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REVIEW OF THE PSYCHOLOGICAL AND NEURAL EVIDENCE CONCERNING THE UNCANNY VALLEY THEORY

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KEYWORDS

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ABSTRACT

This article reviews the psychological and neuroscientific evidence concerning the Uncanny Valley theory, originally proposed by Masahiro Mori in 1970. The theory posits that human affinity towards robots increases with their realism, but only up to a certain point, beyond which emotional responses become markedly negative. Neuroimaging studies suggest that this phenomenon stems from perceptual conflicts within the brain. Recent technological advances have made it possible to develop increasingly realistic humanoid robots and animated characters, thereby reshaping human–technology interactions. This study emphasises the significance of the human face as a central stimulus in social identification, an especially pertinent issue in light of developments in generative image-based artificial intelligence, which demands heightened accuracy in reproducing human features. How we navigate this phenomenon will shape the future of our relationship with emerging technologies.

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1. Introduction

Human interest in creating replicas of oneself dates back to ancient cultural expressions, reflecting a longstanding fascination with animating the inanimate and simulating human form and behaviour.

In the modern era, cosmopolitan societies are increasingly exposed to images of avatars and artificial entities designed to mimic humans. These digitally generated, and now, increasingly, AI-generated images are beginning to replace photographs, videos, and even real people, owing to the greater flexibility and control they afford senders over the stimuli they intend to convey (de Borst & de Gelder, 2015).

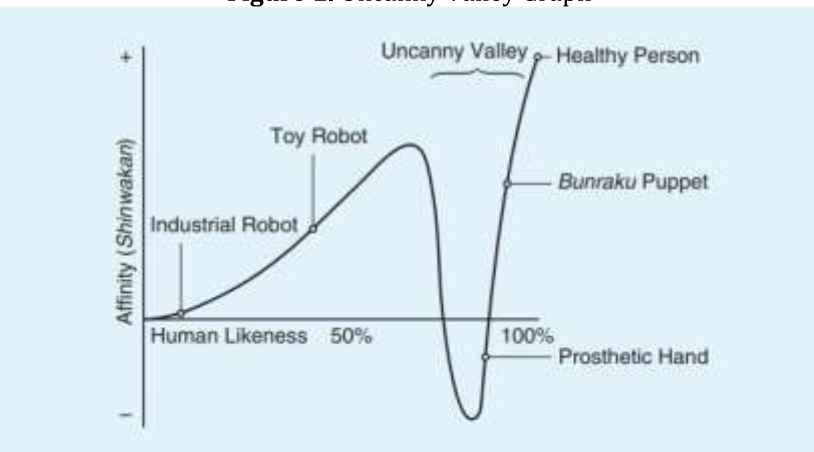
The prospective use of these technologies to supplant communication between real humans promises profound transformations across multiple sectors, starting with the design of virtual characters to enhance interactions between users and computers. Likewise, applications in affective computing, healthcare, and market research are undergoing revolutionary change (Khare et al., 2024), and our relationships with technology, both personal and professional, are being fundamentally redefined (Chen et al., 2024).

In this study, we analyse how stimuli elicited by the faces of artificial characters can be perceived as either pleasant or unpleasant, depending on their degree of realism and associated conditioning factors. This duality underpins the phenomenon known as the Uncanny Valley (VI), whereby emotional responses to artificial entities may change dramatically as their resemblance to humans increases.

The theory was proposed by Masahiro Mori in 1970, a Japanese engineer and professor who introduced the idea that human emotional affinity towards robots grows in line with their aesthetic human realism, up to a critical point near indistinguishability, at which the emotional response suddenly becomes markedly negative. This phenomenon, represented visually as a valley in a graph of emotional response, suggests that minor imperfections in an almost human appearance can provoke feelings of strangeness or even repulsion (Vaitonytė et al., 2023).

Mori used a graph to illustrate his hypothesis (Figure 1). The abscissa of the graph represents the degree of realism in the human appearance of objects. For example, androids indistinguishable from natural humans would be plotted at the far right of the abscissa axis. The ordinate represents the impressions that human observers have of these human-like objects. Positive values on the ordinate correspond to comfortable (or pleasant) impressions, while negative values indicate uncomfortable (or unpleasant) impressions (Mori et al., 2012).

Figure 1. Uncanny Valley Graph



Mori, M. (1970). Bukimi no tani [The Uncanny Valley]. Energy, 7, 33.

Mori never empirically proved this theory; however, his approach has been highly influential. Although Mori initially focused on robots and mechanical devices, the hypothesis is sufficiently broad to encompass other domains, such as digitally generated realistic-style images. Particularly over the past two decades, rapid advances in computer animation technologies have occurred. Unsurprisingly, the Uncanny Valley hypothesis has been employed to explain the limited commercial success of certain animated films (Geller, 2008) and video games (Parra Pennefather, 2023), attributed to the human yet subtly unsettling appearance of their characters.

Since its initial proposal, the Uncanny Valley theory has been explored across various disciplines. More recent research has utilised advanced techniques, including neuroimaging, to examine the neural underpinnings of perceiving apparently human agents and their psychological effects (Saygin et al., 2010). One of the primary current and future goals in creating robots, images, and artificial avatars is to assist people in real-life situations. For this assistance to be effective, it is crucial that users develop positive attitudes towards these creations. One approach to achieving this is through eliciting empathy via human-like design (Sasaki et al., 2017).

Several studies have combined behavioural and neuroscientific methods to investigate these phenomena (Cheetham & Jäncke, 2013). This article aims to integrate findings from neural and psychological research, both separately and in combination, to explore the neural basis of perceiving human and artificial agents in relation to the Uncanny Valley.

2. Objectives

The main objective of this work is to enhance understanding of the perceptual processes related to the Uncanny Valley theory and human faces more broadly, in order to determine the effect of computer-generated faces on audiences. The aim is not only to deepen the theoretical comprehension of the Uncanny Valley but also, through this, to explore its practical applications in the design of technologies that interact closely with humans. Identifying the point at which human representation elicits social acceptance may prove crucial to its functional success (Saygin et al., 2012; Cheetham, 2011).

3. Rationale

The study of the biology of emotion is a relatively recent field within brain science; prior to the advent of neuroimaging techniques, emotional experiences had been examined primarily through psychological methods. Brain signals reflect the neurophysiological activity that occurs during cognitive processes and provide a robust and reliable foundation for the detailed investigation of emotional processes related to face recognition (Bagdasarian, 2020; Cha et al., 2015; Mustafa & Magnor, 2016). This appears to be the initial step towards the broad integration of new technologies aimed at human interaction in the future.

The findings of this study have significant implications for character designers, the media, social services, film, and video games. Understanding the neural mechanisms underlying the perception of realism and emotional responses can assist in designing characters that avoid the Uncanny Valley effect and instead promote a deeper, more empathetic connection with users.

4. Methodology

We conducted a search for articles addressing the Uncanny Valley in relation to visual stimulus exposure using the most common neuroimaging techniques: electroencephalography (EEG) and functional magnetic resonance imaging (fMRI). The search was performed across three databases: primarily Scopus and Web of Science, supplemented by Google Scholar to complete the theoretical framework. These databases were selected for their extensive coverage of scientific literature in neuroscience, psychology, engineering, and technology.

The keywords used were: “Uncanny Valley”, “Images”, “Image”, “EEG”, “fMRI”, “neuroscience”, “neural”, “neuro”, and “brain” combined using the following syntax: Uncanny Valley and (Images or Image) and (EEG or fMRI or Neuroscience or Neural or Neuro or Brain).

Articles published between 2005 and March 2024 identified through the keywords included 13 in Scopus and 21 in Web of Science. Inclusion criteria focused on articles investigating the Uncanny Valley using psychological and neuroimaging methods with artificial agent stimuli (such as faces, robots, and computer-generated avatars). After removing duplicates found in both databases (n = 9), an additional nine relevant studies located via Google Scholar were included. The total number of selected articles was 34.

5. Summary of Results

Table 1. Comparison of Brain Activation in Response to Real Faces and AI-Generated Faces, and Results Related to the Uncanny Valley Theory.

ARTICLE	STUDY METHOD	TYPE OF STIMULUS AND METHODOLOGY	CONDUCTUAL or NEURONAL TASK	U.V.	RELEVANT RESULTS
(Mori M. Energy, 7(4), pp.33 -35 1970)	**Theoretical**	**Contact with Robots**	**Emotional response**	✓	**Analysis of the importance of robot and prosthetic design for the future.**
(Cavanagh, 2005)	Theoretical/Psychological	Observation of works of art	Fundamental aspects of perception.	X	Perspectives for scientifically addressing human perception through art.
(Macgillivray, 2007)	Theoretical/Psychological	Dynamic audiovisual stimulus: Animations	Psychophysical perception of movement: from the abstract to the realistic	✓	Analysis of how viewers process images and how motion can affect the quality of animations.
(Seyama & Nagayama, 2009)	Psychological with eye-tracking techniques	Static visual stimulus: Images of faces	Psychological experimental analysis on eye size using an Efficient Likelihood Estimation procedure.	✓	The VI could reflect that artificial faces are processed inefficiently by perceptual mechanisms that are, however, common with the processing of real faces.
(Saygin et al., 2010)	Neuroimaging: fMRI	Dynamic visual stimuli: Videos with body movements	Neural adaptation analysis	✓	The VI phenomenon could originate in processing conflicts within the brain's action perception system.
(Mones & Friedman, 2011)	Theoretical/Psychological	Static visual stimulus: Images of faces.	Emotional response to displayed expressions.	✓	Stylised facial alterations are perceived as emotional expressions.
(Cheetham, 2011)	Behavioural/ Neuroimaging	Static visual stimulus: Pictures of faces.	Response to categorical perception	✓	Recognition of artificial faces as human acts under common mechanisms that are poorly processed.
(Ghazanfar & Shepherd, 2011)	Eye-tracking techniques in monkeys	Dynamic audio-visual stimuli: Film clips	Measurements of gaze fixation on specific areas of the screen and comparison of gaze patterns between different individuals and species.	✓	The findings suggest crucial differences in how different species process and respond to visual scenes, especially in terms of joint attention and narrative comprehension.
(Saygin et al., 2012)	Neuroimaging: fMRI	Dynamic visual stimuli: Videos with body movement	Psychophysical perception of movement: discrepancies between the agent's appearance and its movements.	✓	To analyse these discrepancies, mainly temporal, premotor frontal and ventral inferior areas of the brain are involved.

(Cheetham & Jancke, 2013)	Theoretical/Psychological	Static visual stimulus: Morphing process	Forced classification task	✓	Perception of images does not always follow a linear change along the continuum, but often shows an abrupt change near the point of categorisation.
(Wang & Quadflieg, 2014)	Neuroimaging: fMRI	Dynamic audiovisual stimulus: Real human-human and human-robot social interactions.	Rating of perceived believability, strangeness, intelligence and emotional capacity.	✓	Differential activation indicates that humans may not apply the same complexity of social inferences to robots as to other humans, which may contribute to the VI phenomenon.
(Kätsyri et al., 2015)	Theoretical/ Neuroimaging: fMRI	Dynamic audio-visual stimulus: Images of social interactions between robots and humans.	Neural response and classification survey on observed restlessness and believability.	✓	Human-robot interactions elicit feelings of greater unease compared to human-human interactions, associated with significant modulations in ventromedial prefrontal cortex activity.
(Mustafa & Magnor, 2016)	Neuroimaging: EEG	Static visual stimulus: computer-generated imagery	Identification of the displayed image to focus their attention, the results of this identification were not used in the analysis.	✓	The results indicate that it is possible to differentiate facial categories based on neural response and suggest that the perception of facial realism significantly influences early and late stages of neural processing.
(Schindler et al., 2017)	Neuroimaging: EEG	Dynamic audio-visual stimuli: Real photographs and stylised representations to simulate different styles of animated films.	Observation of presented images	✓	Differences in the location of brain activity suggest different modes of processing: more structural analysis for stylised faces and more holistic processing for realistic faces.
(Sasaki et al., 2017)	Theoretical/Psychological	Static visual stimulus: Morphing process on faces.	Rating perceived "strangeness" and confidence in categorising images.	✓	Findings indicate that novelty aversion may be an important factor in the perception of "strangeness" in VI, especially for objects that are difficult to categorise.
(Seymour et al., 2017)	Theoretical/Psychological	Static visual stimulus: Images of faces.	Participants perform a London holiday planning task with the help of the computer assistant (avatar).	✓	Interactivity can mitigate the VI effect, making avatars that initially seemed disturbing more acceptable when interacted with in real time.

(Urgen et al., 2018)	Neuroimaging: EEG and fMRI.	Static and dynamic visual stimuli	Observation of presented images	✓	The results support prediction violation theory as an underlying mechanism of VI, suggesting that the processes that govern perception of other individuals in our environment are inherently predictive.
(Reuten et al., 2018)	Neuropsychological with fMRI and eye-tracking techniques	Static visual stimulus: Images of faces.	Observation of the presented images and subjective assessment of the appearance of the faces.	✓	Responses on physiological reactions suggest that robot emotions are processed as human emotions.
(Rosenthal-Von der Pütten et al., 2019)	Neuroimaging: fMRI	Static visual stimuli: Images of faces	Rating of stimuli in terms of sympathy, familiarity and human likeness.	✓	Different brain areas respond differentially to human and artificial stimuli, influencing sympathy, human likeness and participants' decisions. The prefrontal cortex showed activity reflecting evaluations of human likability and human resemblance, suggesting its role in the VI reaction.
(J. Chen et al., 2020)	Psychological with eye-tracking and neuroimaging techniques: EEG	Static visual stimuli: Human and robotic faces with different degrees of realism and emotional expressions.	Making judgements about the emotional expression shown in the images.	✓	Robotic faces with a high degree of realism elicited greater aversive responses and activated brain areas related to error detection and potential threat assessment.
(Milena T. Bagdasarian, 2020)	Neuroimaging: EEG	Static visual stimuli: Stylised faces with different levels of realism, including different emotional expressions.	Rating of images in terms of their attractiveness, comfort level, realism and familiarity.	✓	Subjective evaluations of realism in stylised faces are closely related to measurable neural responses.
(Wilson et al., 2020)	Psychological, eye-tracking techniques.	Static visual stimulus: Images of real and virtual macaque heads.	Macaques did not perform an explicit behavioural task.	X	Results indicate that macaques showed similar visual attention to virtual images, with no evidence of the VI effect.
(Ladwig et al., 2020)	Using Artificial Intelligence for real-time face reconstruction in telepresence and live-streaming applications	Dynamic visual stimulus	Artificial Intelligence reconstructs and improves 3D transmissions of facial expressions.	✓	The proposed system improved the quality of the generated images compared to previous systems. Despite this, the presence of artefacts can still cause the sensation of VI.

(Petrova, 2021)	Theoretical/philosophical	——	——	✓	Due to expected technological advances, the outlook on the information society has changed to humanitarian pessimism.
(Ota & Nakano, 2021)	Psychological with Neuroimaging fMRI	Static visual stimulus: Facial images, both of the participants (self-portraits) and of other unknown women.	Assessment of the attractiveness of the facial images.	✓	Activity in the nucleus accumbens was positively correlated with facial attractiveness, while activity in the amygdala showed a negative correlation. Frontotemporal and midline cortical areas showed greater activation for own faces than for the faces of others, but such self-related activation was absent when faces were extremely retouched.
(Vaitonytė et al., 2023). **Scoping review**	Bibliographic review	——	——	X	——
(Sarigul & Urgen, 2023)	Psychological with fMRI Neuroimaging	Static audiovisual stimuli: Agents: Images of humans, human-like robots and mechanical-like robots, and auditory stimuli of a human voice and a synthetic robotic voice.	Rapid response task where they had to press a key in response to presented stimuli, either congruent or incongruent.	——	The results suggest that congruency between visual and auditory cues facilitates participants' perception and response, and that human visual cues are processed more quickly than non-human cues.
(Parra Pennefather, 2023)	Theoretical	Dynamic audio-visual stimuli: AI-generated images, and multimedia content from humanoid robots and ventriloquist dummies.	——	✓	The results indicate that VI is a persistent and relevant phenomenon in interaction with advanced technologies, generative art, and ventriloquist dummies.
(Igaue & Hayashi, 2023)	Psychological and artificial intelligence techniques, specifically using an artificial neural network called CLIP (Contrastive Language-Image Pre-training).	Static visual stimulus: Morphing process.	Participants did not perform behavioural tasks. Instead, the study used the CLIP neural network to assess how the manipulated images correspond to specific words and adjectives related to VI.	✓	The results showed that the strangeness index was highest at the midpoint of the morphing continuum, where visual cue conflicts were maximal. Artificial intelligence techniques provide a new perspective in understanding the VI effect.

(Yashin, 2023)	Theorist	___	___	✓	A brain-computer interface that approaches the reaction time of human motor control but with slight deficiencies in accuracy could be perceived as less effective and more disruptive to the user.
(Y. Chen et al., 2024)	Neuroimaging: EEG	Static visual stimulus: Faces with different levels of realism	Observation of the presented images	✓	Images with intermediate levels of realism are perceived as less natural and elicit less pronounced neural responses.
(Ito et al., 2024)	Theoretical/Psychological	Static visual stimuli: Real robot and human faces with varying levels of detail.	Rating of perceived humanness and disturbing sensations	✓	Images with variations in detail may be perceived as more human than intact images even though they have a lower level of realism. On the other hand, unvaried robot faces that appeared slightly human tended to evoke strong feelings of unease.
(Diel & Lewis, 2024)	Theoretical/Psychological	Static visual stimuli with distortion: Real faces, cartoon faces, computer-generated faces, and robot faces.	Rating of degree of realism	✓	Sensitivity to distortions in more realistic stimuli increases the sense of unease.

Source: Results obtained from the literature review conducted in this study, 2025.

6. Causes of the Uncanny Valley Phenomenon

This section organises the hypotheses identified in this research as contributing to the Uncanny Valley phenomenon, providing a comprehensive overview of the factors that underlie this complex emotional response associated with the realism of artificial characters, and analysing how these factors interact with one another.

6.1. The Familiarity of Faces

This is an element that plays an important role in face perception and recognition. When confronted with an unfamiliar face, a neophobia response may be triggered (Seyama & Nagayama, 2009). This fear or rejection of the new or unfamiliar may be part of the Uncanny Valley phenomenon.

6.2. Atypical Characteristics and Violation of Expectations

This hypothesis suggests that the Uncanny Valley effect could be due to a discrepancy between human and artificial features of an entity (Chen et al., 2020; Sarigul & Urgen, 2023; Urgen et al., 2018). For example, a human face that is accompanied by a robotic voice can create a sense of incongruity, causing discomfort for the observer.

6.3. Perceptual Mismatch and Categorisation Conflict

This hypothesis proposes that when observers are confronted with stimuli that straddle the boundary between human and non-human, they experience perceptual ambiguity that generates uncertainty and discomfort (Chen et al., 2020; Igaue & Hayashi, 2023 ; Kätsyri et al., 2015). The inability to clearly discern and appropriately categorise these artificial entities makes it difficult to form a coherent emotional response, which in turn leads to a rejection reaction.

6.4. Danger Avoidance

Modulation of the Uncanny Valley curve is more pronounced for expressions of anger, suggesting that threatening features capture greater attention, possibly as a result of evolutionary survival mechanisms (Schindler et al., 2017). This hypothesis further proposes that humans evolved a rejection response to individuals who appeared ill, activating a pathogen avoidance mechanism (Ghazanfar & Shepherd, 2011; Igaue & Hayashi, 2023).

6.5. Fear of Technological Advances

The perspective on the information society is evolving alongside a growing fear linked to the uncontrolled advancement of new technologies. This fear has led some members of the population to reject the increasing immersion in and dependence on technology (Petrova, 2021). Such resistance may contribute to the negative perception of artificial agents and hinder their integration across various everyday contexts.

6.7. Mental Perception

Nowadays, artificial agents can become so realistic that humans tend to attribute a mind to them (Vaitonytė et al., 2023). This implies that artificial beings are perplexing because they prompt us to perceive a mind where there may not be one (Kätsyri et al., 2015), despite the fact that, currently, computers do not exhibit genuinely intelligent behaviour, or at least not in a fully convincing manner. This attribution of mind to artificial entities can evoke complex and negative emotional expectations and reactions, thereby contributing to the phenomenon of the Uncanny Valley.

7. Analysis and Discussion of the Psychological and Neural Expression of the Uncanny Valley Theory

The human ability to recognise and interpret facial expressions is among our most sophisticated and innate perceptual skills (Mones & Friedman, 2011). This ability relies on a complex brain network that engages regions involved in planning and interpretation to perceive the actions of others (Vaitonytė et al., 2023). Specifically, brain areas implicated in face recognition include the occipital cortex (responsible for processing visual information), the fusiform gyrus (specialised in face identification), and selective regions of the anterior temporal lobe (which contribute to understanding the social and emotional context of faces) (Duchaine & Yovel, 2015).

The perception of humanity in artificial characters varies considerably according to individual interpretation (Kätsyri et al., 2015). The complex relationship between a face's realism and the emotion it conveys can influence processing from the earliest stages of visual and cognitive perception (Schindler et al., 2017). In light of a near future where one of our innovative tasks will be to engage directly with virtual entities and images generated by artificial intelligence, our adaptation to these interactions will need to be as natural as possible.

Although progress remains to be made in robotics, the use of generative artificial intelligence to produce fully realistic images is already a present-day reality.

To address these issues, it is essential to understand the phenomenon of the Uncanny Valley. Masahiro Mori, the originator of this theory, suggests that, to avoid the Uncanny Valley effect, designers should aim for the first peak of the graph (Mori et al., 2012). This involves opting for a less human-like design to maintain high familiarity, rather than risking a plunge into the Uncanny Valley by attempting a perfect imitation. However, for decades, graphics developers have pursued creating characters so human-like that they can function as actors, striving for ever more realistic recreations with varying degrees of success.

The following subsections will analyse how artificial faces are perceived along a spectrum of human likeness within the context of the Uncanny Valley. This psychological study, grounded in neuroscientific principles, is approached from a variety of research perspectives. This review will integrate the multiple approaches used in the analysed articles to provide a deeper understanding of the phenomenon.

7.1 Specialised Face Recognition

Our review reveals that EEG studies consistently show the visual perception of a face generates an early evoked potential, with a latency of approximately 170 milliseconds, known as the N170. This is a key neural marker of face recognition (Bagdasarian, 2020; Kuang et al., 2021; Mustafa & Magnor, 2016; Proverbio et al., 2019; Schindler et al., 2017).

Furthermore, a magnetoencephalography study demonstrated that artificial faces elicit brain responses equivalent to those evoked by natural faces in terms of localisation, activating the fusiform gyrus, a critical region for face recognition (Seyama & Nagayama, 2009).

7.2. Real and Artificial Faces Show Neural Similarities in the Perception Process

In an EEG study, visual stimuli included images of objects resembling faces but unrelated to actual human faces, such as a plug. The results suggest that artificial objects with face-like features are initially perceived as faces during an early stage of visual processing, rather than being first categorised as general objects and subsequently reinterpreted cognitively as faces at later stages (Seyama & Nagayama, 2009). This indicates that, in face perception, the brain prioritises analysing the essential features of a visual stimulus rather than its detailed appearance. For instance, iconic characters may be drawn using basic shapes and minimal detail, yet remain easily recognisable (Macgillivray, 2007).

In an experiment measuring pupil size variation, it was found that robot emotions are processed similarly to human emotions (Reuten et al., 2018). Pupillary dilations were comparable when participants were exposed to emotional stimuli presented by both robots and humans, indicating that, at a physiological level, responses to these stimuli are alike. These findings suggest that the human brain employs similar strategies for interpreting emotions in faces, whether natural or artificial, which is a crucial factor for effective interaction with advanced technologies such as robots and avatars.

Another study revealed that faces expressing strong emotions, such as anger, generate more intense responses for both realistic and abstract faces, further supporting the existence of a common mechanism in emotional processing across these cases (Schindler et al., 2017 ; Seyama & Nagayama, 2009).

7.3. Real and Artificial Faces are Neuronally Processed by Common Mechanisms Although with Differences in Efficiency and Adaptability

If natural and artificial faces engaged equivalent perceptual processes, concerns about the positive and negative effects associated with the degree of realism in the Uncanny Valley might be alleviated. However, the literature indicates otherwise. The reviewed studies reveal significant differences in how stimuli are perceived depending on whether they depict real or artificial faces.

Specifically, artificial faces have been shown to require a longer neural adaptation period compared to natural stimuli (Sarigul & Urgen, 2023; Seyama & Nagayama, 2009). These findings suggest that the human visual system is not optimised for processing artificial stimuli, potentially leading to inefficient perceptual processing and necessitating more time to achieve perception comparable to that of real stimuli (Seyama & Nagayama, 2009). This inefficiency may partially explain the discomfort humans experience when confronted with artificial faces and contribute to the Uncanny Valley phenomenon.

In one experiment, participants were asked to perform a classification task, categorising images as either “human” or “avatar”. This task helped identify the point on the continuum where participants experienced the greatest uncertainty in categorisation, known as the “categorisation point”. The results showed that response times were longer for stimuli positioned at or near the boundary between real and artificial categories (Cheetham & Jäncke, 2013). These response time data from forced-choice classification tasks indicate cognitive difficulty and support the hypotheses proposed in related studies.

From a different perspective, lifelike artificial faces have been found to elicit neural responses of lower intensity compared to real faces (Rosenthal-Von der Pütten et al., 2019 ; Seyama & Nagayama, 2009). Similarly, research indicates that images with intermediate levels of realism also evoke neural responses characterised by lower amplitude patterns (Chen et al., 2024). One explanation for this differential activation is that humans may not apply the same complexity of social inferences to artificial characters as they do to other humans, which may contribute to feelings of strangeness in response to artificial faces that closely resemble humans (Wang & Quadflieg, 2014).

In addition, significant neural differences associated with the familiarity of the face presented to the viewer have been identified. Studies indicate that familiar faces activate neural networks differently compared to unfamiliar faces, suggesting processing based on prior experience (Reuten et al., 2018). In the case of unfamiliar faces, a neophobia response, a defensive mechanism, has been observed, which has previously been linked to the emergence of the Uncanny Valley (Seyama & Nagayama, 2009).

Another distinction found in the literature is that the brain appears to have developed a dual system for analysing faces: a "fine-mesh system" for processing realistic faces, and a "coarse-mesh" system for interpreting artificial faces or faces viewed under challenging conditions (Mones & Friedman, 2011). The "fine-mesh" system focuses on analysing small deviations from precise facial norms, enabling the interpretation of subtle changes in facial expression. By contrast, the "coarse-mesh" system employs broader, less detailed pattern recognition, thereby simplifying the facial recognition process.

7.4. Perceptual Differences for Real and Artificial Faces According to the Location of Neural Activity in the Brain

The results can be synthesised from the following perspectives:

For stimuli based on artificial faces that possess sufficient realism to be perceived as real, increased activity has been observed in the anterior intraparietal cortex. This neural response appears to address the dissonance produced by the stimulus characteristics, with heightened activity in this region reflecting an effort to reconcile the discrepancy between perception and expectation. In contrast, to analyse mismatches between the expected and actual stimuli, primarily temporal, premotor frontal, and ventral inferior brain areas are engaged, indicating increased attentional processing (Saygin et al., 2010).

During the visualisation of human-to-human interactions, increased brain activity is observed in the left temporoparietal junction, a region associated with the attribution of specific mental states (Wang & Quadflieg, 2014). This finding aligns with another study showing a positive linear relationship between activity in this area and human similarity (Rosenthal-Von der Pütten et al., 2019). By contrast, human-robot interactions activate the precuneus and ventromedial prefrontal cortex more extensively, reflecting social reasoning based on more generalised and stereotyped behavioural patterns (Wang & Quadflieg, 2014).

Similarly, it has been observed that brain activity in the prefrontal cortex exhibits a "valley" in response to artificial face stimuli, correlating with subjective decision-making and suggesting a neural manifestation of the Uncanny Valley (Chen et al., 2020; Wang & Quadflieg, 2014).

These differences in the localisation of neural activation may significantly influence impression formation and the emotional responses of observers, thereby contributing to the emergence of the Uncanny Valley (Wang & Quadflieg, 2014).

7.5. The Relationship Between Facial Realism and Emotional Response

The literature suggests that, regardless of the level of facial realism, emotional expressions modulate both the N170 and Early Posterior Negativity (EPN) responses (Schindler et al., 2017). The EPN component is an evoked potential occurring with a latency of 200–300ms and is associated with selective attention and the processing of emotional stimuli. Notably, the degree of realism in facial representation and the emotional expressions conveyed interact within the N170 response. This indicates an early integration of structural analysis and emotional classification, rather than separate processing pathways for identity and expression. Such findings are important to consider in future research and in the design of artificial characters.

In one experiment, images of faces displaying varying levels of realism were selected, ranging from cartoonish styles to images closely resembling real photographs. Each image was manipulated to exhibit different emotional expressions, allowing assessment of how the perception of realism might be influenced by the emotional context of a face. The results indicated that faces expressing positive emotions were perceived as more realistic and attractive.

Furthermore, as previously noted, faces expressing intense or aggressive emotions such as anger elicit significantly stronger neural responses compared to those displaying more moderate emotional expressions (Schindler et al., 2017; Seyama & Nagayama, 2009). These findings indicate that the intensity of the emotional response depends not only on the realism of the face but also on the type and strength of the expressed emotion. Such observations suggest that the neural system is particularly sensitive to highly salient emotional cues, reflecting an adaptive mechanism that prioritises the detection and response to potentially threatening stimuli. Consequently, the Uncanny Valley effect may be partially influenced by the emotions conveyed in facial representations.

Approaching the Uncanny Valley phenomenon from a different perspective, one study suggests that interactivity influences perception independently of the appearance dimension and may help to overcome the Uncanny Valley effect (Seymour et al., 2017). As AI-generated images become increasingly ubiquitous, our perception of what is real and authentic may be significantly altered. This proliferation of artificial images raises questions about whether we will be able to integrate the resulting violations of expectation caused by widespread use of AI robots into everyday life (Saygin et al., 2010; Urgen et al., 2018). The ability to adapt to these new visual realities and accept artificial agents will depend on several factors, including familiarity, interaction, and consistency with existing social norms.

8. Conclusions

After analysing the results of the selected articles, we found broad empirical support for the Uncanny Valley phenomenon. Although methodologies vary, the findings collectively endorse the notion that the Uncanny Valley is a genuine and measurable effect influencing human perception of artificial faces. However, the absence of conclusive evidence suggests that the Uncanny Valley is not universally triggered by all forms of human likeness manipulations, nor by any single specific factor.

8.1. Divergence in the Perception of the Real and the Artificial

Although the brain processes real and artificial faces using similar neural mechanisms, differences in processing efficiency and the modulation of these mechanisms reveal profound distinctions. Artificial faces, particularly those near an ambiguous categorisation point, require greater cognitive effort, often eliciting an emotional response characterised by rejection. This increased cognitive demand, reflected in the need for extended neural adaptation, highlights the brain's difficulty in reconciling the familiar with the unfamiliar, the human with the inhuman. These findings suggest that the human brain continuously predicts and adjusts its perception of the environment according to deeply ingrained social and biological norms. When these predictions fail, an alert response is generated, influencing immediate perception and shaping how individuals engage with such technologies today.

The discussion arising from this review highlights the complexity of the relationship between empathy and the perception of artificial agents. Activation of brain regions associated with positive emotions is fundamental to the acceptance of these artificial agents in everyday life. However, the Uncanny Valley effect demonstrates that feelings of increased pleasantness towards lifelike artificial agents can be easily undermined by minor imperfections in their appearance or behaviour. This paradox reveals that empathy depends not only on physical resemblance but also on the congruence between appearance and behaviour.

It is concluded that the design of robots, avatars, and other technologies interacting with humans must take into account both aesthetic realism and the cognitive and emotional expectations of users.

Future research is proposed to investigate more deeply the specific neural mechanisms underlying the Uncanny Valley phenomenon, with the aim of developing more effective design strategies that minimise its impact and promote more natural and positive interactions between humans and artificial agents.

8.2. The Uncanny Valley as a Reflection of the Human Condition and its Future Applications

The Uncanny Valley is not merely a phenomenon of aesthetic rejection but rather a manifestation of how our brains have been shaped by millennia of evolution to recognise and respond to specific social stimuli. The ability to identify human faces relies not only on detecting facial features but also on the immediate and profound interpretation of intentions, emotions, and mental states. This capability is intimately connected to our survival as a social species, where reading subtle facial cues was essential for cooperation and threat detection. Understanding how the brain amplifies responses to intense emotional expressions could have significant implications for the study of emotional disorders. Consequently, the accurate design of technologies aimed at interpreting or replicating human emotions may aid future medical research by fostering more effective and empathetic interactions with humans.

It is imperative to develop the necessary tools to assist in the design of such characters.

9. Limitation

Recent advances in artificial intelligence have opened new possibilities, making it important for future studies to investigate the applications of these systems in real-world environments. To date, much research has been conducted in controlled or simulated settings, limiting our understanding of how these models perform in complex and unpredictable situations. Concurrently, developments in robotics highlight the need to progressively integrate artificial intelligence into robots operating in real scenarios. It will be essential to equip these systems with greater interactivity and autonomy to examine the emotional responses and empathy they elicit during communication with humans.

The use of subjective terms such as “pleasant” or “disturbing” may undermine scientific rigour, as such concepts are open to individual interpretation. To maintain objectivity, it is advisable to avoid ambiguous terminology, particularly in disciplines requiring precision, such as biological and neural sciences. An improvement would be to provide precise operational definitions that enable the concrete measurement of emotions, for example, by using specific neural activity markers or physiological response patterns. This approach necessitates identifying and quantifying the neurobiological correlates underpinning subjective sensations, such as activation of particular brain regions or neurotransmitter release associated with emotions.

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