features mixed in with some non-human features. This study seeks to examine the significance of the eyes and general differences in visual exploration patterns in the Uncanny Valley Effect. For this, you will be asked to rate how uncanny you find faces presented to you while your eyes will be video-recorded to gather eye-tracking data. The study will take approximately 15 minutes to complete.

This study has been approved by the BMS Ethics Committee.

Risks

In response to looking at uncanny faces, you may feel a slight discomfort which is why we have limited exposure to a minimum.

Right to Withdrawal

You have the right to withdraw from this study at any given time without any particular reason.

Anonymisation of data

Any of your personal information will be immediately anonymized for further data analysis purposes. Any of your personal information (e.g., your name) will be handled confidentially by the three researchers of this study (see at the bottom of this sheet).

Data Usage

We will video record your eyes which will be translated into eye-tracking data in the form of coordinates. These will be used to analyse how much distance your eyes travel in total, how often you look from one facial feature to another, and on which facial features you focus the most. This is so that we can investigate whether you visually explore faces differently depending on how uncanny they are to you. The degree of uncanniness will be determined based on your rating scale data.

Any video footage will be immediately destroyed after you complete, or withdraw from, this study. The anonymised data will be shared between the three researchers (see at the bottom of this sheet) and their supervisors. In accordance with APA (American Psychological Association) guidelines, this data will be stored for five years, upon which it will be destroyed. The anonymised data will be used as part of a Bachelor thesis research report, which will be published in the University of Twente's online repository.

For further information (e.g., on study results), please contact:

Jamy L. M. Borninkhof: j.l.m.borninkhof@student.utwente.nl

Marc G. van Dijk: m.g.vandijk@student.utwente.nl

Isa Dollée: i.dollee@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant: If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee/domain Humanities & Social Sciences of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee hss@utwente.nl

UNIVERSITY OF TWENTE.

Appendix C

Informed Consent Form

Informed Consent Form

The Significance of Sclera Colour in the Uncanny Valley Effect: An Eye-Tracking Study

Please tick the appropriate boxes	**Yes**
Taking part in the study	
I have read and understood the study information, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○
I understand that taking part in the study involves the recording of my eyes in video-only form and, therefore, the recording of my eye-tracking data. The only data that will be kept is eye-tracking data, which encompasses coordinates indicating how my eyes move and focus on the pictures presented to me. Any video footage will be immediately destroyed. Further, this study involves the ratings I fill in on the rating scales provided to me in print form.	○
Risks associated with participating in the study	
I understand that taking part in the study involves the following risks: Slight discomfort in response to presentation of uncanny faces.	○
Use of the information in the study	
I understand that the anonymous information I provide will be used for the three researchers' Bachelor theses research reports, which may be published on the University of Twente's online repository.	○
I understand that personal information collected about me that can identify me, such as [e.g., my name or where I live], will not be shared beyond the study team.	○
Consent to be video recorded	
I agree be video recorded.	○

UNIVERSITY OF TWENTE.

Signatures

______________________ ______________________ ________

Name of participant

Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_________________________ ___________________ ________

Researcher name Signature Date

For further information, contact:

Jamy L. M. Borninkhof: j.l.m.borninkhof@student.utwente.nl

Marc G. van Dijk: m.g.vandijk@student.utwente.nl

Isa Dollée: i.dollee@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant:

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee/domain Humanities & Social Sciences of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee-hss@utwente.nl

UNIVERSITY OF TWENTE.

Appendix D

Rating Sheet for One-Item Likeability Scale (Mathur & Reichling, 2016)

Picture 1

-100 100

"unfriendly,unpleasant,creepy" "friendly,pleasant,not creepy"

Picture 2

-100 100

"unfriendly,unpleasant,creepy" "friendly,pleasant,not creepy"

Picture 3

-100 100

"unfriendly,unpleasant,creepy" "friendly,pleasant,not creepy"

Picture 4

-100 100

"unfriendly,unpleasant,creepy" "friendly,pleasant,not creepy"

Picture 5

-100	100
“unfriendly,unpleasant,creepy”	“friendly,pleasant,not creepy”

Picture 6

-100	100
“unfriendly,unpleasant,creepy”	“friendly,pleasant,not creepy”

Picture 7

-100	100
“unfriendly,unpleasant,creepy”	“friendly,pleasant,not creepy”

Picture 8

-100	100
“unfriendly,unpleasant,creepy”	“friendly,pleasant,not creepy”

Picture 9

-100	100
“unfriendly,unpleasant,creepy”	“friendly,pleasant,not creepy”

Picture 10

-100 100

“unfriendly,unpleasant,creepy” “friendly,pleasant,not creepy”

Picture 11

-100 100

“unfriendly,unpleasant,creepy” “friendly,pleasant,not creepy”

Picture 12

-100 100

“unfriendly,unpleasant,creepy” “friendly,pleasant,not creepy”

Picture 13

-100 100

“unfriendly,unpleasant,creepy” “friendly,pleasant,not creepy”

Picture 14

-100 100

“unfriendly,unpleasant,creepy” “friendly,pleasant,not creepy”

Picture 15

-100 100

“unfriendly,unpleasant,creepy” “friendly,pleasant,not creepy”

Picture 16

-100 100

“unfriendly,unpleasant,creepy” “friendly,pleasant,not creepy”

Picture 17

-100 100

“unfriendly,unpleasant,creepy” “friendly,pleasant,not creepy”

Picture 18

-100 100

“unfriendly,unpleasant,creepy” “friendly,pleasant,not creepy”

Appendix E
R Script for Data Analysis

````
---
title: "YET with R basic workflow"
author: "M Schmettow"
date: "09/05/2022"
output: html_document
---

```{r setup, include=FALSE}
knitr::opts_chunk$set(echo = TRUE)
knitr::opts_chunk$set(fig.width = 8)
knitr::opts_chunk$set(fig.height = 8)
data_path = "CSV"
```

```{r}
library(tidyverse)
library(printr)

require(readxl)
require(jpeg)
require(ggimg)
```

# Preparation

```{r}
WIDTH = 450
HEIGHT = 450
IMG_DIR = "Images/"
```
````

````
## Reading csv

```{r}
csv_files <- dir(path = data_path,
                 pattern = "*.csv",
                 recursive = T,
                 full.names = T)

UV22_0 <-
  csv_files %>%
  map_df(~read_csv(.x,
                   col_types = cols(Part = col_double(), # <-- we change this later
#                                   Obs = col_double(),
                                    time = col_double(),
                                    x = col_double(),
                                    y = col_double(),
                                    Picture = col_character()
                   )) %>%
           mutate(File = .x)) %>%
  mutate(is_duplicate = lag(x) == x & lag(y) == y) %>% ## Yeta1 seems to duplicate measures. This is a bugfix
  filter(!is_duplicate) %>%
  filter(!str_detect(Picture, "dummy")) %>%
  mutate(Obs  = row_number()) %>%
  mutate(Part = as.factor(as.integer(Part - min(Part)) + 1)) %>% ## reducing the Part identifier
  group_by(Part) %>%
  mutate(time = time - min(time)) %>% # time since start experiment
  ungroup() %>%
  mutate(y = HEIGHT - y, ### reversing the y-axis
         manipulated = stringr::str_detect(Picture, "manipulated"),
         Face = stringr::str_extract(Picture, "[0-9]+"),
         humlike = as.numeric(Face)) %>%
  select(Obs, Part, Picture, Face, humlike, manipulated, time, x, y)
````
````

````
sample_n(UV22_0, 10)

summary(UV22_0, 10)
```



## Reading PictureInfo and AOI

```{r}
Pinfo <-
  read_csv(str_c(IMG_DIR, "PictureInfo.csv"),
           col_types = cols(File = col_character(),
                            width = col_double(),
                            height = col_double(),
                            humLike = col_double(),
                            humskull = col_logical(),
                            whitesclera = col_logical(),
                            congruency = col_double()
           )) %>%
  rename(Picture = File) %>%
  mutate(Skull = if_else( humskull, "human", "ape"),
         Sclera = if_else( whitesclera, "human", "ape"),
         congruent = (Sclera == Skull))

UV22_1 <- left_join(UV22_0, Pinfo,
                    by = "Picture") %>%
  select(Obs, Part, Picture, Face, humlike, Sclera, Skull, congruent, time, x, y)
```


```{r}
AOI <-
  readxl::read_xlsx("AOI.xlsx") %>%
  #right_join(Pinfo, by = "Picture") %>%
  mutate(Face = str_extract(Picture, "[0-9]+"),
````

````
        Path = str_c(IMG_DIR, Picture, sep = ""),
        #Image = map(Path, ~jpeg::readJPEG(.x)),
        xmin = x,
        xmax = x + w,
        ymax = HEIGHT - y, ## reversing the y coordinates
        ymin = HEIGHT - (y + h)) %>%
  arrange(Face, AOI) %>%
  select(Face, AOI, xmin, xmax, ymin, ymax, Path)

head(AOI)
```


## Data preparation

- measuring distance and duration
- vertical mirroring off coordinates
- extracting variables from file names
- shortening some variables

```{r}
UV22_2 <-
  UV22_1 %>%
  mutate(Sequence = as.factor(str_c(Part, Picture, sep = "_"))) %>%
  group_by(Sequence) %>%
  mutate(distance = sqrt((x - lag(x))^2 + ## Euclidian distance
                         (y - lag(y))^2),
        duration = lead(time) - time) %>% ## duration
  ungroup() %>%
  select(Obs, Part, Picture, Face, Sequence, humlike, Sclera, Skull, congruent, time, x, y, distance, duration) %>%
  filter(Face != "dummy")

sample_n(UV22_2, 10)
````

summary(UV22_2)
```

# Visualization

## Grid of pictures

We create a re-usable ggplot object G_0 containing a grid of pictures

```{r, fig.height = 8, fig.width = 8}
G_0 <-
  AOI %>%
  ggplot(aes(xmin = xmin, xmax = xmax, ymin = ymin, ymax = ymax)) +
  facet_wrap(~Face) +
  ggimg::geom_rect_img(aes(img = Path, xmin = 0, xmax = WIDTH, ymin = 0, ymax = HEIGHT)) +
  xlim(0, WIDTH) +
  ylim(0, HEIGHT)

G_0
```

Raw measures visualization

```{r}
G_0 +
  geom_point(aes(x = x, y = y, col = Part),
             size = .5,
             alpha = .5,
             inherit.aes  = F,
             data = UV22_2)
```

AOI visualization
```

````
```{r fig.height = 8, fig.width = 8}
G_1 <-
  G_0 +
  geom_rect(aes(xmin = xmin, ymin = ymin,
                xmax = xmax, ymax = ymax,
                fill = AOI),
            alpha = .2,
            inherit.aes  = F)

G_1
```

## AOI Classification

```{r}
UV22_3 <-
  UV22_2 %>%
  left_join(AOI, by = "Face") %>%
  mutate(is_in = x > xmin & x < xmax & y > ymin & y < ymax) %>%
  filter(is_in) %>%
  select(Obs, AOI) %>%
  right_join(UV22_2, by = "Obs") %>%
  mutate(AOI = if_else(is.na(AOI), "Outside", AOI)) %>%
  arrange(Part, time)

summary(UV22_3)
```

```{r}
UV22_3 %>%
  group_by(AOI) %>%
  summarize(n())
````
````

```

```{r}
G_0 +
  geom_point(aes(x = x, y = y,
                 col = AOI),
             size = .5,
             alpha = .5,
             inherit.aes  = F,
             data = UV22_3)
```

```{r}
G_0 +
  geom_count(aes(x = x, y = y,
                 col = AOI),
             alpha = .5,
             inherit.aes  = F,
             data = UV22_3)
```

Measuring visits

A *visit* is a closed sequence of eye positions in the same region. The following code uses a combined criterion for setting a new visits:

- the position falls into a different AOI
- OR: the distance traveled from the previous position exceeds a certain threshold

```{r}
distance_threshold <- 50

UV22_4 <-
  UV22_3 %>%

~~~~
  group_by(Part, Picture) %>%
  filter(AOI != lag(AOI) | distance > distance_threshold) %>% ## logical OR
  mutate(visit = row_number(),
         duration = lead(time) - time) %>%
  ungroup()

sample_n(UV22_4, 10)
```

Plotting visit paths and duration

```{r fig.width=8, fig.height = 8}
G_3 <-
  G_0 +
  geom_point(aes(x = x, y = y,
                 shape = Part,
                 size = duration), # <--
             alpha = .5,
             inherit.aes  = F,
             data = UV22_4)

G_3
```

```{r}
G_4 <-
  G_0 +
  geom_path(aes(x = x, y = y,
                col = Part),
            inherit.aes  = F,
            data = UV22_4) # <--
G_4
```
~~~~

Population-level AOI frequencies

```{r}
UV22_5 <-
  UV22_4 %>%
  group_by(AOI, congruent, Face, Part) %>%
  summarize(n_visits = n(),
            total_dur = sum(duration, na.rm = TRUE)) %>%
  ungroup()

UV22_5
```

```{r}
G_5 <-
  UV22_5 %>%
  ggplot(aes(x = AOI, y = n_visits, fill = congruent)) +
  geom_col()

G_5
```

Frequencies per participant

```{r}
UV22_6 <-
  UV22_4 %>%
  group_by(Part, Face, AOI, congruent, Sclera, Skull) %>%  # <--
  summarize(n_visits = n(),
            total_dur = sum(duration, na.rm = TRUE)) %>%
  ungroup()

sample_n(UV22_6, 10)
```

```{r}
G_6 <-
  UV22_6 %>%
  ggplot(aes(x = congruent, y = n_visits, fill = AOI)) +
  facet_wrap(~Part) +
  geom_col()

G_6
```

Durations per participant

```{r}
G_7 <-
  UV22_6 %>%
  ggplot(aes(x = AOI, y = total_dur, fill = manipulated)) +
  facet_wrap(~Part) +
  geom_col()

G_6
```

```{r}
save(AOI, UV22_1, UV22_2, UV22_3, UV22_4, UV22_5, UV22_6, file = "UV22.Rda")
```

Your analysis

Reading the ratings

```{r}
UV22_7 <-
  read_xlsx("Ratings of Uncanniness .xlsx") %>%
```

````
  pivot_longer(-Part,
              names_to = "Picture",
              values_to = "rating") %>%
  left_join(Pinfo) %>%
  select(Part, Picture, humLike, congruency, Skull, Sclera, rating)
```

```{r}
load(file = "UV22.Rda")
```

```{r}
library(rstanarm)
options(mc.cores = 4)
library(bayr)
```

Preparing data sets
Filtering out incorrectly manipulated picture
```{r}
sample_n(UV22_4, 3)

UV22_4 <- UV22_4 %>%
  filter(Face != "27")

UV22_4$pos_curve <- cut(UV22_4$humlike,
                     breaks=c(0, 50, 80, 100),
                     labels=c('shoulder', 'valley', 'upwards slope'))

sample_n(UV22_4, 3)
```

```{r}
UV22_5 <- UV22_5 %>%
````

```
  filter(Face != "27")
sample_n(UV22_5, 10)

UV22_6 <- UV22_6 %>%
  filter(Face != "27")
sample_n(UV22_6, 10)
```
Computing outcome variables
```{r}
UV22_8 <-
  UV22_4 %>%
  filter(congruent != "NA") %>%
  group_by(Part, Picture, Face, AOI, congruent, Skull, Sclera, pos_curve) %>%
  summarize(n_visits = n(),
            total_dur = sum(duration, na.rm = TRUE),
            total_dist = sum(distance, na.rm = TRUE)) %>%
  ungroup()

sample_n(UV22_8, 6)
```
Exploration

H1: Ratings
```{r}
sample_n(UV22_7, 3) #for reference
```
transforming the ratings to between 0 and 1
```{r}
UV22_7 <- mutate(UV22_7, rating_trans = rating + 101)
```

```{r}
UV22_7 <- mutate(UV22_7, rating_final = rating_trans / 202)
```

```{r}
sample_n(UV22_7, 5) #for checking the transformation
UV22_7 %>% summary(rating_final) #for checking the transformation
```

by congruence, population level

```{r}
M_rating1 <- stan_glm(rating_final ~ 1 + congruency,
                      data = UV22_7,
                      family=mgcv::betar(link = "logit"))
```

```{r}
fixef(M_rating1)
```

by sclera and skull, population level

```{r}
M_rating2 <- stan_glm(rating_final ~ 1 + Sclera*Skull,
                      data = UV22_7,
                      family=mgcv::betar(link = "logit"))
```

```{r}
fixef(M_rating2)
```

graph by congruence

```{r}
G_rating <-
  UV22_7 %>%
  ggplot(aes(x = congruency, y = rating_final)) +
  geom_col()
```

G_rating
```

by congruence, multi-level
```{r}
M_rating3 <- stan_glmer(rating_final ~ 1 + congruency + (1 + congruency | Part),
            data = UV22_7,
            family=mgcv::betar(link = "logit"))
```

```{r}
fixef(M_rating3) #fixed effects
grpef(M_rating3) #random effects
```

by sclera and skull, multi level
```{r}
M_rating4 <- stan_glmer(rating_final ~ 1 + Sclera * Skull + (1 + Sclera * Skull | Part),
            data = UV22_7,
            family=mgcv::betar(link = "logit"))
```

```{r}
fixef(M_rating4) #fixed effects
grpef(M_rating4) #random effects
```

H2: N_visits

by congruence, population level
```{r}
M_3 <- stan_glm(n_visits ~ 1 + congruent,
            data = UV22_5,

````
              family = neg_binomial_2())
```


```{r}
fixef(M_3, mean.func = exp)
```


by sclera and skull, population level
```{r}
M_4 <- stan_glm(n_visits ~ 1 + Sclera * Skull,
              data = UV22_6,
              family = neg_binomial_2())
```


```{r}
fixef(M_4, mean.func = exp)
```


could be used for graph by sclera and skull
```{r}
M_5 <- stan_glm(n_visits ~ 0 + Sclera : Skull,
              data = UV22_6,
              family = neg_binomial_2())
```


```{r}
fixef(M_5, mean.func = exp)
```


graph by congruence
```{r}
G_visits <-
  UV22_5 %>%
  ggplot(aes(x = congruent, y = n_visits)) +
````

~~~~
  geom_col()

G_visits
```


#### by congruence, multi-level
```{r}
M_visits1 <- stan_glmer(n_visits ~ 1 + congruent + (1 + congruent | Part), #(1 + congruent | Part) ist der random effect - die 1 macht den random intercept, das "congruent" macht den random slope
            data = UV22_5,
            family = neg_binomial_2())
```


```{r}
fixef(M_visits1, mean.func = exp) #fixed effects
grpef(M_visits1, mean.func = exp) #random effects
```


#### by sclera and skull, multi level
```{r}
M_visits2 <- stan_glmer(n_visits ~ 1 + Sclera * Skull + (1 + Sclera * Skull | Part),
            data = UV22_6,
            family = neg_binomial_2())
```


```{r}
fixef(M_visits2, mean.func = exp) #fixed effects
grpef(M_visits2, mean.func = exp) #random effects
```


### H2: Total distance travelled
#### by congruence, population level
```{r}
~~~~

````
M_dist1 <- stan_glm(total_dist ~ 1 + congruent,
              data = UV22_8,
              family = Gamma())
```

```{r}
fixef(M_dist1, mean.func = exp)
```



#### by sclera and skull, population level
```{r}
M_dist2 <- stan_glm(total_dist ~ 1 + Sclera * Skull,
              data = UV22_8,
              family = Gamma())
```

```{r}
fixef(M_dist2, mean.func = exp)
```

#### graph by congruence
```{r}
G_dist <-
  UV22_8 %>%
  ggplot(aes(x = congruent, y = total_dist)) +
  geom_col()

G_dist
```

####by sclera and skull, multi level
```{r}
MLM_dist2 <- stan_glmer(total_dist ~ 1 + Sclera * Skull + (1 + Sclera * Skull | Part),
````

````
data = UV22_8,
family = gaussian)
```

```{r}
fixef(MLM_dist2) #fixed effects
grpef(MLM_dist2) #random effects
```

### H3: AOI

```{r}
UV22_4 %>%
  group_by(AOI, congruent) %>%
  summarize(mean_dur = mean(duration, na.rm = TRUE),
            sd_dur = sd(duration, na.rm = TRUE))
```

#### by congruence, population level
```{r}
M_1 <-
  UV22_4 %>%
  stan_glm(duration ~ 1 + AOI + congruent + AOI:congruent, # AOI*congruence
           data = .,
           family = Gamma())

```

```{r}
fixef(M_1)
```

#### by congruence, population level, for graph
```{r}
````

````
M_2 <-
  UV22_4 %>%
  stan_glm(duration ~ 0 + AOI:congruent,
           data = .)

```

```{r}
fixef(M_2)
```

```{r}
T_2 <-
  fixef(M_2) %>%
  mutate(fixef = str_remove_all(fixef, "AOI|congruent")) %>%
  separate(fixef, into = c("AOI", "congruence")) %>%
  select(AOI, congruence, center, lower, upper)

T_2
```

```{r}
T_2 %>%
  ggplot(aes(x = AOI, col = congruence,
             y = center, ymin = lower, ymax = upper)) +
  geom_point() +
  geom_line(aes(group = congruence))
```

#### by sclera and skull, population level
```{r}
M_AOI_1 <- UV22_4 %>%
  stan_glm(duration ~ 1 + AOI + Sclera + Skull + AOI:Sclera + AOI:Skull + Sclera:Skull,
           data = .,
````

~~~~
    family = Gamma())
```

```{r}
fixef(M_AOI_1, mean.func = exp)
```

#### by congruence, multi-level
```{r}
MLM_AOI1 <- stan_glmer(duration ~ 1 + AOI + congruent + AOI:congruent (1 + AOI +
congruent + AOI:congruent | Part),
data = UV22_4,
family = Gamma())
```

```{r}
fixef(MLM_AOI1, mean.func = exp) #fixed effects
grpef(MLM_AOI1, mean.func = exp) #random effects
```

#### by sclera and skull, multi level
```{r}
MLM_AOI2 <- stan_glmer(duration ~ 1 + AOI + Sclera + Skull + AOI:Sclera + AOI:Skull +
Sclera :Skull + (1 + AOI + Sclera + Skull + AOI:Sclera + AOI:Skull + Sclera:Skull | Part),
data = UV22_4,
family = Gamma())
```

```{r}
fixef(MLM_AOI2, mean.func = exp) #fixed effects
grpef(MLM_AOI2, mean.func = exp) #random effects
```

####Graph
~~~~

````
```{r}
AOI <- c("eyes", "eyes", "eyes", "eyes",
         "outside", "outside", "outside", "outside",
         "snout", "snout", "snout", "snout")
Sclera <- c("ape", "human", "ape", "human",
            "ape", "human", "ape", "human",
            "ape", "human", "ape", "human")
Skull <- c("ape", "ape", "human", "human",
           "ape", "ape", "human", "human",
           "ape", "ape", "human", "human")
Effect <- c(16, 16.82, 16.95, 17.22,
            16.92, 16.81, 16.55, 16.77,
            17.54, 17.86, 17.38, 18.55)
T_graph <- data.frame(AOI, Sclera, Skull, Effect)

T_graph
```


```{r}
T_graph %>%
  filter(Skull == "human") %>%
  ggplot(aes(x = AOI, col = Sclera, y = Effect)) +
  geom_point() +
  geom_line(aes(group = Sclera))

T_graph %>%
  filter(Skull == "ape") %>%
  ggplot(aes(x = AOI, col = Sclera, y = Effect)) +
  geom_point() +
  geom_line(aes(group = Sclera))
```
````