Updating the Uncanny Valley: A Meta-Analysis and Examination of the Self-Reference Effect

By

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Abstract

The uncanny valley phenomenon describes discomfort from imperfectly human stimuli. I conducted a meta-analysis of 70 empirical studies to synthesize knowledge, finding a significant combined effect (d = .93) and confirming the phenomenon's polythetic nature. Five hypothesized mechanisms (e.g., categorization ambiguity) significantly impacted four dependent variables (i.e., affect, cognition, behavior, and attitudes). Additionally, moderation analysis identified influence from participants' age and sex— a first in uncanny valley review. However, hypothesized mechanisms were found underexplored. To address such, my subsequent study (N = 188) tested the doppelgänger hypothesis guided by self-reference theory, and explored a third media exposure variable to account for potential age and sex confounds— participants' science fiction and technology affinity (SF&T affinity). Contrary to expectations, self-face morphs elicited positive self-biases for self-oriented outcomes. Congruent with expectations, participants' SF&T affinity attenuated uncanny effects. Instead of the "uncanny valley" predicted by Mori (1970), a consistent growth relationship dubbed "the anthropomorphic escalator" implied reliable positive effects of stimuli's anthropomorphism. My research provides theoretical and methodological expansion of the uncanny valley phenomenon beyond Mori (1970) in intellectual contribution to the Communication field.

Keywords: meta-analysis, uncanny valley, self-reference effect, anthropomorphism, face morphs

Unveiling the Uncanny Valley:

A Meta-Analysis of Mechanisms, Moderators, and Effects

In 1970, roboticist Masahiro Mori penned the now seminal essay "The Uncanny Valley" in which he anticipated how individuals would react to increasingly humanoid robots. Here, Mori (1970) hypothesized that as humanlike robots approached a more natural appearance but fell short of perfect human-likeness, they would evoke feelings of revulsion rather than empathy. This phenomenon, characterized by a sudden negative shift in elicited emotional response, is designated the "uncanny valley". In the years since, the uncanny valley hypothesis has gained enduring popularity, manifesting in both widespread recognition within the public consciousness and through extensive examination across diverse academic disciplines, including communication, psychology, computer science, and engineering (Wang et al., 2015).

Given the advent of generative artificial intelligence (AI) enabling the creation of ever more humanlike chatbots, avatars, and androids, it has become timely and relevant for open science systematic review and empirical research to advance the study of the uncanny valley and inform improvements regarding human interaction with synthetic beings. Indeed, there exists strong social and economic imperatives that motivate this study. For example, the adoption of novel technologies that benefit society, such as healthcare robots, can be hindered by uncanny valley perceptions (Olaronke et al., 2017). Healthcare robots including Aethon's *Tug* hold the potential to fill critical gaps in care, and reduce inefficiencies in the medical system to increase accessibility and affordability (Carrus et al., 2020). Additionally, uncanny valley perceptions have been identified as a contributing factor to the stubborn persistence of negative attitudes toward service chatbots (Ciechanowski et al. 2019). Despite a 92% increase in the use of virtual human technologies as brand representatives between 2019 and 2020, nearly 40% of consumers

continue to hold non-positive sentiment toward these digital agents (Drift, 2020; Liveperson, 2021). Hence, with exposure to potentially uncanny stimuli increasingly becoming a part of daily life, it is imperative for academia to expand understanding of the mechanisms, outcomes, and moderators of the uncanny valley to advance scientific, societal, and economic progress.

I begin my Dissertation with a preregistered open science meta-analysis of the uncanny valley to survey existing literature as a foundation for groundbreaking empirical research. First, my meta-analysis will define and examine support for leading uncanny valley theories in description of the working mechanisms of the phenomenon, informed by prior systematic review. Second, my meta-analysis extends prior review by providing a focused examination of uncanny valley outcomes beyond affect to also include attitude, behavior, and cognition. In doing such, I posit that the uncanny valley has several causes and several effects. From this lens, I forward that the uncanny valley phenomenon is conceptually polythetic within empirical works: being defined by multiple characteristics and features that are united in the hypothesis that near-human entities shall generate negative response. In advancement of the systematic study of the uncanny valley and to address heterogeneity observed within prior uncanny valley review, I additionally examine the moderation effects of message channel and message target, guided by social presence theory, as well as participants' demographic variables of sex and age. To confirm the validity of my meta-analytic results I test my universe of examined literature for publication bias.

Informed by my meta-analysis, I conduct an empirical work to address timely and pertinent gaps identified in the uncanny valley literature. My empirical study provides a detailed examination of the doppelgänger hypothesis of the uncanny valley, relevant to scholarly understanding of virtual recreations of the self, guided by self-reference theory. Here, computer-

generated self and stranger robot-to-human morph continuum images are utilized to test the doppelgänger hypothesis-linked self-reference effect on the uncanny valley. Computer-generated morph continuum images are found to be an effective and common manipulation within uncanny valley research (Diel et al., 2022). Importantly, such stimuli allow my present work to investigate how the shape of the uncanny valley phenomenon is influenced by the self-reference effect; the graphical relationship between the human-likeness of stimuli and participants' response a topic of perennial controversy within empirical work (Wang et al., 2015). Additionally, recognizing the polythetic nature of the uncanny valley phenomenon, upheld by my meta-analysis, I examine how the self-reference effect influences uncanny valley outcomes linked to participants' affect, behavior, cognition, and attitudes. Last, I explore how participants' demographic traits of biological sex, and science fiction and technology affinity (hereinafter SF&T affinity) moderate uncanny valley outcomes. Note that, my meta-analysis identified that female participants experienced stronger behavior-linked uncanny valley outcomes relative to male participants. This raises the question of how participants' biological sex may moderate participants' ratings of self and stranger robot-to-human morph continuum images, to inform the design of technologies which alter users' self-image. Further, I hypothesize that affinity with technology drives the moderation effects of the demographic factors recorded by my meta-analysis. Thus, I offer participants' SF&T affinity as a third variable to explain variance in uncanny valley outcomes by participants' gender and age, while reducing assumptions based on these demographic factors. Participants' age is not examined by my empirical work due to the inherent limitations of an undergraduate convenience sample. Taken together, my Dissertation profoundly advances the study of the uncanny valley into our modern era of AI-facilitated computer-mediated communication.

Causal Mechanisms of the Uncanny Valley

Prior review sought to uphold the existence of the uncanny valley phenomenon and provide explanation for its eerie effect through analysis of theorized causal mechanisms explored within the literature (e.g., Kätsyri et al., 2015; Wang et al., 2015). Continuing this tradition, I forward eight hypothesized mechanisms of the uncanny valley organized here into four mechanism models for purposes of clarity, to provide a comprehensive investigation of the leading theories examined by existing empirical works. The eight theorized uncanny valley mechanisms I test are the categorization ambiguity and perceptual mismatch hypotheses of the perceptual tension model, the theory of mind agency and theory of mind experience hypotheses of the mind perception mechanism model, the audio fidelity and movement fidelity hypotheses of the fidelity mechanism model, and the morbidity and doppelgänger hypotheses of psychoanalytic mechanism model.

Ernst Jench (1906) proposes that "a lack of orientation" met with "misoneism" is responsible for the perception of uncanniness (Wang et al., 2015). According to the perceptual tension mechanism model, such disorientation may arise from stimuli which present conflicting perceptual cues at the human nonhuman categorization boundary (Moore, 2012), more particularly detailed by the categorization ambiguity and perceptual mismatch hypotheses. The categorization ambiguity hypothesis prescribes that difficulty in the classification of targets as natural human or artificial human triggers uncanny valley perceptions (Pollick, 2010; Ramey, 2005). Under the categorization ambiguity hypothesis perceptions of the uncanny valley peak when classification difficulty is at its highest (Tinwell & Sloan, 2014). Tinwell and Sloan (2014) presented 67 children with manipulated emotive human and humanlike avatars to find that their participants experienced the most affective discomfort when encountering humanlike avatars to

which they were uncertain how to respond. Notable examples of empirical manipulations in test of the categorization ambiguity hypothesis additionally include the display of 13-step avatar-human face morph continuums on reaction time, categorization accuracy, and brain activation in a fMRI study conducted by Cheetham et al. (2011). Further, Mathur and Reichling (2016) provide quantitative cartography of the uncanny valley through presentation of 80 real world android faces in measure of likeability, trust, and reaction time by stimuli's human-likeness.

Likewise, the theoretically independent perceptual mismatch hypothesis provides further explanation for the elicitation of uncanny valley perceptions via the perceptual tension model (Kätsyri et al., 2015). The perceptual mismatch hypothesis stipulates that negative affinity is triggered by inconsistency in the mechano-humanness of targets' sensory cues (Kätsyri et al., 2015). This negative affinity may be enhanced in line with the uncanny valley hypothesis by viewers' heightened sensitivity to violations of human norms for humanlike characters (Brenton et al., 2005; MacDorman et al., 2009). Examinations of this hypothesized mechanism include the presentation of bizarre, enlarged eyes on real-human and near-human morph targets to impact attitude formation (Seyama & Nagayama, 2007), as well as the digital removal of eyes and noses from real world human faces in manipulation of targets' apparent soullessness, uncanniness, agency, and experience (Schein & Gray, 2015). Hence, to note, empirical manipulations seen in test of the perceptual mismatch hypothesis frequently remind of Freud's (1919) postulation that the fear of losing one's eyes evokes uncanny perceptions.

According to the mind perception mechanism model, the human-likeness of synthetic entities is judged not only by aesthetic appearance, but also by the broader aspects of social cognition, including entities' apparent display of mind (Wang et al., 2015). Present research examining the role of mind perception on the formation of uncanny valley effects highlights the

need for a theoretical distinction between the theory of mind (ToM) agency and experience hypotheses (Gray et al., 2007; Gray & Wegner, 2012). Take that, the display of humanlike mind along the dimensions of agency and experience may trigger uncanny valley perceptions (Wang et al., 2015). The ToM agency hypothesis forwards that the apparent ability of near-human entities to plan and conduct action is unnerving (Gray et al., 2007). Separately, the ToM experience hypothesis stipulates that synthetic beings' perceived capacity to feel and sense trigger the uncanny valley effect (Gray et al., 2007). Gray and Wegner (2012) utilized 5-point *Likert*-type scales to measure participants' agreement with prompts including, "this robot has the capacity to plan actions" and "this robot has the capacity to feel pain" to identify more robust support for the ToM agency hypothesis to impact participants' affect relative to the ToM experience hypothesis.

Further, in his seminal hypothesis, Mori (1970) proposes that the presence of stimuli's movement will amplify the strength of the uncanny valley phenomenon (Kätsyri et al., 2015). Recent systematic review of uncanny valley mechanisms provided by Kätsyri et al. (2015) presents the "movement hypothesis" to suggest that the human-likeness of stimuli's movement will generate an uncanny valley curve of its own, in expansion of Mori (1970). Building upon both Mori (1970) and Kätsyri et al. (2015), the fidelity mechanism model explores the role of movement, as well as audio, on the elicitation of the uncanny valley. In particular, the movement fidelity hypothesis postulates that the display of movement by humanoid entities will amplify the positive and negative experiences predicted in line with the uncanny valley hypothesis (Kätsyri et al., 2015; Mori 1970). Prior review examining this hypothesis identifies that the violation of expected motion as cued by automata's appearance should amplify the affinity component of the uncanny valley curve (Wang et al., 2015). fMRI study provided by Saygin et al. (2011) manipulated robot, android, and human motion to find that agents which display biological or

mechanical movement incongruent with their human or robot appearance increased hemoglobin response in the temporal, parietal, and frontal brain regions in proxy measure of participants' cognition.

In like manner, the audio fidelity hypothesis suggests that manipulations of humanlike voices will produce negative reactions in line with the fidelity model. Consider Scott et al. (2020), who examine focus group and YouTube commenter's verbal responses to identify that NOAA Weather Radio text-to-speech voices elicit listeners' perceptions of anthropomorphism, nostalgia, and emotional connection. Significantly, Scott et al. (2020) highlight that "human sounding" synthetic audio triggers significant negative affective, cognitive, and attitudinal response. Further, Mitchell et al. (2011) demonstrate that the presentation of a human actor with synthetic voice or robot actor with human voice elicits the affective response of eeriness through the mismatch of audio-visual cues.

Finally, in 1919 essay *Das Unheimliche*, Freud presents the psychoanalytic mechanism model to explore the realm of experiences that arouse dread and horror (Jonte-Pace, 2001). Through this essay, Freud (1919) contends that uncanny experiences are aroused by stimuli which evoke repressed fears of mutilation—in particular castration— as well as repressed thoughts related to death, immortality, and the mother (Jonte-Pace, 2001). According to the morbidity hypothesis, human replicas remind of death on a subconscious level, and thereby generate uncanny valley effects through the deeply rooted anxiety regarding harm and mortality (Ho et al., 2008; MacDorman & Ishiguro, 2006; Wang et al., 2015). Indeed, the static unblinking nature of dolls and waxwork may trigger thoughts of corpses, while the jarring motion of humanoid machines may elicit fear of losing bodily control in sickness and the terminal stages of life (Freud, 1919; Jench, 1906; MacDorman & Ishiguro, 2006; Wang et al., 2015). Research

examining this hypothesis includes Poliakoff et al. (2013), who displayed to participants photographs of mechanical, prosthetic, and real-human hands to identify that intermediately humanlike prosthetic hands generated the greatest affective response of eeriness, in an effect uncorrelated with the categorization ambiguity of utilized stimuli.

Correspondingly, Freud (1919) presents the doppelgänger hypothesis to outline how exposure to aberrant replicas of the self generate uncanny perceptions through the elicitation of anxieties involving identity, the repressed subconscious, and the fear of being replaced, in accordance with the psychoanalytic model (Vardoulakis, 2006). Empirical work testing the doppelgänger hypothesis was performed by Weisman and Peña (2021) who displayed to participants talking head avatars featuring participants' self-likeness, or the likeness of strangers in yoked design. Weisman and Peña (2021) identify that self-talking head avatars increase uncanny valley perceptions in wholistic affective, cognitive, and attitudinal measure, and decrease affect-based trust toward artificial intelligence relative to stranger-talking head avatars. With the advent of generative artificial intelligence reducing barriers to digital recreations of the self, effects of the doppelgänger hypothesis on the uncanny valley are ripe for further investigation. See Table 1 for summary of the eight theorized uncanny valley mechanisms examined.

Outcomes of the Uncanny Valley

Prior meta-analyses and reviews identify diverse conceptualizations of the outcome of the uncanny valley phenomenon within empirical works (Diel et al., 2022; Kätsyri et al., 2015; Wang et al., 2015). Initial meta-analysis and review of the uncanny valley limited systematic examination to affective outcomes, thereby adhering to common translations of Mori's 1970 seminal treatise (Kätsyri et al., 2015; Wang et al., 2015). More recent meta-analysis of the

uncanny valley expands investigation of this phenomenon's dependent variables beyond affect to also include the broad category of "indirect measures" to more fully capture the full scope of observed uncanny valley literature (Diel et al., 2022). The broad "indirect measures" category employed by Diel et al. (2022) contained fourteen fine-grained items being "dislike frequency", "like frequency", "categorization reaction time", "viewing duration", "encounter duration", "preferential looking", "avoidance", "termination frequency", and "trust behavior"; "cognitive conflict", "information processing", and "ABX task"; and, "preference choice" and "lie detection".

In advancing Diel and colleagues' examination of the diverse body of uncanny valley outcomes, my present review is guided by a meta-analysis on the effects of violent video gameplay provided by Anderson et al. (2010). Anderson et al. (2010) supply comprehensive and detailed summarization of the effects of violent video gameplay on gamers' aggression, among other outcome measures, with the three dependent variable categories of "aggressive affect", "aggressive behavior", and "aggressive cognition". Following feedback from a journal reviewer, I likewise classify the dependent measures of the uncanny valley into affective, behavioral, cognitive, and attitudinal outcomes to provide meaningful summarization of the fine-grained measures belonging to "indirect" outcomes inquiry posed by Diel et al. (2022). The reader may note that I have sorted Diel et al.'s (2022) fine-grained indirect measures into groups of behavioral, cognitive, and attitudinal outcomes, in list above, to illustrate of my methodology.

Affective measures of the uncanny valley describe participants' feelings, emotions, attachment, and mood in response to target stimuli (Hogg et al., 2010). Notably, affect is commonly conceptualized as the traditional outcome of the uncanny valley phenomenon (Diel et al., 2022; Kätsyri et al., 2015; Mori, 1970; Wang et al., 2015). Studies examined by this meta-

analysis that measured participants' affect include Tu et al. (2020) which displayed 84 robot face photos to young adult, middle-aged adult, and older adult participants in examination of the effect of participant age on the likeability of robot faces. Likewise, Burleigh et al. (2013) examine the relationship between the human-likeness of avatars and their elicited eeriness through participants' exposure to digitally created human face morph continuums.

Behavioral outcomes of the uncanny valley refer to measures of observable, recordable, physical action (Watson, 1913). Recorded empirical works that examined participants' behavioral outcomes of the uncanny valley include Mathur and Reichling (2016) who measured participants' resource investment to displayed robot faces in one-shot wager game to identify an uncanny valley in participants' trust of displayed robots. Further, Lewkowicz and Ghazanfar (2011) suggest developmental origins of the uncanny valley through measures of infants' eye contact with human and avatar faces.

Cognitive measures of the uncanny valley refer to outcomes associated with participants' memory, association, perception, pattern recognition, problem solving, and mental imagination (Best, 1999). This meta-analysis identifies diverse methodology in the empirical examination of cognitive uncanny valley outcomes. For instance, Cheetham et al. (2011) utilized fMRI to plot participants' brain activation against the human-likeness and categorization difficulty of morph stimuli. Alternatively, Koschate et al. (2016) utilized word fragmentation task to measure participants' death-thought accessibility following exposure to humanoid robot images. Wiese and Weis (2020) apply mouse tracking methodology in measure of participants' cognitive conflict in response to human-nonhuman categorization task.

Attitudinal outcomes refer to participants' summary evaluations of uncanny stimuli (Vogel & Wänke, 2016). Take Chattopadhyay and MacDorman (2016) who evaluate

participants' perceptions of stimuli's familiarity and realism through manipulation of stimuli's realism and human-likeness. Additionally, Tinwell et al. (2011) manipulated the display of human and avatar facial expressions to find significant impact on stimuli rated human-likeness and familiarity. Wang and Quadfleig (2015) further expand empirical knowledge of the uncanny valley's affective outcomes through describing the sub-routes of participants' impression formation toward humanoid robots. Thereby, I examine:

H1 The uncanny valley mechanisms will yield significant effect on participants' (a) affect, (b) behavior, (c) cognition, and (d) attitudes.

Literature Review of Contemporary Examinations on the Uncanny Valley

Present meta-analyses and literature review of the uncanny valley identify varying levels of support for this eerie phenomenon. These systematic reviews employ diverse methodology for the examination of the theoretical mechanisms, dependent variables, and potential moderators of the uncanny valley, contributing an opaque understanding of this phenomenon to science. As such, this meta-analysis builds upon the following investigations.

Meta-analysis provided by Kätsyri et al. (2015) provides primary guidance for my present work through examination of five theoretically motivated uncanny valley mechanisms. Kätsyri and colleagues identify robust support for the perceptual mismatch hypothesis of the uncanny valley, which outlines that inconsistency between the human-likeness of targets' cues trigger uncanny perceptions. In turn, Kätsyri and colleagues failed to find consistent support for the movement and naive hypotheses of the uncanny valley; both hypotheses built upon the seminal work of Mori (1970). The meta-analysis provided by Kätsyri et al. (2015) was unable to examine the proposed categorization ambiguity hypothesis due to insufficient data within examined literature.

Review provided by Wang et al. (2015) critiques seven theoretical mechanisms of the uncanny valley to highlight inconsistent support for this phenomenon within examined literature. Wang et al. (2015) forward that as empirical works have struggled to validate Mori's 1970 hypothesis, the uncanny valley may best be described as a "plausible conjecture" rather than as a "real phenomenon". Nevertheless, Wang and colleagues propose a dehumanization hypothesis in explanation of the uncanny valley. This dehumanization hypothesis suggests the detection of mechanistic features in anthropomorphized human replicas will trigger uncanny valley perceptions (Wang et al., 2015). From their findings, Wang et al. (2015) posit that the uncanny valley remains a challenge for robot designers and computer engineers to overcome.

Recent meta-analysis provided by Diel et al. (2022) takes a novel approach to the summarization of uncanny valley literature. Here, Diel and colleagues identify a large average effect size associated with observed uncanny valley outcomes (Hedges $g = 1.01$). Deviating from prior reviews, these authors assess operationalizations of human-likeness as their meta-analysis' independent variable (Diel et al., 2022), rather than theorized mechanism of the uncanny valley as examined by previous works. Through their innovative analysis, Diel et al., (2022) find that targets presenting face distortion images were associated with the greatest uncanny valley effect size (Hedges $g = 1.46$) of examined manipulations. Additionally, recognizing diverse conceptualizations of the dependent variable of the uncanny valley phenomenon within empirical works, Diel and associates examined both traditional affective outcomes, as well as "indirect measures", which included reaction time, dislike frequency, avoidance, and viewing duration, among other variables. Through use of Egger's test and *p*-curve analysis, Diel et al. (2022) identify mixed evidence of publication bias within their literature review, though ultimately uphold support for the uncanny valley phenomenon.

Testing for Publication Bias in Uncanny Valley Research

Publication bias is the phenomenon that occurs when the outcome of an experiment influences decisions related to its distribution (Song et al., 2010). Meta-science identifies that research with significant results is three times more likely to achieve publication than similar quality research with insignificant results (Dickersin et al., 1987). Publication bias encourages data dredging by researchers seeking to achieve publication, potentially confounding the validity of meta-analytical results (Kicinski, 2013; Pearce & Derrick, 2019).

Preregistration of research protocols, and the registration of collected data have been offered as a partial solution to the challenge of publication bias (Wacholder et al., 2004). As such, I urge academic journals to welcome null results to lessen the pressures that lead to this so-called "file drawer effect" (DeVito & Goldacre, 2018). I anticipate that open science practices, which have now become standard, will help advance the study of the uncanny valley through increased data transparency, replicability, and efficiency to ultimately allow more innovative research on the design of the near-human other in the years ahead.

Prior meta-analysis of the uncanny valley provided by Diel et al. (2022) identified potential evidence of publication bias within their examined uncanny valley works. More particularly, Diel et al. (2022) utilized Egger's test of funnel plot asymmetry to identify a significant right skew between their recorded outcomes' standard errors, and effect sizes. In the absence of potential evidence of publication bias, funnel plots of meta-analytic results are expected to present random and symmetry distributed datapoints (Egger, 1997). To address this potential evidence of publication bias, Diel and associates followed advice from Borenstein et al. (2009) to conduct Egger's test upon a reduced dataset where the observed effects with the greatest standard errors were excluded from analysis. After removing 27% (n = 66) of recorded

effects, publication bias was no longer detected within the dataset examined. This reduced dataset continued to hold a significant overall uncanny valley effect (Diel et al., 2022).

Diel and associates also deepened their investigation of publication bias through *p*-curve analysis. *P*-curve analysis is a statistical method to identify the presence of *p*-hacking and other data mining techniques through plot of *p*-values against the percentage of observed effects (Simonsohn et al., 2014). A significantly left skewed *p*-curve demonstrates evidence of p-hacking within an examined dataset, while a significantly right skewed *p*-curve indicates truly significant results (Simonsohn et al., 2014). Diel et al. (2022) identify a significant right skew in the *p*-curve of their examined uncanny valley dataset. From the wholistic results of their Egger's test of funnel plot asymmetry and *p*-curve analysis, Diel et al. (2022) conclude that the uncanny valley effect observed by their meta-analysis is true, and not merely the result of publication bias or *p*-hacking. In examination of such bias, I examine the following research question:

RQ1 Is there evidence of publication bias within examined uncanny valley literature?

Moderation of Message Channel and Target on Uncanny Valley Effects

This meta-analysis applies foundational computer-mediated communication theory to advance the systematic review of the uncanny valley with an investigation of the moderation effects of message channel and message target on observed uncanny valley outcomes. Consider that, empirical uncanny valley research has identified smaller than expected perceptions of a highly humanlike real world robot's theory of mind agency and emotion when displayed to participants via video (Fortunati et al., 2022). Social presence theory, which examines how communication channel influences "the sense of being with another" provides theoretical explanation for this attenuated effect. Under this theory, computer-mediated communication

diminishes social presence relative to face-to-face communication, holding profound implication to the formation of the uncanny valley phenomenon (Chang et al., 2016).

Social presence is a broadly defined concept within the fields of Communication and Psychology that may best be explicated as the illusion of unmediated communication across mediated communication channel (Lombard & Ditton, 1997). Media scholars have increasingly begun to consider the role of media channel on both the formation and impact of social presence (Lombard & Ditton, 1997). Take for example, research provided by Ivory and Kalyanaraman (2007), which investigates how increases in the graphical and audio fidelity of video games influence players' psychophysiological outcomes. This study exposed participants to newer or older versions of violent and non-violent videogames in between subjects factorial design to identify that newer higher fidelity videogames enhanced participants ratings of presence, involvement, and physiological and self-reported arousal, relative to older less technologically advanced videogames. Additionally, empirical work provided by Skalski and Tamborini (2007) contributes additional insight into how interactive technology influences social presence, information processing, and persuasion. This work exposed participants to a health communication message from "Cardia", a virtual social agent. In 2 x 2 between subjects factorial design, Cardia was presented to participants in an interactive or non-interactive form, with an attractive or unattractive avatar. Here, path analysis revealed that the presence of interactivity facilitated the formation of social presence, which in turn heightened participants' health communication message processing to impact attitude and behavioral intentions. Given that the presentation of high fidelity (e.g., video) and low fidelity (e.g., text, image) stimuli may likewise influence the findings of uncanny valley research, as well as stimuli that may cue thoughts of

interaction (e.g. real world robots), it has become timely and relevant for meta-analysis to examine the influence of social presence on the uncanny valley effect.

To conduct my novel meta-analytic examination on the influence of social presence on uncanny valley outcomes, I record the channel through which uncanny valley stimuli is transmitted. Here, I divide the display of uncanny valley stimuli into the following nine categories: text, audio only, real photo, real video without audio, real video with audio, CG image, CG video without audio, CG video with audio, and direct contact to most completely capture the communication mediums utilized to transmit uncanny valley cues. Further, I delve into the potential confound of message target which may influence the observed moderation effects of social presence on the strength of uncanny valley results.

Consider that, in uncanny valley works, real world robots are presented to participants through both direct contact and computer-mediated channels, such as image and video. In contrast, virtual robots and virtual humans are exclusively displayed to participants via computer-mediated means. There may be baseline differences in the social presence and resulting uncanny valley effects that real world robots, virtual robots, and virtual humans instigate independent of message channel (Zhao, 2006). Such confounding factor is necessary to explore given the moderate and high heterogeneity observed within uncanny valley effects by meta-analysis provided by Diel et al. (2022). In exploration of such, I utilize the following six post hoc target categories: visual continuum, morph continuum, real robot, virtual human, vignette, and text-based chat. Accordingly, I pose:

H2 Stimuli displayed via message channels with greater audiovisual bandwidth will heighten the uncanny valley effect on participants' (a) affect, (b) behavior, (c) cognition, and (d) attitudes.

Moderation Effect of Participant Age and Sex on the Uncanny Valley Phenomenon

While current research upholds the existence of the uncanny valley phenomenon, there is no empirical consensus on how participants' age moderates the uncanny valley effect (Diel et al., 2022; Feng et al., 2018). Take Nitta and Hashiya (2021), who presented 24, 12-month-old infants with self-face images, a stranger-face image, and a morph image (consisting of 50% self-face and 50% stranger-face blend) to identify support for the doppelgänger mechanism of the uncanny valley through analysis of these infants' visual fixation behavior. Incongruently, Brink et al., (2017) presented 240 children ages three through 18 with an image either a machine-like or humanlike robot to identify that only children ages nine and older experienced an affective response in line with the ToM agency hypothesis. In contrast, children ages three through eight reported reduced feelings of uncanniness as their perceptions of robots' agency increased. Thereby, Brink et al., (2017) conclude that the uncanny valley phenomenon is not experienced by individuals before middle childhood, and forward a developmental component to the uncanny valley experience. An enhanced understanding of how children perceive potentially uncanny valley stimuli may help guide the aesthetic design of children's media. Likewise, in examination of the uncanny valley phenomenon over the adult lifespan, Tu et al. (2020) presented younger adult, middle-aged, and older adult participants with 83 robot images in an online study. Here, Tu et al. (2020) find that younger and middle-aged adult populations rate humanlike robots more negatively than non-humanlike robots, consistent with the categorization ambiguity hypothesis. Nevertheless, older adult participants— individuals 60-87 years of age— preferred the images of humanlike over non-humanlike robots, suggesting a decline in the strength of affective uncanny valley response in the later years of life. The findings by Tu and colleagues hold important implications for the aesthetic design of healthcare and elder care related service robots.

Similarly, current empirical works yield conflicting evidence on the moderation effects of participants' biological sex. For example, research provided by Thaler et al. (2020) presented 150 female and 65 male participants with autonomous and human-driven embodied conversational agents to find that participant sex did not impact the affect-linked categorization ambiguity relationship between stimuli's perceived humanness and elicited eeriness.

Alternatively, an online study conducted by Bailey et al. (2023) presented a set of 10 avatar faces with varying levels of realism to 1050 female and 1003 male participants to examine sex-linked effects on the categorization ambiguity hypothesis. Here, male participants demonstrated greater affective response through rating all but one avatar as more uncanny than did female participants (Bailey et al., 2023). Similarly, male participants exhibited greater attitudinal uncanny valley response through rating a majority of avatars as less real than did female participants (Bailey et al., 2023). In contrast, poster presentation provided by McQueen (2012) outlined research in which 25 female and 25 male participants were shown an image continuum of humanlike androids to identify that female participants experienced stronger affect-based uncanny valley effects than did male participants. Hence, existing empirical research lacks reliable insight into how participants' gender impact perceptions elicited by uncanny stimuli. My meta-analysis thus provides excellent scholastic opportunity to shed light on the potential moderation effects of participant age and sex given the uncertainty provided by present literature (Carpenter, 2015). Through this investigation, I provide novel meta-analytic guidance for the intentional design of synthetic humans potentially customized for target populations. As such, I pose the question:

RQ2 Will participant age and sex moderate the uncanny valley phenomenon?

Methods

Open Science. This systematic review followed open science practices guided by Crüwell et al. (2020). The preregistration for this meta-analysis occurred on June 12th, 2021. The preregistered data analysis plan, database, code, and additional material of this meta-analysis are freely available on the Open Science Foundation: https://osf.io/t3qvm/?view_only=41e81313cf074bec847fb7a67b457ab0.

Article Search. Articles examined by the meta-analysis were obtained through systematic electronic scrape of the *APA PsychInfo, EBSCO, IEEE Xplore, Scopus, PubMed, and Science Direct* databases. Google Chrome extension *Webscraper.io* was utilized to perform the scrape of these five academic databases between June 15th and 16th, 2021. The use of *Webscraper.io* presents no known limitations. The search term "uncanny valley" was utilized in scrape of these five databases to capture all relevant works. To limit the collection of spurious articles, reasonably off-topic database categories were excluded from my systematic scrape where such filters were available. In total, 397 articles were scraped, of which 330 comprised unique works.

Eligibility Criteria and Exclusion Process. To be included in the statistical analysis of the meta-analysis, scraped articles must: (1) include the term "uncanny" or "valley" in their title or abstract, (2) describe an empirical work, (3) examine at least one of the eight hypothesized mechanisms of the uncanny valley, (4) contain dependent variables in measure of at least one of my four outcome measures, (5) report sufficient statistics so that Cohen's *d* measure of effect size can be calculated, (6) present English language text, and (7) examine human (rather than primate) participants.

Of the 330 unique works collected, 45 were excluded from analysis for not containing "uncanny" or "valley" in their title or abstract, 96 were excluded for not describing empirical research, 52 were excluded for being off topic or not containing an independent variable representing a hypothesized mechanism, 56 were excluded for providing insufficient statistics as to allow effect size calculation, four were excluded for presenting research in a language other than English, two were excluded for using primate rather than human subjects, and five were excluded due to being unable to access following two months of emailing the studies' authors. Accordingly, my uncanny valley meta-analysis is informed by 70 works that survived the preregistered inclusion criteria. See Figure 1 for a detailed flowchart of the article exclusion process.

Article Coding. In line with best practices recommended by Wilson (2009), I underwent rigorous training and independently coded all 330 unique articles scraped by the meta-analysis. I met regularly with a second coder to resolve differences in coding by consensus (Wilson, 2009). From the agreed upon dataset, I calculated Cohen's *d* effect sizes from recorded main effects, between-subjects effects, within-subjects effects, and mixed designs utilizing available reported statistics as appropriate (Cohen, 1988). Interaction effects, which cannot cleanly be attributed to a singular manipulation or outcome variable, were excluded from analysis for reasons of simplicity (see Diel et al., 2022). Separately, effect sizes from within-subjects *F*-tests, within subjects *t*-tests and mediation models were excluded from analysis as Cohen's *d* effect size scores from these sources are not directly comparable with the effect size scores of more common measures (Dunlap et al., 1996; Preacher & Kelley, 2011). This meta-analysis recorded a total of 578 Cohen's *d* effect sizes from the 70 examined empirical works, for an average of 8.26 recorded effects per study. Each recorded Cohen's *d* effect size was associated with a singular

best fitting hypothesized mechanism of the uncanny valley, dependent measure, message channel, and message target.

Examined Mechanisms. This meta-analysis observed 377 results in test of the categorization ambiguity hypothesis, 79 results in measure of the ToM experience hypothesis, 41 results for the ToM agency hypothesis, 36 results associated with the movement fidelity hypothesis, 31 results in test of the perceptual mismatch hypothesis, eight results for the doppelgänger hypothesis, three results in measure of the audio fidelity hypothesis, and three results in test of the morbidity hypothesis. Hence, results from the doppelgänger, audio fidelity, and morbidity hypotheses could not be individually examined without outsized risk of type 1 error (Sauro & Lewis, 2016).

Recorded Outcomes. Regarding the dependent variables, 236 results were in measure of affective uncanny valley outcomes, 211 results described attitudinal uncanny valley outcomes, 102 results outlined behavioral uncanny valley measures, and 29 results recorded measures of participants' cognitive uncanny valley outcomes.

Message Channels. In examination of the message channels utilized to trigger the uncanny valley effect, I find that 127 results were from participant exposure to computer-generated images, 123 results were from participant exposure to computer-generated video with audio, 115 results were from participant exposure to photographs of real world stimuli, 114 results were from participants' direct contact with real world stimuli, 35 results were from participant exposure to computer-generated videos without audio, 34 results were from participant exposure to text, 20 results were from participant exposure to real video with audio, 10 results were from participant exposure to real video without audio, and zero recorded effects

were from audio alone. Thus, results from the real video without audio and audio only message channels could not be individually examined due to insufficient data (Sauro & Lewis, 2016).

Message Targets. Across these message channels I additionally examine the specific uncanny valley-inducing targets utilized. Here, I observed 162 results stemming from the display of visual continuums, 140 results from participant exposure to single real robots, 139 results from participant exposure to virtual humans, 97 results triggered by morph stimuli, 23 results through the use of vignettes, and 12 results from participant exposure to text-based chat conversations.

Moderators of Participant Age and Sex. For use in novel moderation analysis, I additionally recorded the common demographic variables of participants' age and sex where available. The mean age of participants recorded was 26.2. Females comprised 54.9% of participants observed.

Results

I analyzed Cohen's *d* effect sizes using R v2023.06.1+524. I used Welch's *t*-tests to analyze the data. Welch's *t*-test is robust in situations where the two samples have unequal variances as well as unequal sample sizes (Derrick et al., 2016). The inference criterion was set at $p < .05$ and Bonferroni correction was used to reduce the risk of type I errors. I set a bar of 10 degrees of freedom as the minimum upon which to perform statistical analyses (Sauro & Lewis, 2016). At fewer than ten degrees of freedom, the type I error rate of Welch's *t*-test becomes significantly inflated and produces potentially misleading results (Sauro & Lewis, 2016). Thus, preregistered predictions linked to categories with too few data points were not examined.

Effect Size of Uncanny Valley Mechanisms on Affect, Behavior, Cognition, and Attitudes

The full data revealed an average Cohen's $d = 23.67$. This extremely large value was caused by 43 extreme outliers, including two recorded effect sizes greater than 3,000. These 43 extreme outliers were excluded from analysis to avoid spurious findings. After removing the outliers, the compounded effect of all causal mechanisms on a combined average of affect, behavior, cognition, and attitudes was Cohen's $d = .93$, $t(529) = 22.49$, $p < .001$, 95% CI [.85, 1.01]. Cognitive outcomes had the largest effect size, ($M_{Cohen's\ d} = 1.63$, $SD = 1.45$), $t(26) = 5.86$, $p < .001$, 95% CI [.86, 2.41], followed by attitudes ($M_{Cohen's\ d} = .96$, $SD = .88$), $t(196) = 15.23$, $p < .001$, 95% CI [.80, 1.12], affect ($M_{Cohen's\ d} = .88$, $SD = .88$), $t(216) = 14.76$, $p < .001$, 95% CI [.72, 1.03], and behavior ($M_{Cohen's\ d} = .76$, $SD = .99$), $t(88) = 7.25$, $p < .001$, 95% CI [.48, 1.03]. Confidence intervals implied that the effect sizes of uncanny valley outcomes did not statistically differ from each other.

Next, I explored the uncanny valley effect sizes associated with each dependent variable. H1 predicted that each causal mechanism of the uncanny valley would yield a significant effect on affect, behavior, cognition, and attitudes. See Figure 2 for a graphical depiction of the recorded effect sizes of uncanny valley mechanisms by outcome measure. Affect was significantly associated with the categorization ambiguity ($M_{Cohen's\ d} = .93$, $SD = .92$), $t(140) = 12.09$, $p < .001$, 95% CI [.73, 1.14], ToM experience ($M_{Cohen's\ d} = .77$, $SD = .74$), $t(34) = 6.17$, $p < .001$, 95% CI [.43, 1.11], and ToM agency hypotheses ($M_{Cohen's\ d} = .57$, $SD = .52$), $t(12) = 3.92$, $p = .002$, 95% CI [.13, 1.01]. The effect size of the categorization ambiguity, ToM experience, and ToM agency hypotheses on affect did not significantly differ from each other.

Cognitive outcomes were strongly associated with the categorization ambiguity hypothesis ($M_{Cohen's\ d} = 2.17$, $SD = 1.49$), $t(14) = 5.66$, $p < .001$, 95% CI [1.03, 3.32]. Only the

categorization ambiguity hypothesis significantly impacted behavior ($M_{Cohen's\ d}$ = .80, SD = 1.05), $t(76) = 6.67$, $p < .001$, 95% CI [.48, 1.11]. No other predictions were tested due to lack of data for these mechanisms.

In addition, the categorization ambiguity ($M_{Cohen's\ d}$ = 1.05, SD = 1.03), $t(101) = 10.24$, $p < .001$, 95% CI [.78, 1.32], ToM experience ($M_{Cohen's\ d}$ = .97, SD = .69), $t(39) = 8.87$, $p < .001$, 95% CI [.67, 1.27], perceptual mismatch ($M_{Cohen's\ d}$ = .89, SD = .68), $t(20) = 6.00$, $p < .001$, 95% CI [.47, 1.32], ToM agency hypotheses ($M_{Cohen's\ d}$ = .77, SD = .67), $t(19) = 5.19$, $p < .001$, 95% CI [.35, 1.20], and movement fidelity hypotheses ($M_{Cohen's\ d}$ = .49, SD = .48), $t(11) = 3.61$, $p < .001$, 95% CI [.07, .92] had significant effects on attitudes. The effect sizes of these causal mechanisms on attitudes did not differ from each other. In sum, the causal mechanisms of the uncanny valley had significant effects across affect, behavior, cognition, and attitudes and, thus, H1 was supported.

Was There Evidence of Publication Bias and P-hacking in the Uncanny Valley Literature?

To address RQ1, I used Egger's test of funnel plot asymmetry to test for evidence of publication bias within my sample of studies (Egger et al., 1997). To conduct Egger's test, I set variance of the calculated Cohen's d as the predictor variable and the effect size of recorded results as the outcome variable. This model was significant $z = 13.15$, $p < .001$, $k = 515$, thus indicating significant funnel plot asymmetry that hinted at publication bias. Diel and associates (2022) encountered a similar scenario and further explored potential publication bias by limiting their analysis to larger studies and then checking whether bias was still present and the effect itself remained large enough (Borenstein, 2009). As such, I retested funnel plot asymmetry by excluding 213 effects with the largest standard errors comprising 37.2% of the dataset, which revealed insignificant funnel plot asymmetry implying that evidence of publication bias was no

longer detectable, $z = 1.82$, $p = .07$, $k = 302$. Of importance, this reduced dataset held significant combined effects across the dependent variables ($M_{Cohen's\ d} = .64$, $SD = .62$), $t(316) = 18.25$, $p < .001$, 95% CI [.57, .71]. See Figure 4 for full and reduced funnel plots of the meta-analysis' recorded effects.

I then utilized a p-curve analysis to test for existence of p-hacking (Simonsohn et al., 2014). If a true effect was observed, researchers expect a p-curve to present a right skew as the data would be composed primarily of significant results (Simonsohn et al., 2014). However, if a p-curve displays a left skew, this may indicate a prevalence of marginally significant or false-positive results (Simonsohn et al., 2014). A plot of p-values against a percentage of effects would be flat if there was no true effect (Simonsohn et al., 2014). Both the half p-curve test which examined p-values < .025 ($z_{half} = -7.76$, $p_{half} = <.001$) and the full p-curve which examined p-values < .05 ($z_{full} = -7.76$, $p_{full} <.001$) were significantly right skewed, thus indicating a true uncanny valley effect. Consistent with this, the 33% power analysis testing for flatness found no support for p-hacking in my sample of studies, $z_{half} = 5.96$, $p_{half} > .99$ and $z_{full} = 6.08$, $p_{full} > .99$. See Figure 5 for *p*-curve of the meta-analysis' recorded effects.

Effects of Message Channel and Target on Affect, Behavior, Cognition, and Attitudes

H2 predicted that experimental stimuli that was transmitted using channels with more audiovisual cues would increase the effect size of affective, behavioral, cognitive, and attitudinal outcomes. See Figure 3 for graphical depiction of uncanny valley effect sizes by message channel. The most frequent target category was visual continuum, accounting for 27.17% (n = 144) of all coded effects. 60.42% (n = 87) of the effects were obtained through real photos, 20.83% (n = 30) via CG video without audio, 11.11% (n = 16) through CG images, 5.56% (n = 8) through real video with audio, and 2.08% (n = 3) via CG video without audio. Visual

continuum use had a large effect on attitudes ($M_{Cohen's\ d}$ = 1.64, *SD* = 1.11), $t(37) = 9.07$, $p < .001$, 95% CI [1.22, 2.06] and affect ($M_{Cohen's\ d}$ = 1.08, *SD* = .97), $t(93) = 10.88$, $p < .001$, 95% CI [.86, 1.31]. Confidence intervals did not reveal differences between these outcomes. Though less frequently employed, there were large effect sizes for continua displayed using video with audio ($M_{Cohen's\ d}$ = 1.81, *SD* = 1.11), $t(11) = 5.67$, $p < .001$, 95% CI [.99, 2.64] and real photos ($M_{Cohen's\ d}$ = 1.49, *SD* = 1.19), $t(20) = 5.72$, $p < .001$, 95% CI [.86, 2.12]. Confidence intervals did not differ. There was also a large effect size of visual continua created using real photos on affect ($M_{Cohen's\ d}$ = 1.41, *SD* = 1.06), $t(57) = 10.20$, $p < .001$, 95% CI [1.10, 1.73] but a small influence for visual continua created using CG images on affect ($M_{Cohen's\ d}$ = .35, *SD* = .21), $t(13) = 6.33$, $p < .001$, 95% CI [.21, .49]. The effect size of visual continuum use on affect was reliably higher for continua created from real photos than CG images.

The second most frequent target category was single real robots. The use of single real robot targets accounted for 26.42% (n = 140) of all examined effects. Of these effects, 81.43% (n = 114) were displayed through direct contact, 7.14% (n = 10) through real world video without audio, 5.71% (n = 8) real world video with audio, and 5.71% (n = 8) through real photo. Single robots had a moderate effect on attitudes ($M_{Cohen's\ d}$ = .77, *SD* = .65), $t(45) = 8.03$, $p < .001$, 95% CI [.58, .96] and affect ($M_{Cohen's\ d}$ = .61, *SD* = .39), $t(29) = 8.45$, $p < .001$, 95% CI [.42, .79]. A small effect was observed for behavior ($M_{Cohen's\ d}$ = .35, *SD* = .29), $t(57) = 9.06$, $p < .001$, 95% CI [.25, .44]. The effect size of single robots was greater on attitudes than behavior. More specifically, direct contact with single robots had a moderate effect on attitudes ($M_{Cohen's\ d}$ = .64, *SD* = .40), $t(33) = 9.31$, $p < .001$, 95% CI [.48, .80] and a small effect on affect ($M_{Cohen's\ d}$ = .47, *SD* = .27), $t(20) = 8.11$, $p < .001$, 95% CI [.33, .61].

In addition, the use of virtual humans accounted for 24.34% of examined effects. 66.67% of these effects were obtained using virtual humans displayed through video with audio, 24.03% via computer-generated video without audio, and 9.30% through CG images. Virtual humans had moderate effects on affect ($M_{Cohen's\ d}$ = .76, *SD* = .86), $t(51) = 6.40$, $p < .001$, 95% CI [.49, 1.04] and attitudes ($M_{Cohen's\ d}$ = .65, *SD* = .69), $t(66) = 7.75$, $p < .001$, 95% CI [.46, .85]. Virtual humans displayed through videos with audio had a large effect on attitudes ($M_{Cohen's\ d}$ = .84, *SD* = .83), $t(39) = 6.41$, $p < .001$, 95% CI [.53, 1.14]. Virtual humans conveyed through CG videos with audio had a moderate effect size effect on affect ($M_{Cohen's\ d}$ = .60, *SD* = .41), $t(37) = 9.13$, $p < .001$, 95% CI [.45, .76]. There was also a moderate effect of virtual humans displayed via videos without audio on attitudes ($M_{Cohen's\ d}$ = .44, *SD* = .23), $t(20) = 8.72$, $p < .001$, 95% CI [.32, .57]. Confidence intervals did not differ.

Using morphs as targets accounted for 15.47% ($n = 82$) of all examined effects. 93.90% ($n = 77$) of these effects were obtained by displaying morphs as CG images, 6.10% ($n = 5$) of the effects were obtained through real photos. Morphs had large effect on behavior ($M_{Cohen's\ d}$ = 1.51, *SD* = 1.48), $t(18) = 4.47$, $p < .001$, 95% CI [.62, 2.41] and attitudes ($M_{Cohen's\ d}$ = 1.05, *SD* = 1.93), $t(29) = 6.17$, $p < .001$, 95% CI [.62, 1.48]. Additionally, morphs had a moderate effect size on affect ($M_{Cohen's\ d}$ = .63, *SD* = .74), $t(24) = 4.28$, $p < .001$, 95% CI [.25, 1.01]. Morphs displayed as CG images had large effects on behavior ($M_{Cohen's\ d}$ = 1.28, *SD* = 1.36), $t(16) = 3.87$, $p = .001$, 95% CI [.39, 2.16] and attitudes ($M_{Cohen's\ d}$ = 1.07, *SD* = .96), $t(27) = 5.92$, $p < .001$, 95% CI [.61, 1.54] and a moderate effects on affect ($M_{Cohen's\ d}$ = .63, *SD* = .75), $t(23) = 4.09$, $p < .001$, 95% CI [.23, 1.03]. Confidence intervals did not differ.

Vignettes accounted for 4.34% ($n = 23$) of all examined effects. 91.30% ($n = 21$) of vignettes were displayed via text prompts and 8.70% ($n = 2$) involved real photos. Vignettes

were associated with a large effect on the combined outcome variable ($M_{Cohen's\ d}$ = .98, *SD* = .97), $t(22) = 4.87$, $p < .001$, 95% CI [.56, 1.40] though these large effects should be interpreted cautiously given how vignettes were infrequently used. There were not enough cases to examine the effect of vignettes across the four dependent variables.

Text-based chat use accounted for 2.26% ($n = 12$) of examined outcomes. Text-based chat was linked to a large effect on the combined outcome variable ($M_{Cohen's\ d}$ = .92, *SD* = .44), $t(11) = 7.17$, $p < .001$, 95% CI [.64, 1.20], but there was not enough data to examine the effects of text-based chat on the four dependent variables. H2 was rejected as though richer encounters lead to more robust effects, there were significant exceptions.

Do Participant Sex and Age Influence the Effect Size of Uncanny Valley Outcomes?

To address RQ2, I examined whether participant sex and age moderated uncanny valley effects. As noted above, across recorded effects 54.8% of the sampled participants were female and the mean participant age was 26.3. I added to my model the percentage of study participants that were female as a measure of participants' sex composition in each study. A simple moderation analysis was used to examine these effects on the combined and specific dependent variables (Hayes, 2022). Studies featuring more females had larger behavioral effects, $B = 13.37$, $SE = 4.69$, $t(75) = 2.85$, $p = .006$, 95% CI [4.01, 22.73]. However, participants' sex not did not moderate affective $B = .05$, $SE = .70$, $t(184) = .07$, $p = .95$, 95% CI [-1.34,1.44], cognitive $B = 10.09$, $SE = 8.58$, $t(21) = 1.18$, $p = .26$, 95% CI [-8.01, 28.19], or attitudinal effects $B = .64$, $SE = .75$, $t(172) = .86$, $p = .39$, 95% CI [-.83, 2.11].

Increases in age were linked to decreased effect sizes for affect $B = -.04$, $SE = .01$, $t(166) = -2.89$, $p = .004$, 95% CI [-.06, -.01], behavior $B = -1.45$, $SE = .49$, $t(71) = -2.94$, $p = .005$, 95% CI [-2.44, -.47], and attitudes $B = -.06$, $SE = .02$, $t(155) = -2.75$, $p = .007$, 95% CI [-.10, -.02].

Age was not linked to cognitive outcomes $B = -.14$, $SE = .07$, $t(24) = -2.06$, $p = .05$, 95% CI [-.29, .002].

Discussion

This meta-analysis summarized the results of 70 empirical articles to identify broad support for all examined hypothesized mechanisms of the uncanny valley. Additionally, it provided a detailed expansion of the uncanny valley's outcome beyond affect, to also include behavior, cognition, and attitudes. Affect was found to be the most common outcome variable examined by empirical uncanny valley works. Nevertheless, cognitive outcomes were associated with the largest uncanny valley-impacted effect sizes, in expansion of knowledge on the uncanny valley effect. Further, the meta-analysis detailed the moderation effects of message channel, message target, participant sex, and participant age within examined works. I identified mixed evidence of publication bias within examined works, like prior uncanny valley meta-analysis provided by Diel et al. (2022).

An Expansion of Uncanny Valley Outcome Measures

A primary contribution of this meta-analysis was the expansion of uncanny valley theory beyond affect through a detailed investigation of uncanny valley outcomes. Within my present work, the uncanny valley phenomenon was found to hold large effect on participants' cognitions, affect, and attitudes, with moderate effect on participants' behavior. While affect was the most commonly examined outcome variable, participants' cognitions were associated with the greatest uncanny valley effect. From my meta-analytic review of the outcomes of the uncanny valley, I established the academic study uncanny valley phenomenon as polythetic within empirical works.

The thorough expansion that my meta-analysis provided for the outcomes of the uncanny valley built upon seminal meta-analytic expansion of the uncanny valley beyond affect provided by Diel et al. (2022). My present meta-analysis, as well as meta-analysis provided by Diel et al. (2022) differed from prior review of the uncanny valley provided by Kätsyri et al. (2015) and Wang et al. (2015) which solely considered measures of affect as measures of the uncanny valley's outcome. I identified that a strict conceptual adherence to the dependent variable described by Mori's graph is unwarranted, given the enduring issues of measurement within uncanny valley research (Diel et al., 2022). Indeed, the diverse conceptualizations of uncanny valley outcomes observed within empirical works in part stem from differing translations of the term "shinwakan" utilized in Mori (1970) (Wang et al., 2015). Note that, this Japanese-language term holds no direct translation to English (Wang et al. 2015).

Thus, my meta-analysis served to inform academia that observed empirical uncanny valley research lacked a singular conceptualization of the uncanny valley effect. Additionally, the uncanny valley phenomenon is found to significant impact measures beyond affect in both my present work, as well as review provided by Diel et al. (2022). To advance the study of the uncanny valley within real world contexts researchers are justified in reframing uncanny valley research from an investigation on traditional outcome measures to a broader focus on the impact of stimuli's human likeness.

Broad Support for Theorized Mechanisms of the Uncanny Valley Phenomenon

The categorization ambiguity hypothesis, which describes difficulty in the classification stimuli as human or nonhuman, was associated with the greatest uncanny valley effects on affect, behavior, cognition, and attitudes. This finding is notable given that initial meta-analysis of the uncanny valley provided by Kätsyri et al. (2015) was unable to examine this theorized

mechanism due to insufficient sample size, thereby demonstrating the expansion of uncanny valley literature with time.

Additionally, I identified the trigger of the uncanny valley phenomenon as polythetic in nature through meta-analytic support for all examined theorized mechanisms of the uncanny valley, those being: the perceptual mismatch, movement fidelity, ToM emotion, and ToM agency hypotheses. Considering this meta-analytic finding, most any manipulation of near-human stimuli may be expected to evoke uncanny valley effects. This empirical finding contrasted guidance from prior uncanny valley literature review which attributed the source of the uncanny valley to a singular proposed mechanism (Wang et al., 2015).

However, my present meta-analysis was unable to examine three of eight hypothesized mechanisms of the uncanny valley phenomenon due to insufficient sample size.
Future empirical uncanny valley works would do well to explore the under-examined doppelgänger, audio fidelity, and morbidity hypotheses which hold long standing prominence within uncanny valley theoretical framework and real world application. In particular, the doppelgänger hypothesis is ripe for empirical study given its relevance to emerging technologies that enable the creation of novel uncanny valley experiences featuring individuals' self-likeness (Weisman & Peña, 2021). Take that, AI now provide the real-time ability to modify oneself presentation through AI-powered filters for purposes of self enhancement (Hancock & Bailenson, 2021); this raises the question of what negative psychological effects may be triggered when such self-enhancements go wrong. I anticipate that such examination will uncover the particular intricacies these mechanisms may hold on the formation of uncanny valley effects, and thereby enhance human-robot and human-AI interactions.

Publication Bias

Mixed evidence of publication bias was detected within my meta-analytic dataset, in identical pattern as uncovered by prior meta-analysis of the uncanny valley provided by Diel et al. (2022). Here, Egger's test revealed a significant relationship between studies' recorded effect size and precision within my recorded dataset, to suggest either evidence of publication bias or a systematic difference between studies of higher and lower precision (Borenstein et al., 2009). After the exclusion of effects with greatest standard errors, the mean effect size of the combined uncanny valley outcome remained large, and Eggers' test no longer displayed significance. Following guidance from Diel et al. (2022), *p*-curve analysis was additionally utilized to examine the source of heterogeneity identified by Egger's test. Observed *p*-curves were significantly right-skewed, indicating the presence of truly significant results that were not the product of *p*-hacking or other manipulative data mining techniques (Simonsohn et al., 2014). Taken together, these findings indicated that the results of this meta-analysis were built upon a valid dataset, and that the uncanny valley itself is a real and reliable phenomenon.

Given the mixed evidence for publication bias identified within the uncanny valley literature examined by my meta-analysis, as well as meta-analysis provided by Diel et al. (2022), I forward the need empirical uncanny valley works to practice open science. The practice of open science will aid the meta-analytic study of the uncanny valley phenomenon through increased research transparency, replicability, and reduction in the file drawer effect to ultimately reduce the antecedents of publication bias (Allen & Mehler, 2019). Further, the adoption of open science practices in the study of the uncanny valley will benefit meta-scientific and empirical researchers alike; through increased confidence in the results of systematic review, as well as the raising the probability that empirical works achieve publication (Allen & Mehler, 2019).

An Examination of Message Channel and Message Targets

There was mixed evidence in support of the hypothesis that message channel bandwidth enhanced participants' uncanny valley perceptions. In line with expectations guided by the media richness and social presence theories, among visual continuum targets (the most examined target category) uncanny valley effect sizes were greater for the video with audio message channel than the real photo message channel. Nevertheless, counter to hypothesized expectations under these theories, the unmediated direct contact with real world robot message channel-target pair did not produce particularly powerful uncanny valley outcomes. Instead, the combined uncanny valley effect of participant exposure to the cues-dearth text-based chat message channel-target pair was greater than the effect of the direct contact with real world robot message channel-target pair on both participants' attitudes and affect.

Overall, this indicated that both message channel, and message target, may influence the effect size of uncanny valley results observed by empirical research. From this finding, I provided guidance that future works may seek to deliberately manipulate stimuli's message channel and message target in examination of the moderation effects of targets' media richness and social presence on the uncanny valley phenomenon. Through such investigation, the moderate heterogeneity of uncanny valley effects detected by Diel et al. (2022) may be further elucidated.

Moderators

This meta-analysis advanced the study of the uncanny valley through identification of significant moderation effects of participants' sex and age on observed uncanny valley effect sizes. More particularly, empirical works with a greater proportion of female participants reported stronger behavior-linked uncanny valley outcomes than studies with greater proportion

of male participants. Likewise, works with younger mean participant ages reported greater affective, behavioral, and attitudinal uncanny valley outcomes than works with older mean participant ages.

My systematic review thus highlighted the importance of the consideration of demographic traits' moderation effects on the interpretation of uncanny valley outcomes. However, this review did not serve to explain why such observed moderation effects occur. Indeed, there may be biological, socialization, as well as other pressures that influence the strength of the uncanny valley by gender and age across the lifespan (Rosenthal-von der Pütten et al., 2019; University of Cambridge, 2019). Future empirical research would do well to intentionally use gender-balanced samples and include populations beyond college-aged convenience samples to provide further examination of the cause and effect of these impactful demographic traits. Such efforts will help explain how individuals' characteristics influence their experienced uncanny valley perceptions, and thereby provide more generalizable knowledge to better human-AI interaction across diverse populations.

Limitations

The primary limitation of this meta-analysis was posed by the insufficient data availability of several hypothesized mechanisms, dependent variables, message channels, and message targets contained within my observed dataset. This limitation hindered my ability to conduct a thorough analysis of each independent, dependent, and moderator variable category, as well as explore the interplay between these variables in detail. Indeed, this limitation highlighted which theoretical, methodological, and socially relevant components of the uncanny valley remain underexplored.

The potential for language bias presented the second limitation of this meta-analysis, in that only English language articles were reviewed for analysis. Language bias occurs when the nature and direction of findings influence the language global research is published (Boutron et al., 2023). It is likely that non-English speaking authors chose to publish significant impactful findings in international English-language journals, and reserved less-impactful results for local language journals (Egger et al., 1997). Additionally, researchers' native languages, as a proxy of local culture, may have influenced participants' responses to robots (MacDorman et al., 2009). Authors of future meta-analyses would do well to apply machine translation to provide a more global understanding of uncanny valley phenomenon (Chew et al., 2023).

Implications for Subsequent Empirical Research

Understudied Mechanisms

Among eight mechanisms hypothesized to explain this phenomenon, my meta-analysis, identified the categorization ambiguity hypothesis as the strongest uncanny valley mechanism. The categorization ambiguity hypothesis stipulated that difficulty in the classification of targets as human or non-human triggered observed uncanny perceptions (Pollick, 2010; Ramey, 2005). Note that image morph continuums, a series of blended images with two distinct endpoints, are frequently utilized to test the categorization ambiguity hypothesis (Kätsyri et al., 2015). My meta-analysis highlighted that CG image morphs were associated with large uncanny valley effects on participants' behavior (d = 1.28), and attitudes (d = 1.07), along with moderate effects on affect (d = .63). In similar finding, uncanny valley meta-analysis provided by Diel et al. (2002) identified that morph stimuli were associated with a large effect on a combined uncanny valley outcome (g = .94).

Likewise, I identified four significant uncanny valley effects stemming from the perceptual mismatch, theory of mind experience, theory of mind agency, and movement fidelity hypotheses of the uncanny valley. However, a limitation of my foregoing meta-analysis (see also Kätsyri et al., 2015) was the inability to examine all theorized mechanisms of the uncanny valley due to insufficient availability of empirical research necessary to inform systematic review. In short, key causal mechanisms have been under explored.

For instance, there was limited examination uncovered on the link between the uncanny valley phenomenon and the doppelgänger hypothesis, which stipulated that synthetic recreations of the self are particularly off-putting (Vardoulakis, 2006). This runs the risk of oversimplifying the eerie effects that are potentially triggered by modern-day technologies. Advancements in machine learning and artificial intelligence have led to the normalization of blockbuster films featuring digitally de-aged actors, e.g. *The Irishman*, as well as digital likeness of deceased actors brought back to life, e.g. *Star Wars: The Rise of Skywalker* (Porter, 2020; Rottenberg, 2020). New technologies have also enabled the synthetic recreation of the self. With the proliferation of easy-to-use AI image-generation systems such as Deep Nostalgia, an AI-powered service that allows the creation of lifelike facial animation from still photos, individuals may increasingly be exposed to synthetic media featuring familiar faces in everyday life (Mello, 2021). This raises the question of whether encounters with synthetic media featuring one's own likeness will intensify the uncanny valley effect of near-human interfaces. Thus, my following study examines the doppelgänger hypothesis in the uncanny valley literature from the perspective of the self-reference effect.

Investigating the Doppelgänger Hypothesis from a Self-Reference Effect Perspective

This phenomenon predicts that near-human targets featuring the self will generate stronger uncanny perceptions than near-human targets featuring strangers. The self-reference effect is a psychological phenomenon which enhances individuals' cognitive processing, interpretation, and memory for personally relevant information (Rogers et al., 1977). Meta-analysis of the self-reference effect reveals that approximately 80% of self-reference research utilizes verbal trait word tasks, a procedure where participants relate trait words to themselves or others (Symons & Johnson, 1997). Nevertheless, Serburn et al. (2011) explore how self-reference behavior enhances participants' visual memory through a two-part experiment. On the first day of the experiment, participants viewed 108 everyday purchasable objects alongside text prompts asking if the participant, their mother, or Bill Clinton would purchase the item in the next year (Serburn et al., 2011). On the second day of the experiment participants' cued recall was tested for the previously viewed items. In broad support for referencing effects, Serburn et al. (2011) reveal that both self-reference, as well as referencing for a close other (here being participants' mothers), enhanced participants' specific and general memory of items recalled.

Additionally, Phua and Kim (2018) provide examination on how participants' self-reference endorsement of advertisements influence brand attitudes and purchase intentions. To do such, Phua and Kim (2018) conduct an online survey of 350 Snapchat geofilter advertisement users to examine how consumers' practice of sharing selfies adorned with brand logos influences their brand related preferences. From the responses of their participants, Phua and Kim (2018) identify a significant main effect of self-reference behavior that heightened participants' brand attitude and purchasing intention. Further, the impact of self-reference behavior on brand attitude and purchasing intention was amplified by an interaction with participants' reported self-brand

congruity (Phua & Kim, 2018). As noted above, few studies have addressed seld-referencing predictions in the uncanny valley literature. Weisman and Peña (2021) identify that persuasive avatars featuring participants' self-faces generate significantly greater uncanny perceptions relative to persuasive avatars featuring the faces of strangers. These strengthened uncanny perceptions mediate participants' affect-based trust toward target avatars (Weisman & Peña, 2021). Additionally, Nitta and Hashiya (2021) find that 12-month-old infants display visual avoidance toward morphed images presenting their self-faces, relative to unmodified images presenting their own faces or the faces of peers, through analysis of eye-tracking data. These two empirical works provide meaningful, though limited, examination of the doppelgänger hypothesis in the uncanny valley literature from the perspective of the self-reference effect.

Based on the foregoing, this study examines how reactions cued by a near-human digitally manipulated uncanny image will be enhanced by the self-reference effect. Conceivably, participants may be especially attentive to alterations that implicate their self-image (Rogers et al., 1977), and thereby experience enhanced uncanny valley reactions toward personally relevant digital content. Alternatively, participants may display an enhanced acceptance of images that bear their own resemblance (Bjornsdottir et al., 2022), and resultant in a homophily effect that attenuates the uncanny valley.

The Polythetic Outcome of the Uncanny Valley

In addition, my meta-analytic findings reveal that the outcome of the uncanny valley phenomenon is polythetic in nature; able to significantly impact variables beyond the monothetic outcome of affect, in expansion of seminal hypothesis provided by Mori (1970). Indeed, my review finds that empirical works record largest uncanny valley effect sizes for participants' cognition (d = 1.63), followed by attitudes (d = .96), affect (d = .88), with a medium sized effect

attributed to behavior (d = .76). These results provide meaningful illumination to the initial meta-analytic expansion of the outcome of the uncanny valley phenomenon beyond affect provided by Diel et al. (2022). Here, Diel and associates highlighted the uncanny valley phenomenon's ability to impact a broad constellation of non-affect based "indirect measures" observed in empirical works. Guided by the results of these two meta-analyses, my next study examines the uncanny valley's impact of self vs. stranger images on measures of affect (i.e., likeability and uncanny perceptions), behavior through simulated resource donation task, and attitudes through evaluation of similarity identification, human perception of stimuli, and ratings of stimuli's agency, emotion, and realism. Thereby:

H1 Relative to stranger-photo morphs, self-photo morphs will (a) be perceived as more human than mechanic, (b) be less likable, (c) elicit increased resource allocation, (d) generate greater uncanny perceptions, (e) increase theory of mind emotion, (f) increase theory of mind agency, (g) heighten identification, and (h) increase perceived realism.

H2 Relative to more mechanic morphs, more anthropomorphic morphs will (a) be perceived as more human than mechanic, (b) be more likable, (c) elicit increased resource allocation, (d) generate reduced uncanny perceptions, (e) increase theory of mind emotion, (f) increase theory of mind agency, (g) heighten identification, and (h) increase perceived realism.

Interaction Effects

I hypothesize that the combined effect of the mechano-anthropomorphic morph manipulation and the self- and stranger-face morph manipulation will be greater than the sum of their individual effects. Specifically, I expect an additive interaction, where the impact of the

mechano-anthropomorphic morph manipulation is enhanced by the presence of self-face morphs relative to the presence of stranger-face morphs, due to the self-reference effect. This expectation is informed by empirical work conducted by Seyama and Nagayama (2007) who provide evidence that manipulations to morph continuum images' eyes enhance participants' uncanny perceptions beyond those elicited by the doll-to-human morph continuum images alone. I forward that the self-reference effect will enhance participants' sensitivity to the mismatched realism of visual stimuli Seyama and Nagayama (2007) attribute as cause of the interaction effect observed within their study. As such, the following research question investigates the interplay between these two manipulations:

H3 More anthropomorphic self-photo morphs will (a) be perceived as more human than mechanic, (b) be less likable, (c) elicit increased resource allocation, (d) generate greater uncanny perceptions, (e) increase theory of mind emotion, (f) increase theory of mind agency, (g) heighten identification, and (h) increase perceived realism relative to less anthropomorphic self-photo morphs.

Establishing the Shape of the Uncanny Valley Phenomenon

Mori (1970) describes a valley between stimuli's human-likeness and stimuli's resulting elicited affect from which the uncanny valley phenomenon receives its name. However, this "valley-like" relationship proposed by Mori (1970) has received mixed evidence (Wang et al., 2015). Mori's hypothesized shape is important to examine as it challenges the assumption that increased human-likeness will invariably lead to more affinity toward virtual humans, robots, and other entities.

In support of Mori's valley-like relationship, MacDorman and Isiguro (2006) present participants with 11-step robot-human face morph continuums to identify classic cubic uncanny

valley rise, fall, and recovery relationships between morph stimuli's empirically manipulated human-likeness and participants' resulting ratings of the stimuli's familiarity. Notably, the negative apex of morph stimuli's rated familiarity coincided with the morph stimuli's peak rated eeriness (MacDorman & Isiguro, 2006). In addition, Mathur and Reichling (2016) present participants with 80 photographs of robots to identify classic cubic uncanny valley rise, fall, and recovery relationships between participants' ratings of the robots' humanness, likeability, and trust. Further, Seyama and Nagayama (2007) identify classical uncanny valley dip and recovery relationship between the manipulated human-likeness of doll-to-human and CG avatar-to-human face morphs and participants' ratings of the morphs' pleasantness, but only when the morph stimuli presented bizarre, enlarged eyes.

Contrary to Mori's valley-like relationship, Cheetham et al. (2014) describe a "happy valley" to describe their inconsistent findings. Cheetham and colleagues observe that participants' difficulty in an ABX (stimuli discrimination) task of human, avatar, and human-to-avatar morph faces were associated with positive instead of negative ratings of familiarity in an inverted "uncanny valley" graphical relationship. This positive effect was strongest for ambiguously human faces, thus suggesting that perceptual difficulty inhibits the development of negative affect (Cheetham et al., 2014). Separately, empirical work presents an "uncanny cliff" (Bartneck et al., 2007). Bartneck et al. (2007) utilize 18 real world and CG human and robot photographs to identify a significant, "cliff-like" parabolic decline in participants' ratings of the likability of stimuli by the stimuli's rated human-likeness, without meaningful "uncanny valley" recovery. Based on the above:

H4 Self and stranger photo morphs will display a classic "uncanny valley" fall and rise in (a) human perception, (b) likability, (c) resource allocation, (d) uncanny perceptions, (e) theory of mind emotion, (f) theory of mind agency, (g) identification, and (h) perceived realism.

RQ1 Will self- and stranger-photo morphs display a classic "uncanny valley" fall and rise in (a) human perception, (b) likability, (c) resource allocation, (d) uncanny perceptions, (e) theory of mind emotion, (f) theory of mind agency, (g) identification, and (h) perceived realism for (α) female participants and (β) male participants?

Moderators

My meta-analysis identifies enhanced behavioral outcomes of the uncanny valley for empirical works with a greater proportion of women relative to men. Gender-linked socialization effects are worth investigating so that these meta-analytically observed differences may be better understood. Insight into the effects of gender on the uncanny valley experience heighten the generalizability of uncanny valley research to facilitate effective human-agent interaction.

This study explores participants' SF&T affinity as a potential moderator of the uncanny valley effect. Consider that participants' familiarity with robots is associated with positive attitudes toward these machines (MacDorman et al., 2009). MacDorman et al. (2009) provide an atheoretical discussion of how differences between Japanese and American culture influence participants' explicit and implicit attitudes for mechanical beings. I harness cultivation theory to provide explanation for the effects observed within MacDorman et al. (2009). MacDorman and colleagues observe that Japanese anime and manga have a longstanding tradition of portraying robots in heroic roles, such as in *Astro Boy* (1952). According to cultivation theory, long-term

positive portrayals of fictional robots in media will better media consumers' attitudes towards robots in the real world (Gerbner & Gross, 1976). Because of this, my SF&T affinity scale includes measure of participants' consumption of media featuring robots. Additionally, I account for participants' interaction with advanced technology as part of my SF&T affinity measure, guided by social learning theory. Social learning theory posits that learning is a cognitive process that occurs through the imitation and modeling of others' behavior (Bandura & Walters, 1977). Observed or experienced positive benefits of AI use within my undergraduate sample may contribute to these individuals' more favorable view of AI as well as humanoid technologies more generally.

If significant moderation effects are indeed observed by participants' SF&T affinity, this variable will serve to unpack the demographic effects of participants' gender and age, found by my meta-analysis. Consider that disparate socialization pressures may lead men to be more familiar with such cutting-edge technology relative to women (Stewart-Williams et al., 2021). Rather than assuming that men experience reduced uncanny perceptions— identified by my meta-analysis— by virtue of being a young male, SF&T affinity is offered as third variable to unpack this effect. Similarly, exposure to SF&T due to affinity with such over the lifetime may explain the effects of participant sex and age that my meta-analysis observed. The explanatory power of participants' SF&T affinity as an uncanny valley moderator may likewise act as a third variable to explain the impact of social economic status, education, and other demographic factors that may be of interest to uncanny valley researchers, while reducing assumptions on groups' technology use that may evolve with time. Thus, the following research questions are forwarded:

RQ2 *Does participants' sex moderate the relationships explored in H1, H2, and H3?*

RQ3 *Does participants' SF&T affinity moderate the relationships explored in H1, H2, and H3?*

Methods

This empirical work's protocols and research material were approved before data collection by the university's Institute Review Board, IRB ID [2019789-1]. Preregistration of this research occurred on June 19, 2023. The registration's analytical plan was updated on November 10, 2023. The study's materials and data are publicly available on the Open Science Foundation (https://osf.io/7rs36).

A total of $N = 210$ participants were recruited from the subject pool of a large US West Coast university for extra credit opportunity. Of these participants, 103 were cisgender male, 95 were cisgender female, and 12 were gender nonbinary. Two of the female participants' data was not fully recorded by the Qualtrics software. In line with the preregistration— to facilitate balanced mediation analysis of participant sex— gender nonbinary participants, participants with missing data, and cisgender participants of either sex collected in excess of 95 were excluded from statistical analysis. This led to the exclusion of 22 participants. As such, the study had 95 cisgender men and 93 cisgender women ($N = 188$).

Power analysis was conducted on G*Power to find that 155 participants were required to achieve a high probability of statistical significance given an expected effect size of .28, an α error probability of .05, and a power (1-B err probability) of .95 in a priori two-sided *t*-tests. Thus, the study had sufficient statistical power to test its hypotheses.

The mean participant age was 19.90 with a standard deviation of 1.79. 65.4% of participants identified as Asian, 16.0% of participants identified as White, 7.4% of participants

identified as Hispanic/Latino, 6.9% identified as multiracial, 1.6% identified as Black, 1.6% identified as Middle Eastern or North African, and 1.1% identified as Native American.

Study Design and Stimuli Randomization

Each participant was exposed in random order to 22 morphs of self vs. stranger faces morphed at various blending degrees with a robot's visage. Latin squares randomization was utilized to randomly assign participants across the two blocking factors of a repeated measures factorial experiment with a between- and within-subjects design, being the 2(identity: self-face, stranger-face) by 11(percent human face morph: 0% human 100% robot to 100% human 0% robot, in 10% human-robot morph increments) conditions. Latin squares randomization serves to mitigate error variation imposed by viewing order effects of the targets across the two blocking factors.

Materials

Kobian-RIV provided the robot face. Kobian-RIV is a real world bipedal humanoid robot designed by the Atsuo Takanishi Lab of Waseda University intended for social interaction with humans (Kishi et al., 2012). The face of Kobian-RIV was selected due to the significant uncanny valley effects identified through its frequent use within prior research, as well as its unique compatibility with utilized image-morph software. Kobian-RIV's face generates the strongest uncanny perceptions in the form of rating response time of 80 real world robot faces examined (Mathur & Reichling, 2016). Additionally, Kobian-RIV is ranked as the seventh creepiest robot out of 231 robots rated by over 1,648 participants in IEEE's online "Robot Rankings" poll (IEEE Spectrum, 2023). Rosenthal-von der Pütten and Krämer (2014), Trovato et al. (2017), and Strait (2018) additionally utilize stimuli featuring Kobian-RIV, among other real robots.

Participants' face photos were transformed into 11-step face morph continuums with Abrosoft *FantaMorph* software. The personalized self-face face morph condition contained 11 face morph targets depicting the current participant's self-face blended with Kobian-RIV robot face from 0% human–100% robot to 100% human–0% robot in 10% human-robot increments. The stranger-face face morph continuums displayed prior same-sex participants' face morph continuums in yoked design to ensure that all participants were exposed to comparable stimuli. As the 0% human–100% robot face morph step contained an identical image of robot Kobian-RIV's face for the self- and stranger-continuums, this step was displayed to each participant only once. See Figure 6 for sample face morph images.

Procedure

After providing signed consent upon arriving to the laboratory, participants were read a cover story about pretesting material for a future study. Participants' face photos were taken in front of a light blue posterboard to create a neutral human-face background consistent with the light-blue background of the Kobian-RIV photo. Participants then completed a pre-test which contained basic demographic information measures, including participants' sex and gender, while research assistants created the human-robot morph stimuli for the experimental manipulation. Once the human-robot morph stimuli were ready for display, participants completed the post-test survey which contained the 21 image stimuli in yoked design for participants to rate in Latin-square randomized order. Lastly, participants were debriefed as to the purpose of the study.

Measures

Uncanny Perceptions. This scale had nine items adapted from (Destephe et al., 2015) utilized three groups of three 7-point semantic differential items to measure target images'

perceived humanness, eeriness, and attractiveness. Prompts included, “Do you perceive the target as: inanimate-living”, “What are your feelings about the target? eerie-reassuring”, and “What do you think of the target’s appearance? unattractive-attractive”. The scale achieved excellent internal consistency with a Cronbach’s alpha of .97 (M = 5.12, SD = 1.74).

Human Perception. This single item visual analogue scale adapted from Mathur and Reichling (2016) measured participants’ explicit judgement of the mechano-humanness of each target image. Here, participants manipulated a -100 to +100 sliding scale to answer, “How mechanical or human does the target look?” (M = -34.73, SD = 69.45). Sliding scale values were not displayed to participants.

Resource allocation. This single item visual analogue scale adapted from Mathur and Reichling (2016) measured participants’ altruistic behavioral intention for each target image. Here, participants manipulated a 0 to 100 sliding scale to answer, “How much of the $100 do you give to the target?” (M = 23.73, SD = 24.31). Sliding scale values were displayed to participants.

Likeability. This single item 7-point semantic differential scale adapted from Mathur and Reichling (2016) examined the perceived pleasantness of each target. Participants were asked, “How unpleasant or pleasant is it to look at the target? Unpleasant – Pleasant” (M = 2.98, SD = 1.73).

Identification. This three item 7-point semantic differential scale adapted from Van Looy et al. (2012) captured participants’ similarity identification, wishful identification, and embodiment of target images. Its questions included, “Do you perceive that the target: Is not at all similar to me – Is extremely similar to me.” This scale earned excellent reliability with a Cronbach’s alpha of .92 (M = 2.42, SD = 1.70).

Mind Perception. Semantic differential measures adapted from Gray and Wegner (2012) examined participants' perceptions of target images' apparent ability to demonstrate agency and experience emotion. Participants were asked, "Do you perceive that the target: Lacks capacity to experience pain and fear – Holds the capacity to experience pain and fear; and Lacks capacity to plan actions and exercise self-control – Holds the capacity to plan actions and exercise self-control." While theory of mind agency (M = 3.69, SD = 2.16) and theory of mind emotion (M = 3.10, SD = 2.16) present two theoretically distinct measures, and thus are separately analyzed, the single items of these two scales demonstrated good reliability with Cronbach's alpha of .86.

SF&T affinity. This 21 item 7-point Likert-type scale expanded upon Weisman and Peña (2021) to broadly measure: participants' baseline perceptions of robots, artificial intelligence, science, and technology. Consumption of media with positive and negative portrayal of robots; use of virtual assistants such as Apple's *Siri*; and use of novel generative AI such as OpenAI's *ChatGPT*. This measure demonstrated good reliability with a Cronbach's alpha of .85 (M = 3.99, SD = .79). While a novel scale, this measure was inspired by empirical work provided by Zanatto et al. (2010), which identified that participants' interactions with robots are guided by their prior experiences and expectations. See Scale A1 for this measure's items.

Perceived Realism. This three item 7-point Likert-type scale adapted from McGloin et al. (2011) polled participants on how realistic the agent the target portrayed appeared. Items included, "Looks like a real human", "Looks like a real android", and "Looks like a real robot" from 1 (strongly disagree) to 7 (strongly agree). Internal reliability was unacceptable with a Cronbach's alpha of -1.28 and could not be improved beyond a poor Cronbach's alpha of .50 through reverse coding. This measure was dropped from the analysis.

Results

Statistical analysis was conducted with IBM SPSS version 29.0.0.0 (241). A Bonferroni-corrected repeated measures multivariate analysis of variance was performed with the empirical self- and stranger-face morph and mechano-anthropomorphic manipulations set as within-subjects factors, and participants' sex and SF&T affinity as between-subjects factors. Mauchly's test was utilized to assess sphericity for the repeated measures MANOVA in the following statistical analysis (Field, 2018). The Greenhouse-Geisser correction was applied to address sphericity issues where detected (Field, 2018). The presence of this correction is indicated by reported *F*-tests with non-whole number numerator degrees of freedom. Following guidance from Lakens (2013), partial eta squared was presented in report of effect sizes from the following MANOVA analysis which contains both manipulated and unmanipulated factors. A significance test of slope differences was utilized to break apart the significant two- and three-way interactions between independent and dependent variables where significant (Dawson & Richter, 2004). Contrast analysis was performed through an adapted simple slope methodology, where the slope of dependent on independent variables were calculated when independent variables were held constant at binary high (+1 SD) and low (-1 SD) values (Dawson & Richter, 2004). In particular, the continuous variables of the mechano-anthropomorphic manipulation and participants' SF&T affinity were made binary categorical at their +1 SD and -1 SD values, while the binary categorical variables of the self- and stranger-face manipulation, and participant sex were left unmanipulated (Dawson & Richter, 2004). The emmeans R package, version 1.10.1, was utilized to compute and test the differences between slope pairs to identify significant contrasts.

H1 predicted that relative to stranger-photo morphs, self-photo morphs would be perceived as more human, be less likeable, elicit increased resource allocation, generate greater uncanny perceptions, increase mind perception, heighten identification, and increase perceived realism. As hypothesized, self-morphs significantly enhanced participant resource allocation $F(1, 3927) = 5.59$, $p = .02$, $\eta^2_p = .05$, and increased participant identification $F(1, 3927) = 135.91$, $p < .001$, $\eta^2_p = .58$, relative to stranger-morphs. However, counter to H1, the effects of self-morphs did not differ from those of stranger-morphs on human perception of target images $F(1, 3927) = .04$, $p = .85$, $\eta^2_p < .001$, likeability $F(1, 3927) = 3.13$, $p = .08$, $\eta^2_p = .03$, uncanny perceptions $F(1, 3927) = 3.51$, $p = .06$, $\eta^2_p = .04$, theory of mind emotion $F(1, 3927) = .65$, $p = .42$, $\eta^2_p = .01$, or theory of mind agency attributed to the photos $F(1, 3927) = .48$, $p = .49$, $\eta^2_p = .01$. See Table 3 for descriptive statistics. Thus, H1(c), and H1(g) received empirical support, while H1(a), H1(b), H1(d), H1(e), and H1(f) did not.

H2 predicted that relative to more robotic face morphs, more anthropomorphic face morphs would be perceived as more human, be more likeable, elicit increased resource allocation, increase mind perception, heighten identification, increase perceived realism, and reduce uncanny perceptions. More anthropomorphic face morphs indeed elicited greater human perception $F(4.35, 3927) = 1364.89$, $p < .001$, $\eta^2_p = .93$, likeability $F(4.20, 3927) = 304.38$, $p < .001$, $\eta^2_p = .76$, resource allocation $F(2.69, 3927) = 141.50$, $p < .001$, $\eta^2_p = .59$, theory of mind emotion $F(4.81, 3927) = 488.56$, $p < .001$, $\eta^2_p = .83$, theory of mind agency $F(3.01, 3927) = 216.10$, $p < .001$, $\eta^2_p = .69$, identification $F(3.85, 3927) = 593.09$, $p < .001$, $\eta^2_p = .86$ and reduced uncanny perceptions $F(3.82, 3927) = 848.73$, $p < .001$, $\eta^2_p = .90$, relative to more robotic face morphs. H2 was fully supported, and thus indicated a reliable effect of the mechano-human face morph manipulation.

H3 predicted an interaction effect between the self- and stranger-photo manipulation and the mechano-anthropomorphic manipulation, such that more anthropomorphic self-photo morphs would be perceived as more human, be less likable, elicit increased resource allocation, generate greater uncanny perceptions, increase mind perception, heighten identification, and increase perceived realism relative to more mechanic stranger-photo morphs. A significant two-way interaction effect of the self- and stranger-morph manipulation with the mechano-anthropomorphic manipulation was found on resource allocation $F(4.28, 3927) = 5.62$, $p < .001$, $\eta^2_p = .05$, identification $F(5.29, 3927) = 48.03$, $p < .001$, $\eta^2_p = .33$, and theory of mind agency $F(6.31, 3927) = 2.11$, $p = .047$, $\eta^2_p = .02$, for self- relative to stranger-face morphs. No significant interaction effects were identified on human perception $F(5.22, 3927) = 1.27$, $p = .27$, $\eta^2_p = .01$, likability $F(5.87, 3927) = 1.63$, $p = .14$, $\eta^2_p = .02$, uncanny perceptions $F(5.01, 3927) = .69$, $p = .63$, $\eta^2_p = .01$, and theory of mind emotion $F(6.59, 3927) = 1.64$, $p = .13$, $\eta^2_p = .02$.

Contrast analyses were utilized to provide insight into the significant two-way interactions of the self- and stranger-morph manipulation with the mechano-anthropomorphic manipulation on participants' resource allocation, identification, and theory of mind agency toward target face morphs in method adapted from Dawson and Richter (2004), discussed above. See Table 4 for these contrasts' statistical reports, and Figure 7 for graphical depiction of the contrasts' effects. When the face morphs were more anthropomorphic, resource allocation was higher for self- relative to stranger-face morphs. In addition, when the face morphs were more anthropomorphic, participants' resource allocation, identification, and ToM agency were higher for both self- and stranger-face morphs. Remaining contrasts were tested and found insignificant. The Discussion section elaborates on potential reasons behind this pattern of results. Thus,

H3(c), H3(f), and H3(g) were supported, whereas H3(a), H3(b), H3(d), H3(e), and H3(h) received no support.

H4 predicted a classic graphical "uncanny valley" dip and recovery relationship for all outcome variables along the mechano-anthropomorphic manipulations of self vs. stranger faces. Consistent with Burleigh et al. (2013), R^2 was utilized to select the best fitting linear, quadratic, or cubic model in description of the shape of the relationship observed between the independent and dependent variables. Cubic relationships best described the relationship of self-face morph targets with human perception (R^2 = .77), likeability (R^2 = .43), resource allocation (R^2 = .23), uncanny perceptions (R^2 = .68), theory of mind emotion (R^2 = .55), theory of mind agency (R^2 = .35), and identification (R^2 = .66). Likewise, cubic relationships best described the graphical relationships between the stranger-face morph manipulation and human perception (R^2 = .73), likeability (R^2 = .45), resource allocation (R^2 = .18), uncanny perceptions (R^2 = .68), theory of mind emotion (R^2 = .53), theory of mind agency (R^2 = .34), and identification (R^2 = .42). Nevertheless, the relationships between the self- and stranger-face morph's mechanic-human likeness and the dependent variables did not resemble the classical uncanny valley relationship. Rather, escalator-like, growth relationships were observed. See Figure 8. As such, H4 is not supported. The escalator-like relationship is further addressed in the Discussion, below.

RQ1 investigated whether men and women equally exhibited the classic rise, dip, and recovery uncanny valley pattern along the mechano-human face manipulations of self vs. stranger-faces on the outcome variables. Akin to methodology utilized in analysis of H4, R^2 was again applied to select the best fitting linear, quadratic, or cubic regression models in description of graphical results. Congruent with the uncanny valley hypothesis, R^2 identified that cubic relationships best described the correlation between self-morphs manipulated near-humanness

and the recorded outcomes of human perception (R^2_{female} = .74, R^2_{male} = .80), likeability (R^2_{female} = .46, R^2_{male} = .40), resource allocation (R^2_{female} = .29, R^2_{male} = .18), uncanny perceptions (R^2_{female} = .70, R^2_{male} = .67), theory of mind emotion (R^2_{female} = .58, R^2_{male} = .52), theory of mind agency (R^2_{female} = .37, R^2_{male} = .34), and identification (R^2_{female} = .69, R^2_{male} = .63) for both female and male participants. Likewise, cubic relationships best described the association between stranger morphs along the mechano-human face manipulation and human perception (R^2_{female} = .69, R^2_{male} = .78), likeability (R^2_{female} = .50, R^2_{male} = .41), resource allocation (R^2_{female} = .23, R^2_{male} = .14), uncanny perceptions (R^2_{female} = .69, R^2_{male} = .67), theory of mind emotion (R^2_{female} = .54, R^2_{male} = .52), theory of mind agency (R^2_{female} = .34, R^2_{male} = .33), and identification (R^2_{female} = .47, R^2_{male} = .37) for women and men. There were minimal differences between cubic model fit by participant sex though women's data demonstrated a better model fit for all outcome measures except human perceptions. Nevertheless, these cubic relationships displayed by male and female participants did not take the form of traditional cubic uncanny valley rise, fall, and recovery pattern described by Mori (1970). Rather, consistent with the results for H4, growth curves implying escalator-like relationships were observed for women and men, demonstrating the importance of visualization in conformation of purported uncanny valley effects. See Figures 9 and 10.

RQ2 assessed the influence of participants' biological sex on the above-described relationships. Participant sex held an insignificant direct effect on all outcome variables. Nevertheless, significant two-way interaction effects between participants' sex and the self- and stranger-face morph manipulation was observed on likeability $F(1, 3927) = 4.74$, $p = .03$, $\eta^2_p = .05$, as well as on uncanny perceptions $F(1, 3927) = 4.05$, $p = .047$, $\eta^2_p = .04$. Likewise, significant two-way interaction effects were observed between participants' sex and mechano-

anthropomorphic manipulation on human perception of face morphs $F(4.35, 3927) = 2.51$, $p = .04$, $\eta^2_p = .30$. No significant three-way interactions between participant sex, self- and stranger-face morph manipulation, and mechano-anthropomorphic manipulation on outcome variables were identified. For descriptive statistics of outcome measures by participant sex, see Table 5.

Contrast analyses were utilized to provide insight into the significant two-way interactions of participants' biological sex and the self- and stranger-face morph manipulation on target's elicited likeability and uncanny perceptions, as well as the significant two-way interaction between biological sex and the mechano-anthropomorphic morph manipulation on participants' human perception of target face morphs. See Tables 6 and 7 for the contrasts' statistical reports, and Figures 11 and 12 for the contrasts' graphical depictions. Women reported greater human perception of mechanical morphs than men. Additionally, for both men and women, human-perception was greater for anthropomorphic morphs than mechanical morphs. Remaining contrasts were tested and found insignificant.

RQ3 examined the influence of participants' SF&T affinity on the relationships examined above. No direct effect of this factor was observed on outcome variables. However, significant interaction effects between SF&T affinity with self- and stranger-face morph manipulations were found on human-likeness $F(59, 3927) = 1.64$, $p = .02$, $\eta^2_p = .50$, likability $F(59, 3927) = 1.76$, $p = .01$, $\eta^2_p = .52$, uncanny perceptions $F(59, 3927) = 1.82$, $p = .004$, $\eta^2_p = .52$, theory of mind emotion $F(59, 3927) = 1.96$, $p = .002$, $\eta^2_p = .54$, theory of mind agency $F(59, 3927) = 2.03$, $p < .001$, $\eta^2_p = .55$, and identification $F(59, 3927) = 1.24$, $p = .18$, $\eta^2_p = .43$.

Contrast analyses were likewise utilized to elucidate the significant two-way interactions between SF&T affinity with the self- and stranger-morph manipulation on participants' perceived human-likeness, likeability, uncanny perceptions, ToM emotion, ToM agency,

identification with target face morphs. See Table 8 for these contrasts' statistical reports, and Figure 13 for graphical depiction of these contrasts' effects. Participants with increased SF&T affinity reported greater ToM emotion and ToM agency for stranger-face morphs, and greater likability, ToM emotion, and identification for self-face morphs. Participants with either low or high SF&T affinity reported greater identification for self-face morphs relative to stranger-face morphs. Remaining binary contrasts were tested and found insignificant.

Further, significant interaction effects were identified between participants' SF&T affinity and the mechano-anthropomorphic manipulation on uncanny perceptions $F(225.57, 3927) = 1.29$, $p = .02$, $\eta^2_p = .44$, theory of mind emotion $F(284.03, 3927) = 1.44$, $p < .001$, $\eta^2_p = .46$, and identification $F(227.01, 3927) = 1.26$, $p = .02$, $\eta^2_p = .43$. Contrast analyses were performed to elucidate these significant two-way interactions. See Table 9 for the contrasts' statistical reports, and refer to Figure 14 for their graphical depiction. Participants with increased SF&T affinity reported greater ToM emotion and identification for both mechanical and anthropomorphic face morphs, along with attenuated uncanny perceptions for mechanical face morphs. In addition, when SF&T affinity was either low or high, ToM emotion and identification were increased while uncanny perceptions were reduced for anthropomorphic relative to mechanical face morphs. Remaining contrasts were insignificant.

Furthermore, a significant three-way interaction between SF&T affinity, self-stranger morph manipulation, and mechano-anthropomorphic manipulation was observed on human perception $F(308.21, 3927) = 1.24$, $p = .02$, $\eta^2_p = .43$ and ToM emotion $F(388.58, 3927) = 1.28$, $p = .003$, $\eta^2_p = .44$. Twelve contrasts were performed to explore each significant three-way interaction. See Table 10 for these three-way contrasts' statistical reports, and Figure 15 for graphical depiction of contrasts. The contrasts revealed that anthropomorphic face morphs

heightened participants' human perception of target images when SF&T affinity was low, and stranger-face morphs were displayed; when SF&T affinity was high, and stranger-face morphs were displayed; when SF&T affinity was low, and self-face morphs were displayed; and when SF&T affinity was high, and self-face morphs were displayed. Additionally, self-face morphs heightened participants' human perception of target images when participants' SF&T affinity was low, and anthropomorphic morphs were displayed. Last, participants with high SF&T affinity showed enhanced human perception of target images when displayed anthropomorphic stranger-face morphs. The remaining contrasts were insignificant.

In the results above, note that the mechano-anthropomorphic manipulation was a consistently reliable factor contained in the three-way interaction on human perception of targets. As such, robot-human face morph continuums were an effective form of uncanny stimuli, in confirmation of meta-analytic guidance. In comparison, the effects of the self- and stranger manipulation and SF&T affinity less consistent.

Continued analysis elucidated that the significant three-way interaction observed between the self-stranger morph manipulation, the mechano-anthropomorphic manipulation, and SF&T affinity that heighted participants' ToM emotion of targets occurred across eight pairs of binary contrasts. See Table 11 for these three-way contrasts' statistical reports, and Figure 16 for graphical depiction of these contrasts' effects. Anthropomorphic face morphs heightened participants' ToM emotion of target images when SF&T affinity was low, and stranger-face morphs were displayed; when SF&T affinity was high, and stranger-face morphs were displayed; when SF&T affinity was low, and self-face morphs were displayed; and when SF&T affinity was high, and self-face morphs were displayed. Additionally, participants with increased SF&T affinity attributed greater ToM emotion for self and stranger mechanical and anthropomorphic

face morphs. The four remaining contrasts belonging to the self- and stranger-face manipulation were insignificant.

Discussion

This study investigated the impact of robot-human face morph continuum of self vs. other images to bring insight into how the self-reference effect impacts the uncanny valley phenomenon. In addition, the use of a robot-human face morph continuum allowed this study to gain insight into the shape of uncanny valley response generated by self- and stranger-morph continuums.

A Self-Reference Perspective on the Doppelgänger Effect

Consistent with H1, participants showed more resource allocation and increased identification with self- relative to stranger-morphs. Hence, participants displayed self-reference behavior on self-interested outcomes. Unexpectedly, self-reference effects did not influence ratings of targets' human-likeness, likeability, theory of mind emotion and agency, or uncanny valley perception. Thus, the self-reference effect that underpins the doppelgänger hypothesis of the uncanny valley, had positive but contained effects.

This finding situated the self-reference effect and the doppelgänger hypothesis within the broader field of uncanny valley and self-reference research. Though the impact of the doppelgänger hypothesis on dependent measures was less consistent when triggered by CG morph image continuums, its effect was more reliable on self-related outcomes of identification and resource allocation than on target-perception oriented outcomes of human perception, likeability, uncanny perceptions, ToM emotion, and ToM agency. This finding contributed to the literature by showing how participants' self-reference effect to morph continuum images is moderated by a self-serving bias. The presence of such self-serving bias informed how

participants' perceptions of the DVs' importance influenced self-reference behavior to face-morph stimuli. This pattern is consistent with self-reference literature that utilized participants' normative importance ratings of trait adjectives in source memory task to predict participants' false memories of the traits having been presented in a self-referential manner, rather than in description of another (Culcea & Freitas, 2017). Across two studies, Culcea and Freitas (2017) identified that participants' subjective ratings of trait importance influenced their self-referential decisions, in support of the hypothesis that cue importance biases self-referential behavior. Thus, Culcea and Freitas' (2017) findings informed that the significant self-reference effect observed within my present work on the outcomes of identification and resource allocation may have been driven both the display of self, as well as participants' subjective self-interested evaluations of these two dependent variables' importance.

Future research should examine how the inclusion of gradations self-mimicking movement or emulations of participants' voice may enhance the self-reference effect that underlies the doppelgänger hypothesis beyond that instigated by morph continuum images. Weisman and Peña (2021) found that participants attributed lower affect-based trust and higher uncanny perceptions to talking-head avatars resembling themselves, compared to those resembling strangers. Stimuli utilized by Weisman and Peña (2021) more closely capture the "doppelgänger" concept discussed by Freud (1919). With the increasing prevalence of AI-powered visual and audio filters optimized for interpersonal communication in daily life, contexts where self-reference effects may be expected to yield significant impact on the doppelgänger hypothesis of the uncanny valley remain ripe for further empirical investigation. Future research would do well to explore the minimum image, movement, and audio conditions

necessary for participants' self-reference behavior to impact both self-interested and target-perception outcomes in the context of virtual recreations of the self.

Broad Support for the Positive Impact of Stimuli's Human-Likeness

Regarding H2, more anthropomorphic morphs were perceived as more human than mechanic, more likable, elicited increased resource allocation, generated reduced uncanny perceptions, increased mind perception, heightened identification, and increased perceived realism of target images relative to more mechanic morphs. These results resonated with the large and moderate effect sizes associated with usage of similar mechano-anthropomorphic manipulations within uncanny valley research, commonly conceptualized as tests of the categorization ambiguity hypothesis (Diel et al., 2022; Kätsyri et al., 2015). Such findings upheld the notion that increasing the human-likeness of stimuli increases participants' positive experiences (Kätsyri et al., 2015; Nowak & Rauh, 2005). As such, these results contributed to the growing body of evidence that unwanted uncanny valley reactions may best be avoided through presentation of evermore humanlike stimuli, rather than stimuli which avoids the appearance of human-likeness altogether.

Significantly, these results demonstrate the importance of avatar anthropomorphism on the person perception process within uncanny valley research. Social cognition theory stipulates that the ability to recognize anthropomorphic characteristics for the categorization of stimuli as human, animal, or object is a foundational cognitive function (Nowak & Rauh, 2005). In face-to-face interaction, communicators rely on information provided by the visible physical cues of interlocutors, whereas in mediated environments, communicators rely on information provided by avatars and interfaces to form perceptions of personhood (Bailenson et al., 2005; Bull & Rumsey, 1988; Burgoon, 1994; McGloin et al., 2014; Nowak, 2004; Nowak & Biocca, 2003).

Avatar anthropomorphism—examined within my present research through display of robot-human face morph continuums— is known to influence such perceptions of personhood (Nowak, 2015; Nowak & Rauh, 2005). Evolutionarily, the differentiation of stimuli as static object, animal, friend, or foe would have been essential for survival, evidenced by the innate low resource nature such cognition (Nowak & Rauh, 2005; Reeves & Nass, 1996). Taken together, the reliable impact of avatar anthropomorphism observed within my present work under the lens of social cognition theory serves to suggest an evolutionary component of the uncanny valley phenomenon (Nowak, 2015; Reeves & Nass, 1996).

Interaction Effect of Self-Reference with Stimuli's Human-Likeness

As anticipated, an additive interaction effect was observed where the positive impact of the mechano-anthropomorphic manipulation was amplified by the presence of self-face morphs relative to stranger-face morphs, consistent with the self-reference effect. This gestalt interaction effect enhanced participants' identification with targets, simulated resource allocation, and heightened perceptions of targets' theory of mind agency for anthropomorphic self-face morphs, compared to mechanical stranger-face morphs.

This finding expanded upon the results of H1 to inform that the self-reference effect served as a broad moderator that reduced uncanny effects for both self- and other-oriented outcomes, unconstrained by a self-serving bias. Across both direct and indirect pathways, participants were found to display an enhanced acceptance for images that bore their self-resemblance, counter to the doppelgänger hypothesis. This finding suggested that the self-reference effect triggered a homophile effect, as informed by Bjornsdottir et al. (2022), rather than a heightened sensitivity to mismatched realism in self-image morph-continuum stimuli, as guided by Seyama and Nagayama (2007). Resultantly, I suggest that developers of synthetic

humans would do well to incorporate their users' visual likenesses to inhibit the development of uncanny valley perceptions.

Further, in expansion of the investigation provided by H2, the mechano-anthropomorphic manipulation was found to reliably drive the two-way interaction on identification, resource allocation, and ToM agency to cement the strength of this manipulation within the broader field of uncanny valley research. This empirical finding upholds meta-analytically guided expectations. Meta-analysis provided by Diel et al. (2022) identified that morphing techniques were associated with large uncanny valley effects. Additionally, my own meta-analysis found that the categorization ambiguity hypothesis— frequently tested through the display of visual continuums— was correlated with greatest combined uncanny valley effect. Thus, this experimental result provided valuable demonstration of the efficacy of anthropomorphic manipulations to inform the design of consistently effective moderators and mediators within future uncanny valley works.

The Anthropomorphic Escalator Relationship

Numerous prior works have failed to identify a consistent uncanny valley relationship as proposed by Mori (1970). Instead, empirical works have described several unique and inconsistent patterns of the graphical relationship between the human-likeness of stimuli and dependent measures. Take Hanson (2005) who found that participants rated an entire human-cartoon image morph continuum as being roughly equally acceptable, regardless of the level of the target's morph's anthropomorphism. Separately, Seyama and Nagayama (2007) explored 11-step and 21-step human-doll morph continuums and found that the imperfect human-likeness of human-doll morph stimuli alone was insufficient to evoke an uncanny valley relationship in participants' impression formation. In pattern reminiscent to that observed by my present work,

Kätsyri et al. (2019) identified a consistent, mostly linear "uncanny slope" relationship between the manipulated human-likeness and rated affinity of both computer-generated and painted-human face morphs. Kätsyri et al. (2019) attributed the observed "uncanny slope" relationship to the perceptual familiarity of the target morphs.

Likewise, within my present study, there was no evidence for the classical "valley" relationship between the human-likeness of stimuli and dependent variables outcomes. Rather, in line with expectations informed by social cognition theory, I observed an "anthropomorphic escalator" between the human-likeness of target morphs and the outcomes of human perception, resource allocation, likability, uncanny valley, theory of mind emotion, theory of mind agency, and identification. These results displayed that participants consistently enjoyed target morphs the more anthropomorphic they were, with no observed decrease in observed response toward stimuli that was near, though imperfectly human. This finding consistent across all seven dependent variables suggested that participants held a robust preference for humanlike face-morphs that eased the person perception process.

As indicated by R^2, the strength of the anthropomorphic escalator effect did not meaningfully differ between the self- and stranger-face morph continuums, or for male and female participants. Notably, R^2 informed that observed anthropomorphic escalator patterns were best described by cubic relationships, a statistical heuristic commonly seen in uncanny valley research to confirm the presence of uncanny valley phenomenon (e.g., Burleigh et al., 2013; Kätsyri et al. 2019; Kim et al. 2019; Mathur & Reichling, 2016). Nevertheless, graphical representation of the anthropomorphic escalator relationships revealed a consistent growth pattern across dependent variables, distinct from Mori's (1970) hypothesized rise, fall, and recovery pattern.

My theory-guided explanation of the anthropomorphic escalator effect is of notable significance to the academic study of the uncanny valley phenomenon. I provided novel stipulation that stimuli's facilitation of the human perception process— in addition to the traditional consideration of stimuli's human-likeness— influenced graphical uncanny relationships. This postulation deepened scientific understanding of the multi-faceted cause of the uncanny valley phenomenon, found to be polythetic by my meta-analysis. Additionally, application of social cognition theory contributed novel theoretical framework to reconcile the frequently inconsistent graphical relationships observed by uncanny valley works. Through the consistent anthropomorphic escalator effect observed across measures of participants' affect, behavior, cognition, and attitudes, I presented guidance to academia and industry that synthetic faces should exhibit a high level of human realism to prevent unwanted uncanny valley effects.

The Impact of Participants' Sex

Many factors have been found to influence perceptions of humanlike stimuli beyond the aesthetic design of the stimuli alone (Bailey et al., 2023). Nevertheless, prior research on the uncanny valley has primarily focused on uncovering the characteristics of stimuli that trigger uncanny valley outcomes, rather than participants' demographic traits that may influence individual level susceptibility to uncanny valley outcomes (Bailey et al., 2023). This has left a pertinent gap in knowledge on the uncanny valley phenomenon. My meta-analysis identified that participants' biological sex and age significantly moderated uncanny valley outcomes within examined literature. Here, older participants exhibited reduced affective, behavioral, and attitudinal responses compared to younger participants. Additionally, female participants displayed greater behavioral outcomes than their male counterparts. These findings underscored the importance of demographic factors in the interpretation of empirical uncanny valley results.

My present research did not identify a direct effect of participants' sex on recorded outcome measures. Nevertheless, interaction analysis revealed that female participants reported heightened human-perception of mechanical targets relative to male participants. This finding suggested that women experienced a reduced uncanny valley effect from exposure to mechanical targets relative to men, counter to expectations guided by my meta-analysis. Such empirical result is not unprecedented. The effect of participants' sex on uncanny valley phenomenon has been found to be unstable within uncanny valley works (e.g., Bailey et al., 2023; McQueen, 2012). One possible explanation for these inconsistent results were baseline differences in male and female participants' affinity for various forms of stimuli utilized in uncanny valley works. Indeed, MacDorman et al. (2009) associated participants' familiarity with robots to positive attitudes toward robot stimuli. I proposed SF&T affinity as a demographic third variable to broaden the generalizability of uncanny valley research and facilitate the development of effective human-agent interaction.

The Impact of Participants' SF&T Affinity

Guided by my meta-analytic results, I have offered SF&T affinity as a meaningful theory-guided alternative to participants' age and sex as moderators of uncanny valley stimuli. Indeed, research examining the impact of participants' age on the uncanny valley phenomenon has asserted exposure as the relevant developmental mechanism (Lewkowicz & Ghazanfar, 2011). This decision was further informed by Zanatto et al. (2010), which identified that participants' interactions with robots are guided by their prior experiences and expectations with such technologies. Thereby, my measure of SF&T affinity differed from other commonly utilized demographic factors such as sex and age which hold no direct connection to the uncanny

valley phenomenon, to contribute to the advancement of more equitable research practices unburdened by stereotypes.

SF&T affinity was not found to hold a direct effect on recorded outcome measures. Nevertheless, SF&T affinity interacted with both the self- and stranger-face morph manipulation, and the mechano-anthropomorphic manipulation to cement this demographic factor as a more robust moderator than participants' biological sex. Of significance to uncanny valley scholars, participants with high levels of SF&T affinity reported enhanced perceptions of ToM emotion and ToM agency for stranger-face morphs. Thereby, SF&T affinity was found to moderate the effects produced by the most utilized form of stimuli within uncanny valley research (Kätsyri et al., 2019). Additionally, participants with high levels of SF&T affinity reported enhanced ToM emotion and identification as well as reduced uncanny perceptions across the mechano-anthropomorphic face morph continuum. Such broad moderation effect brought into question the generalizability of uncanny valley research often conducted upon undergraduate samples who were more familiar with novel technologies than the general population (Smith et al., 2011).

Further, participants with high levels of SF&T affinity reported greater likeability, ToM emotion, and identification for self-face morphs. Moreover, participants with high levels of SF&T affinity were found to reliably report enhanced ToM emotion for target morphs in three-way interaction analysis. Such positive moderation effects of participants' SF&T affinity for self-face morph targets may have contributed to the weak-to-null support that the doppelgänger hypothesis received in this study. Together, these results situated participants' SF&T affinity as an important demographic factor that influenced theory relevant outcomes in traditional and novel uncanny valley manipulations. These findings highlighted the need for future research to

account for SF&T affinity as a powerful third variable to broaden the generalizability of uncanny valley results and better inform the design of humanlike stimuli.

Limitations

The primary limitation of this empirical work was the use of a singular humanoid robot as endpoint of image morph continuums posed limitation to the generalizability of observed results. Kobian-RIV was selected for use in this study based on prior research that demonstrated this robot's exceptional ability to evoke eerie perceptions within participants (IEEE Spectrum, 2023; Mathur & Reichling, 2016). The inherent uncanny properties of Kobian-RIV may have led to baseline unmodified robot-face measures falling within— rather than before— the uncanny valley's trough. Such possibility well explains the observed anthropomorphic escalator relationship that was inconsistent with the uncanny valley relationship proposed by Mori (1970). This limitation serves to inform future works utilizing image morph continuums that the selection of robot faces identified by participants as being least human, rather than most uncanny, may be necessary for the detection of classical uncanny valley relationships.

Second, the utilization of face morph continuums, although the most common controlled stimulus generation technique in uncanny valley research, pose challenge to the investigation of the shape of the uncanny valley phenomenon (Kätsyri et al., 2019). This is as humanoid robot-to-human face morph continuums present participants with a severely restricted range of stimuli's human-likeness, potentially obfuscating the formation of classical uncanny valley relationships (Kätsyri et al., 2019). As such, authors of future face morph continuum research may consider the use of a greater number of face morph steps to better elucidate uncanny valley-linked relationships between the human-likeness of stimuli and outcome variables.

Taken together, these two limitations serve to inform that scholars may further improve the detection of the classic uncanny valley rise, fall, and recovery relationship through morph continuum research that more closely adheres to the broad range of stimuli proposed by Mori (1970). Mori's seminal hypothesis presented a series of 13 entities, ranging from industrial robots to healthy humans, to illustrate the counterintuitive prediction of a nonlinear relationship between a stimulus's level of anthropomorphism and its resulting affinity. As noted by Kätsyri et al. (2019), the presentation of clearly nonanthropomorphic entities as described by Mori (1970)— i.e., industrial robots— may be essential to trigger the initial peak of the uncanny valley. Nevertheless, the creation of well-controlled morph continua from fully non-human to human stimuli poses significant methodological challenge given the lack of objective measure for the subjective concept of anthropomorphism (Bailenson et al., 2005; Kätsyri et al., 2019; Nowak, 2015).

To address this complication, I propose the utilization of entities contained within Mori's (1970) treatise as a theory-guided starting point for future uncanny valley research. Scholars may wish to present to participants a series of separate morph continua to facilitate the creation of empirical stimuli that more fully capture the range of mechano-human likeness described by Mori (1970). Endpoints of such morph continua could include: industrial robot and anthropomorphic robot; anthropomorphic robot and prosthetic human; and, prosthetic human and natural human. In addition to enabling the more reliable observation of the classical uncanny valley pattern, such proposed morph continuum methodology will serve to elucidate the specific levels of anthropomorphism required to trigger the uncanny valley's eponymous phenomenon.

Third, the use of still robot-to-human morph face photos presents limitation to the external validity of my study, when animated morph stimuli may have generated stronger

uncanny valley effects. Indeed, Mori (1972) predicted that the presence of visual movement would amplify the nonlinear qualities of the uncanny valley relationship. Additionally, the use of static photos without audio may have limited the external validity of my findings for naturalistic contexts (e.g., AI-powered video filter content, videogame self-avatars, and emerging forms of AI-mediated interpersonal communication). Future research would do well to examine the moderation of animation and audio modalities on the formation of doppelgänger-linked effects to better understand the influence of the self-reference effect on the uncanny valley phenomenon in real world contexts.

Fourth, the use of a convenience sample precludes a meaningful investigation on the potential moderation effect participants' age and non-binary sex on observed uncanny valley outcomes. An investigation on the moderation effect of age is found to be pertinent for the more complete understanding of observed uncanny valley results as identified by my meta-analysis. Likewise, this study purposefully excluded gender nonbinary and intersex individuals from the convenience sample to standardize data collection and analysis. This design decision limits the investigation of the moderation of participant sex on the uncanny valley phenomenon to cisgender women and men. Future research would do well to expand beyond the gender binary to provide greater representation in science and more fully capture the complexities of the human experience.

Conclusion

For my Dissertation I conducted a two-pronged approach to provide profound intellectual contribution to academia's knowledge on the uncanny valley phenomenon. In theoretical and methodological expansion, my meta-analysis summarized the results of 70 empirical works to inform that the uncanny valley phenomenon is fundamentally polythetic in nature. Here, the

uncanny valley phenomenon was found to significantly impact participants' affect— as originally hypothesized by Mori (1970)— and participants' behavior, cognitions, and attitudes. Likewise, my meta-analysis provided support for all examined mechanisms of the uncanny valley that presented sufficient sample size, those being: the perceptual mismatch, movement fidelity, ToM emotion, and ToM agency hypotheses. From my meta-analysis, I advocate the need for Communication researchers to unbind uncanny valley framework from the limitations of traditional cause and effect to better capture the impact of emerging agents' human-likeness in the real world. Of note, mixed evidence of publication bias was uncovered within my meta-analytic dataset, in identical pattern to that observed by Diel et al. (2022). As open science practices are adopted by the Social Sciences, I anticipate that evidence of publication bias with future uncanny valley meta-analyses will be reduced.

Additionally, my meta-analysis identified limited evidence that message channel bandwidth influenced participants' uncanny perceptions. In line with social presence theory, uncanny valley effect sizes were greater for visual continuum targets displayed via video with audio than real photo. Nevertheless, cues-dearth text-based chat was found to elicit greater uncanny perceptions than did exposure to real world robots. Further, my meta-analysis identified significant moderation effects of participants' sex and age to reveal the need for representative samples within uncanny valley works. Women reported stronger behavior-linked uncanny valley outcomes than did men, while older participants reported attenuated affective, behavioral, and attitudinal uncanny valley outcomes relative to younger participants. The primary limitation of my meta-analysis was the insufficient data availability of several theory and societally relevant hypothesized mechanisms within examined uncanny valley works. This limitation served to

guide my research to advance Communication scholars' knowledge on socially relevant components of the uncanny valley phenomenon that remain underexplored.

In addition, my empirical study ($N = 188$) investigated the doppelgänger hypothesis of the uncanny valley from a self-reference effect perspective to inform academia of the aesthetic relationship between synthetic agents' resemblance to the humanoid self with their elicited psychosocial response. The doppelgänger hypothesis, which lacked sufficient sample size to allow examination by my meta-analysis, holds relevance to Communication's study of the social impact of real-time filters intended to optimize self-presentation in mediated interpersonal interactions (Hancock & Bailenson, 2021). Counter to expectations informed by Weisman and Peña (2021), the doppelgänger mechanism of the uncanny valley did not enhance the strength of negative outcomes. Rather, the direct effect of participants' self-reference behavior enhanced the self-oriented outcomes of identification and resource allocation. An additive interaction of the self-reference effect with the mechano-anthropomorphic manipulation was found to further heighten self- and other-oriented outcomes.

When results were visualized, a consistent "anthropomorphic escalator" effect was observed, to demonstrate the importance of avatar anthropomorphism on the person perception process within uncanny valley research. This intellectual contribution informed that congruent with social cognition theory, participants reliably preferred human-like stimuli which facilitated human-nonhuman distinction. Of relevance to the design of academic works as well as the creations of industry, the consistent anthropomorphic escalator relationship further served to inform that uncanny valley effects are best avoided through the display of evermore humanlike stimuli, rather than stimuli which avoid the appearance of human-likeness.

Finally, informed by my meta-analysis, the demographic factors of participants' biological sex and SF&T affinity were examined as moderators of the uncanny valley phenomenon within my empirical work. Here, women and participants at high levels of SF&T affinity displayed a reduced uncanny valley effect relative to men and those at low levels of SF&T affinity. I propose that SF&T affinity be used as a key demographic factor in future uncanny valley research to better capture participants' science fiction consumption and familiarity to technology, avoiding stereotypical assumptions.

Taken together, the present dissertation provided theory informed guidance that meaningfully advances the study of the aesthetic design of digital recreations of the self. My findings shall guide academia and industry on the development of AI-powered technologies to revolutionize computer-mediated communication. Nevertheless, pertinent gaps in knowledge remain at the intersection of the uncanny valley hypothesis and the self-reference effect. Future research would do well to expand theory-guided knowledge at these interconnected frameworks.

Artificial Intelligence Disclosure:

Open AI's Chat GPT was utilized to assist interpretation of meta-analytic results. Microsoft Copilot was utilized to assist in the identification of relevant research, inform statistical analysis strategy, and correct small issues of grammar. All information provided by AI was double-checked with traditional non-AI sources to confirm accuracy and veracity before utilization in the manuscript.

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Figure 1

Study Selection Flowchart

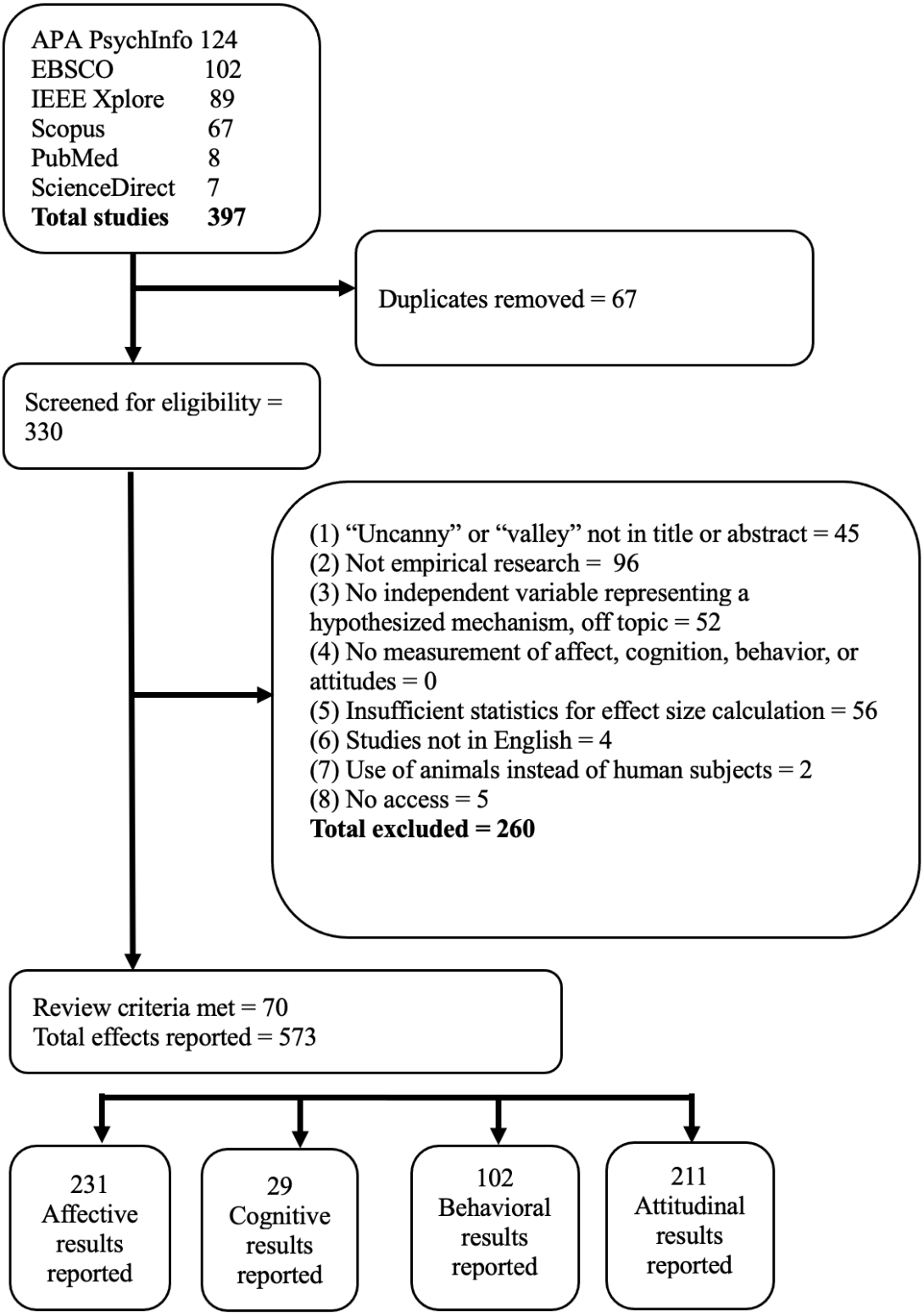


Figure 2

Effect Size of Uncanny Valley Mechanisms by Outcome Measure

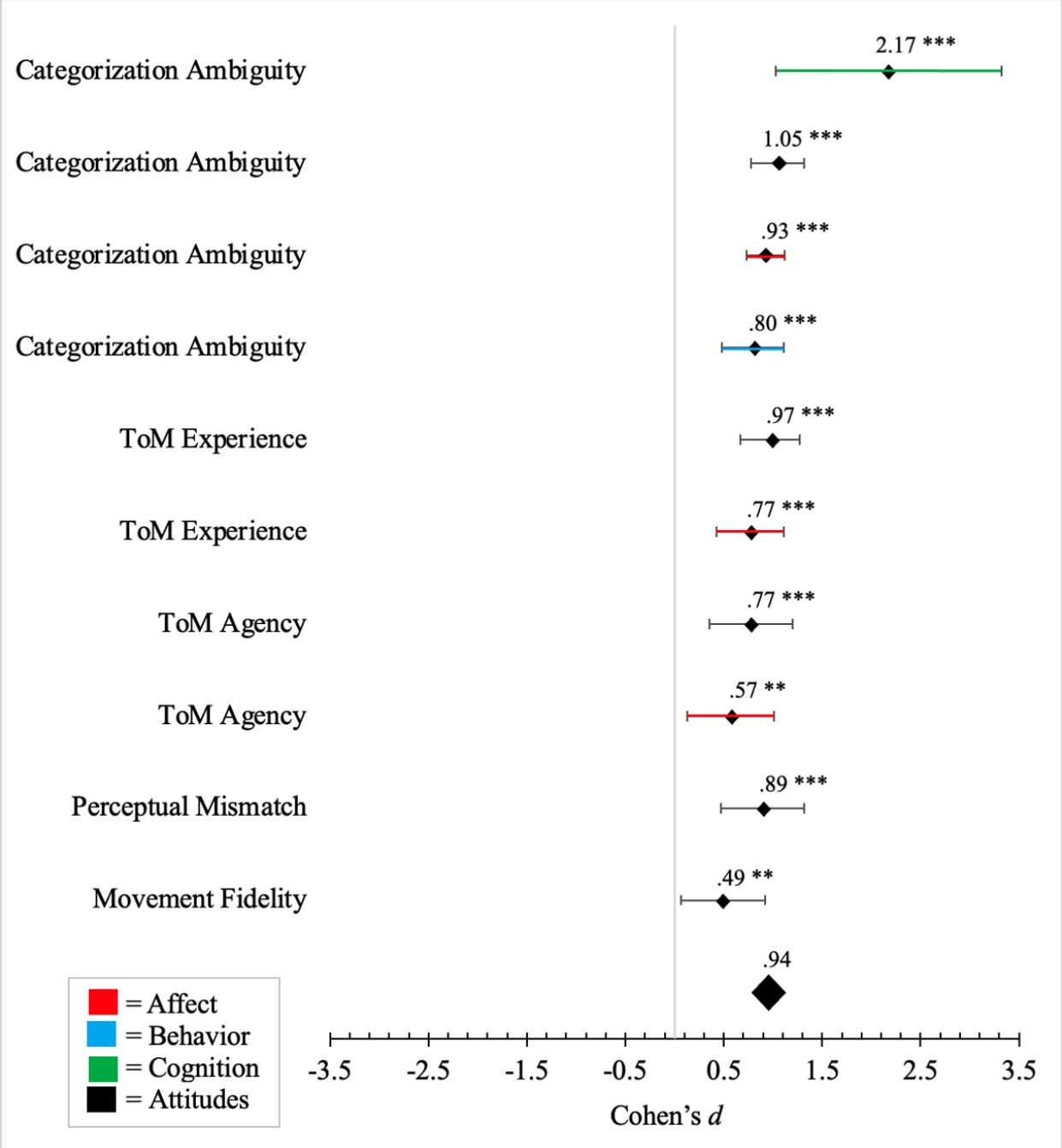


Figure 3

Uncanny Valley Effect Size by Message Channel

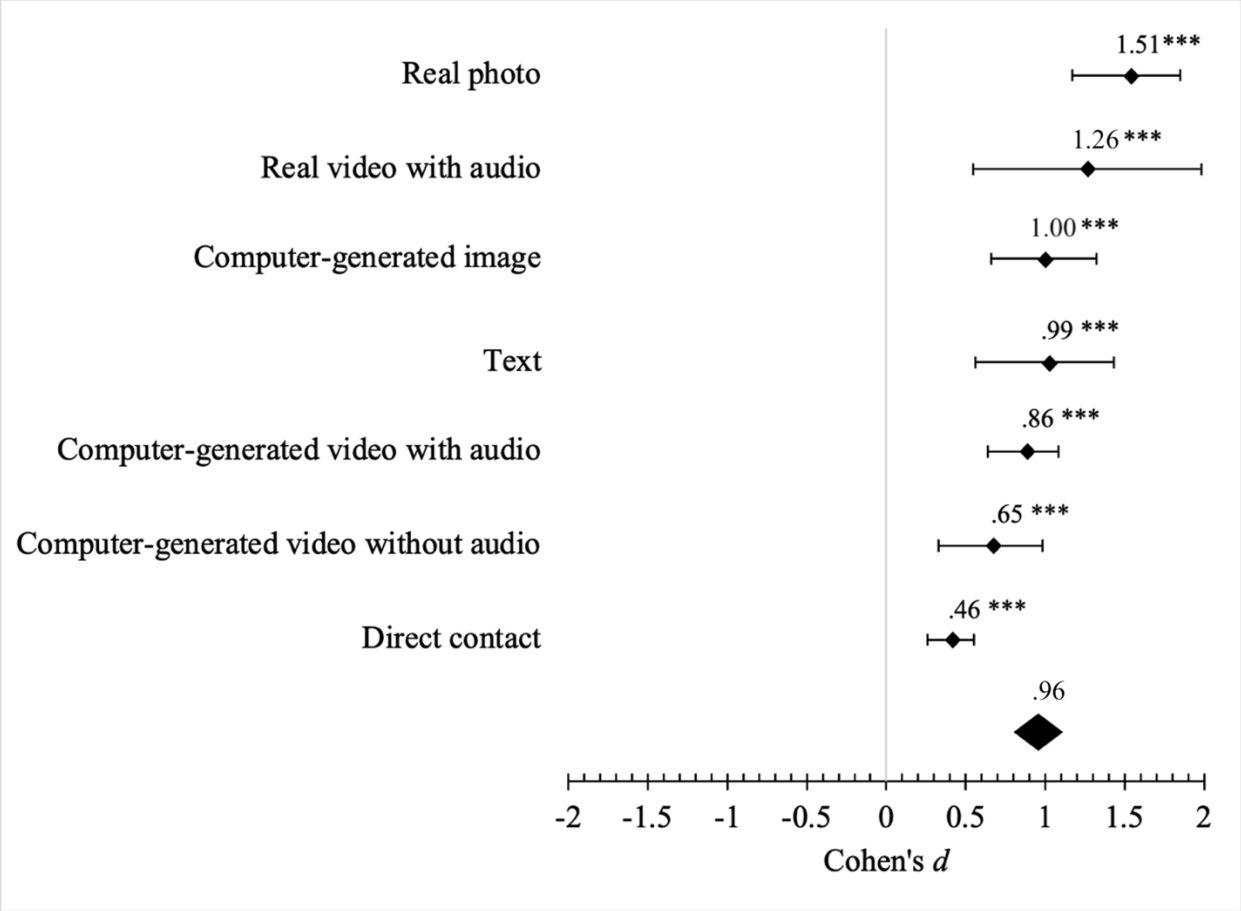
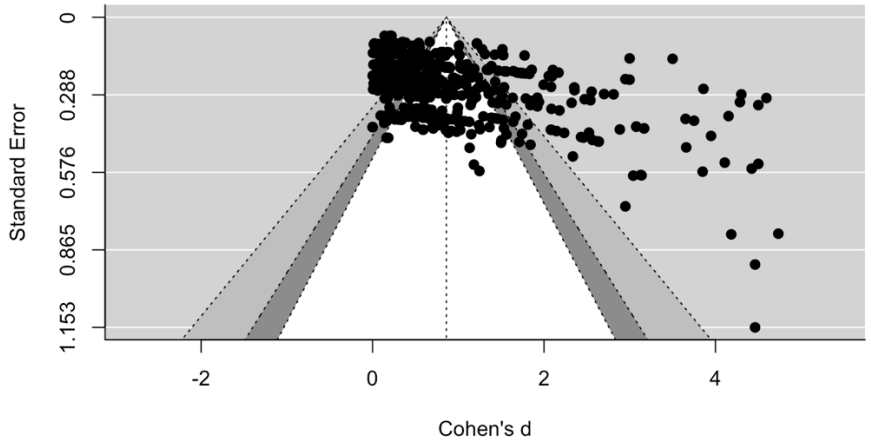


Figure 4

Egger's Test of Funnel Plot Asymmetry, For Full And 37.2% Reduced Dataset



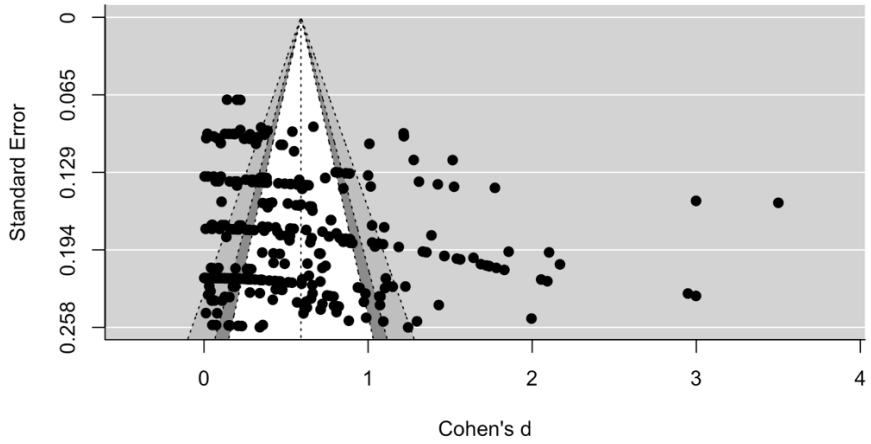


Figure 5

P-curve Analysis of Full 573 Effects

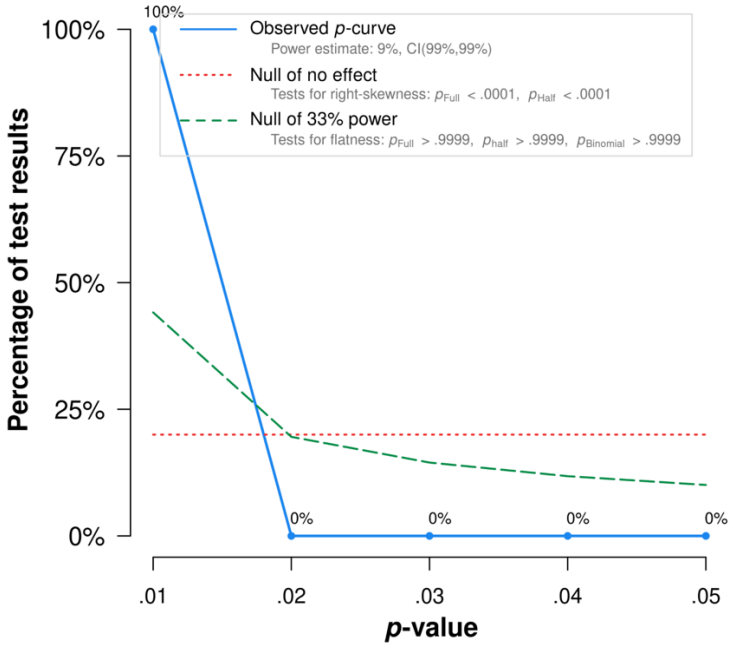
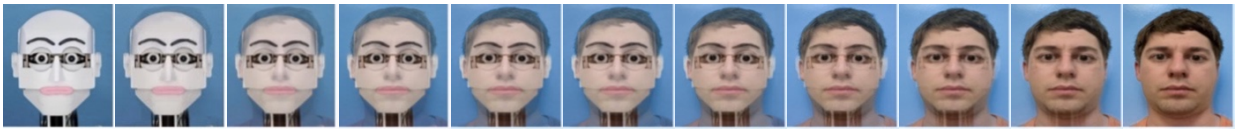


Figure 6

Example Face Morph Continuum



0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Morph Percent Human

Figure 7

Contrasts in Visualization of Significant Two-Way Interaction Effect Between the Self- and Stranger-Morph Manipulation with the Mechano-Anthropomorphic Manipulation on Participants' Altruism, Identification, and ToM Agency of Targets

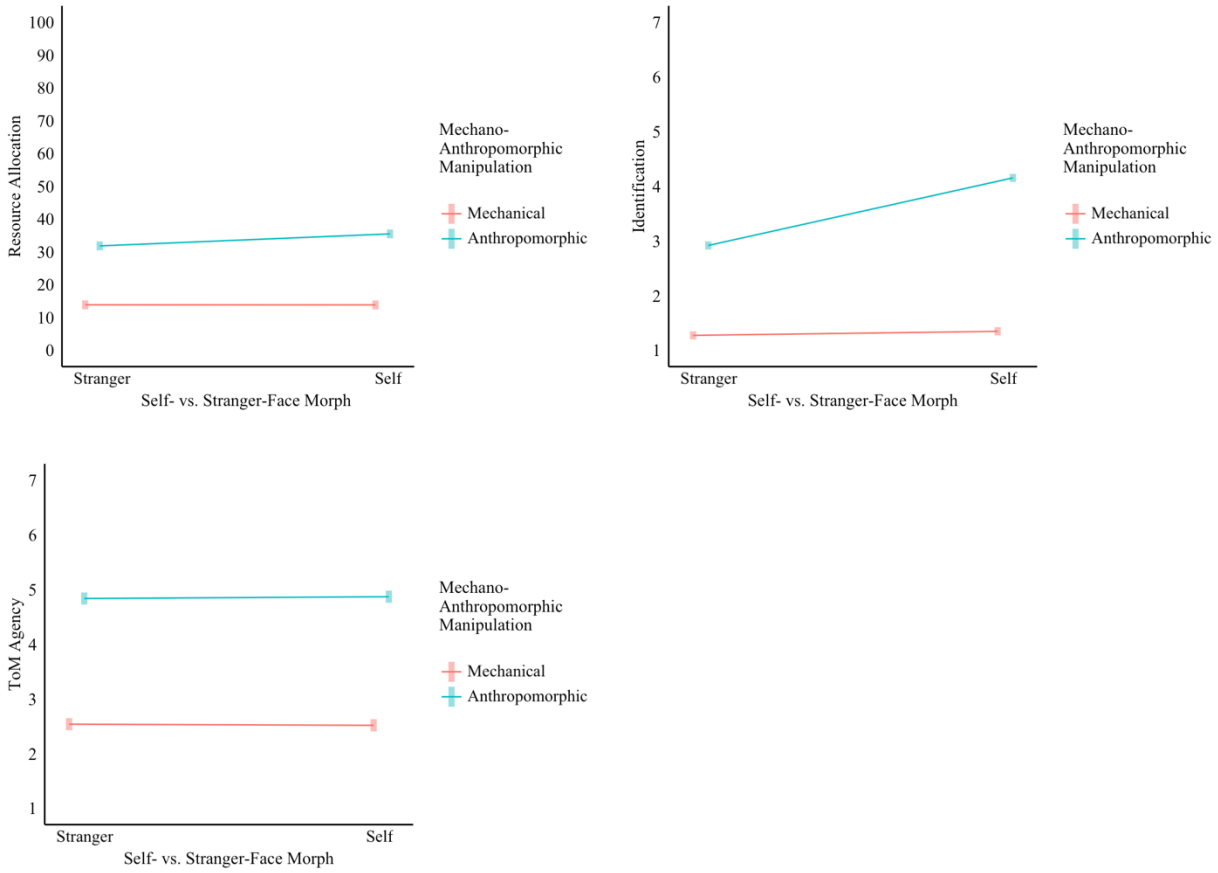
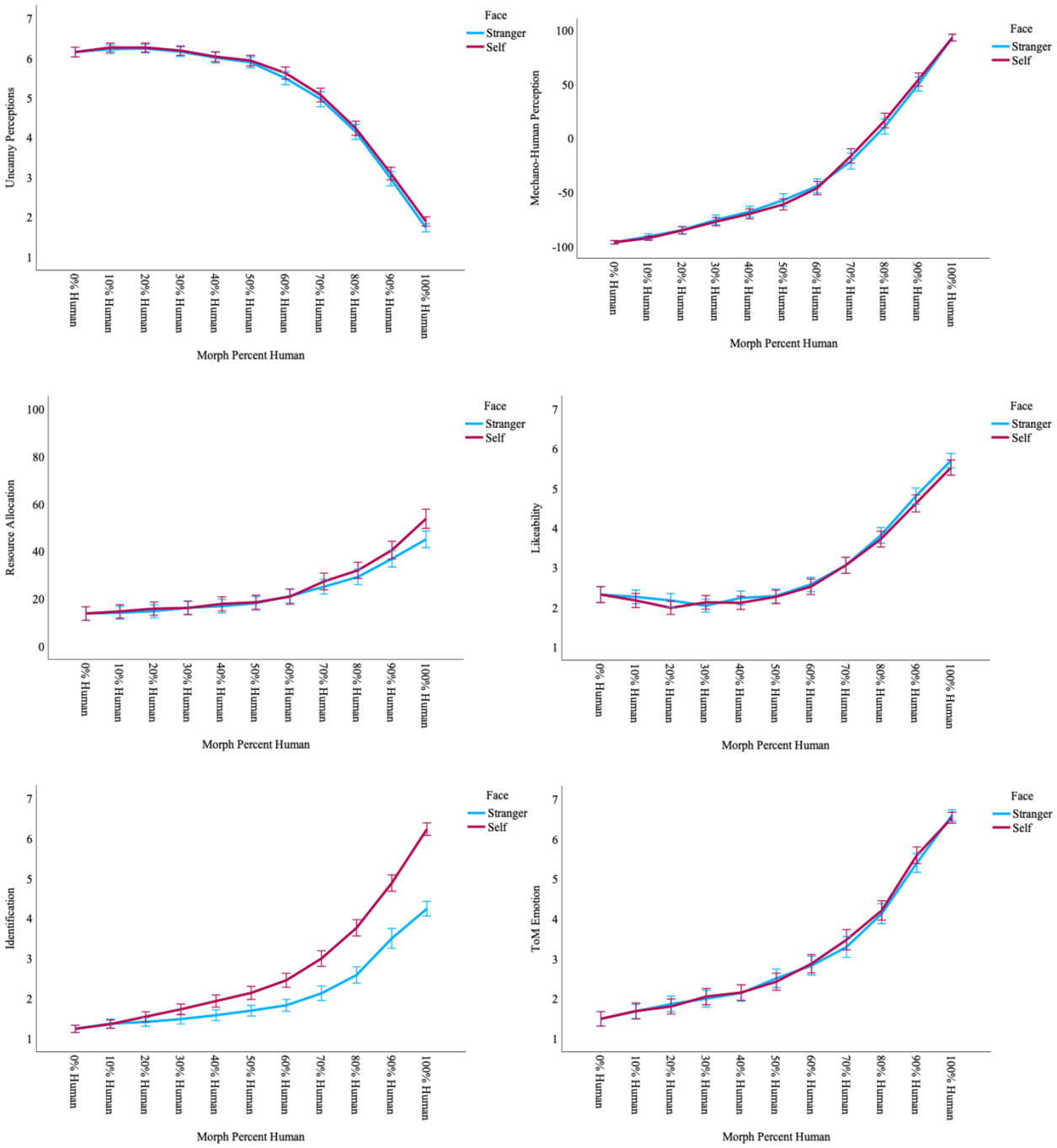


Figure 8

Dependent Variables by Morph Percent of Self- and Stranger-Face Morphs



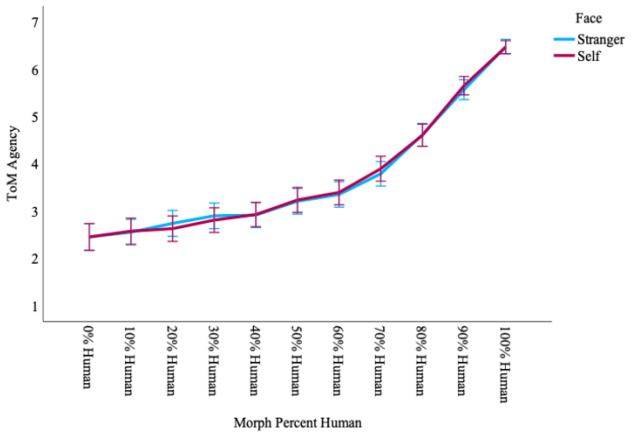
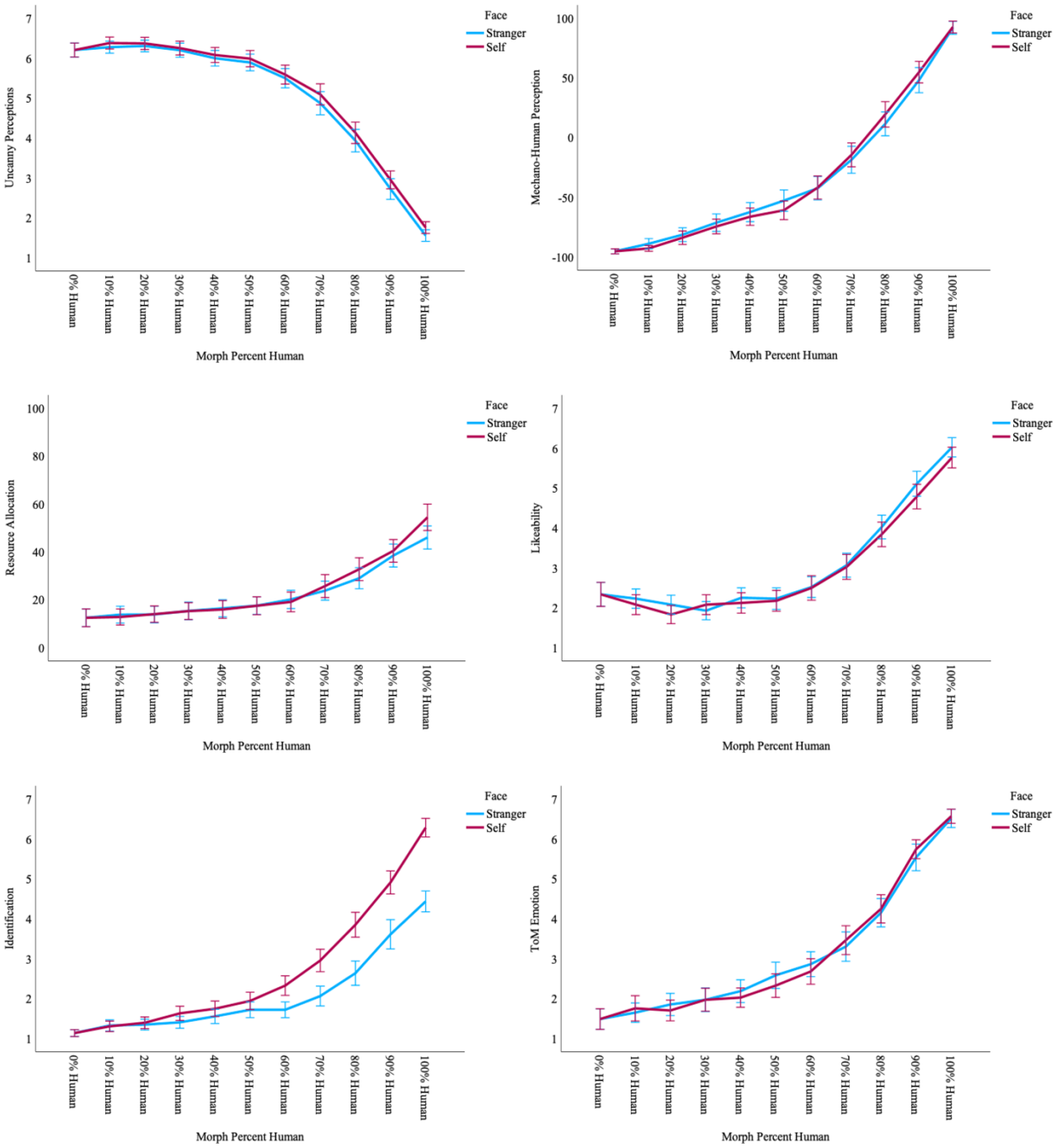

Face
Stranger
Self
ToM Agency
7
6
5
4
3
2
1
0% Human
10% Human
20% Human
30% Human
40% Human
50% Human
60% Human
70% Human
80% Human
90% Human
100% Human
Morph Percent Human

Figure 9

Female Participants' Outcomes by Morph Percent of Self- and Stranger-Face Morphs



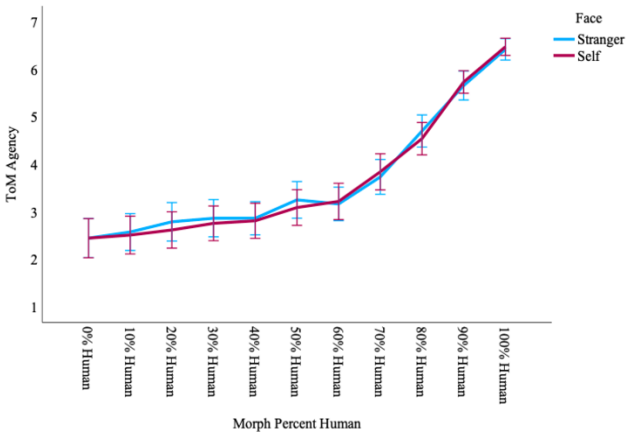
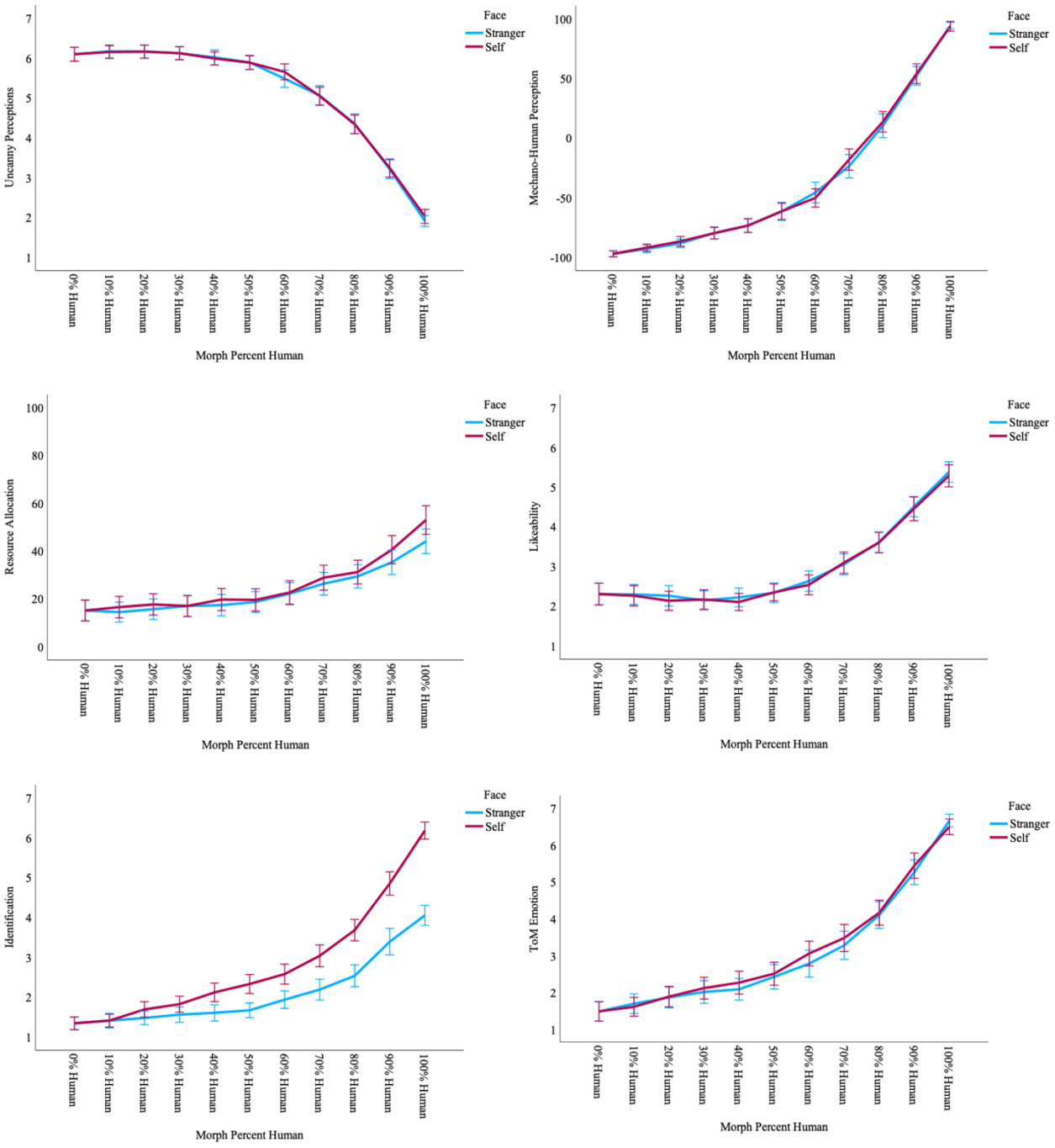

Face
Stranger
Self
ToM Agency
7
6
5
4
3
2
1
0% Human
10% Human
20% Human
30% Human
40% Human
50% Human
60% Human
70% Human
80% Human
90% Human
100% Human
Morph Percent Human

Figure 10

Male Participants' Outcomes by Morph Percent of Self- and Stranger-Face Morphs



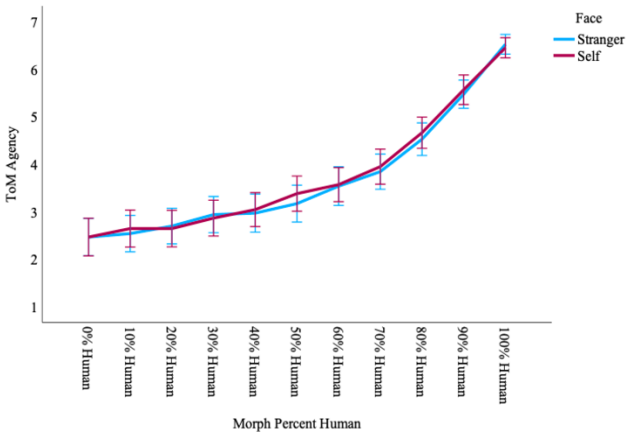

Face
Stranger
Self
ToM Agency
7
6
5
4
3
2
1
0% Human
10% Human
20% Human
30% Human
40% Human
50% Human
60% Human
70% Human
80% Human
90% Human
100% Human
Morph Percent Human

Figure 11

Contrasts in Visualization of Significant Two-Way Interaction Effect Between Participants' Biological Sex and the Self- and Stranger-Morph Manipulation on Targets' Elicited Likability and Uncanny Valley Perceptions

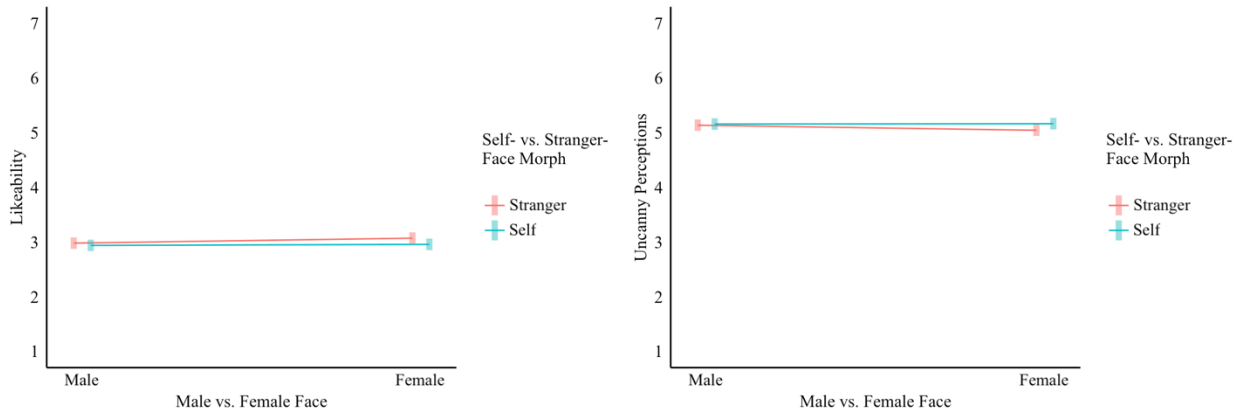


Figure 12

Contrasts in Visualization of Significant Two-Way Interaction Effect Between Participants' Biological Sex and the Mechano-Anthropomorphic Morph Manipulation on Targets' Elicited Human Perceptions

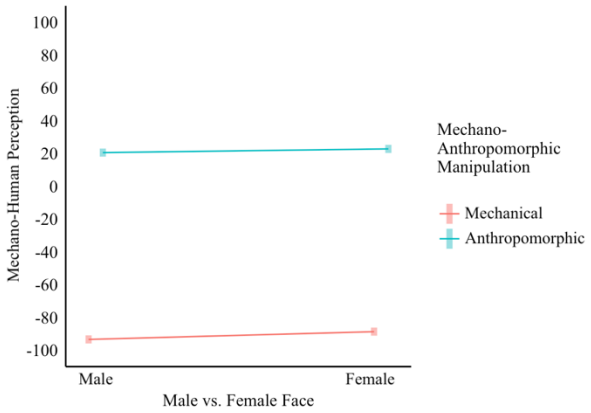


Figure 13

Contrasts in Visualization of Significant Two-Way Interaction Effect Between Participants' SF&T Affinity with the Self- and Stranger-Morph Manipulation on Targets' Human Perception, Likeability, Uncanny Valley Perceptions, ToM Emotion, ToM Agency, and Identification

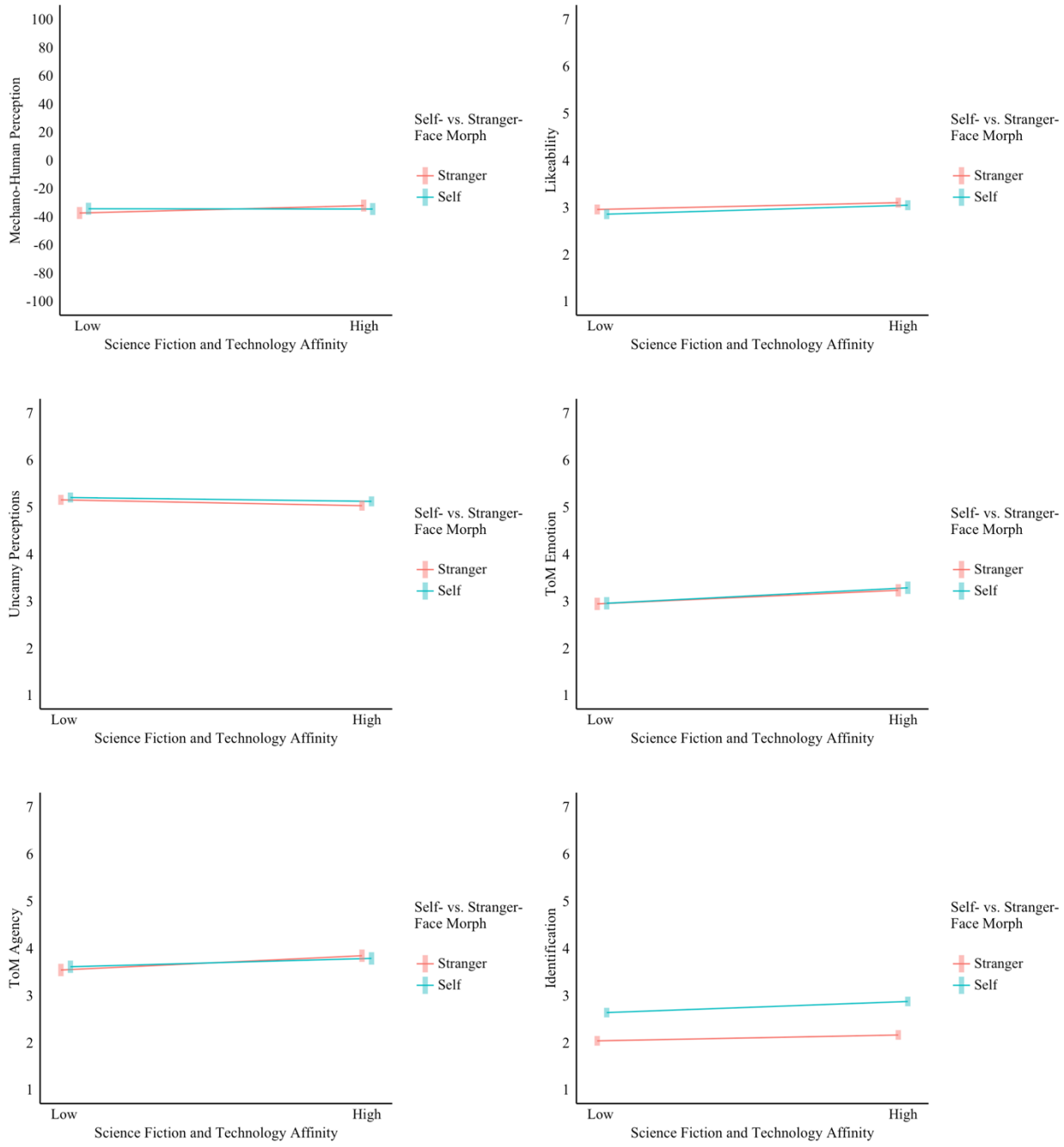


Figure 14

Contrasts in Visualization of Significant Two-Way Interaction Effect Between Participants' SF&T Affinity with the Mechano-Anthropomorphic Manipulation on Targets' Elicited Uncanny Valley Perceptions, ToM Emotion, and Identification

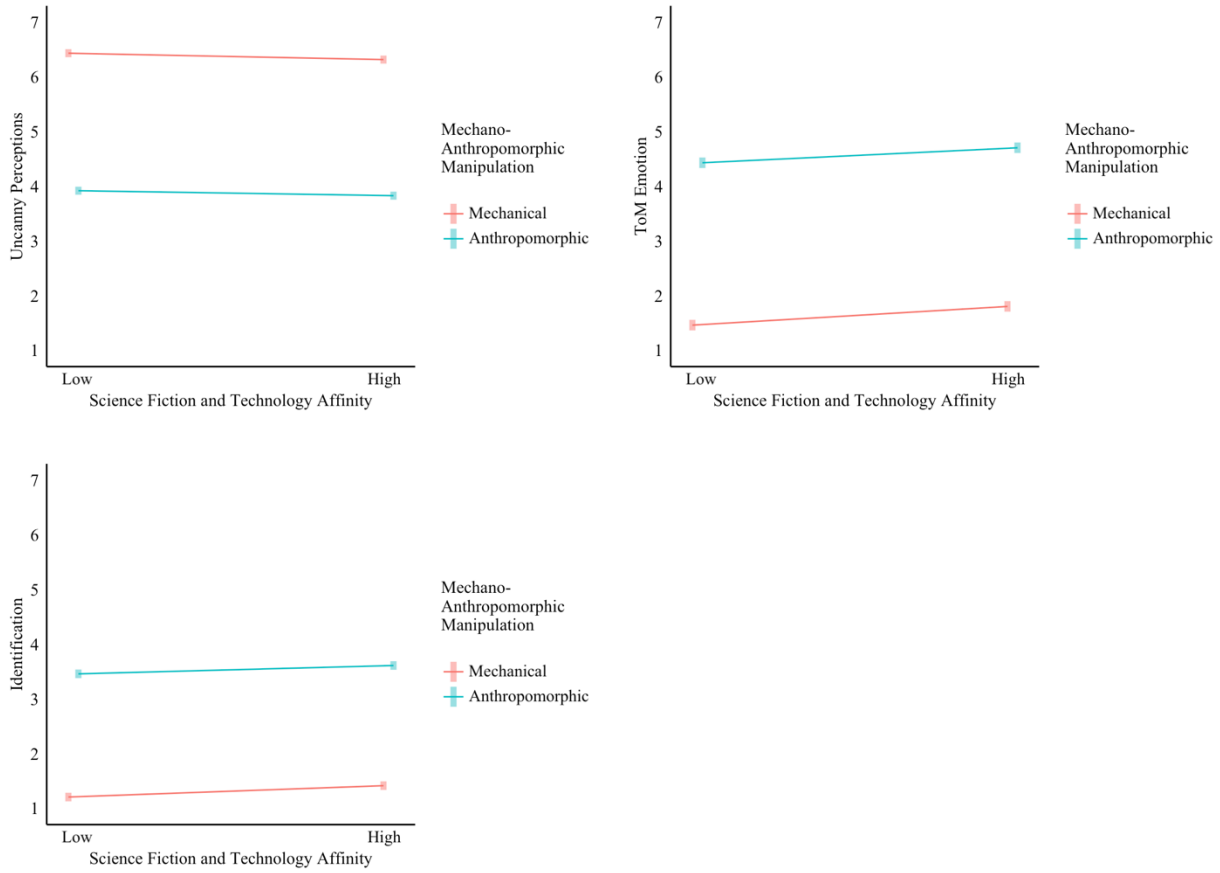


Figure 15

Contrasts in Visualization of Significant Three-Way Interaction Effect Between the Self- and Stranger-Morph Manipulation with the Mechano-Anthropomorphic Manipulation and Participants' SF&T Affinity on Participants' Human Perception of Target Images

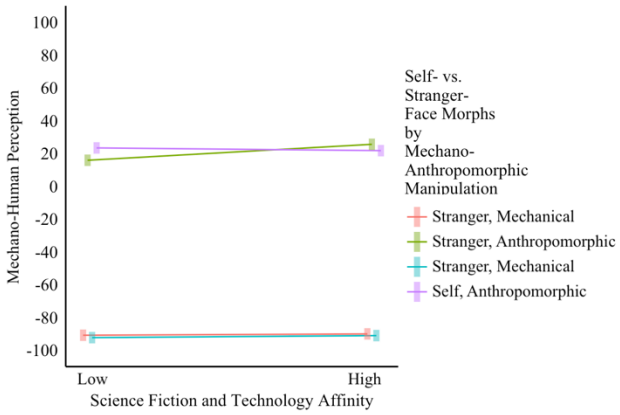


Figure 16

Contrasts in Visualization of Significant Three-Way Interaction Effect Between the Self- and Stranger-Morph Manipulation with the Mechano-Anthropomorphic Manipulation and Participants' SF&T Affinity on Participants' Theory of Mind Emotion of Target Images

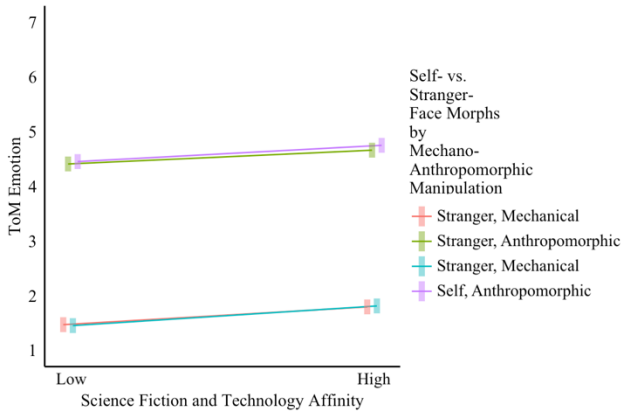


Table 1

Hypothesized Uncanny Valley Mechanisms Defined

Mechanism Title	Mechanism Definition	Empirical Example
Categorization ambiguity	Difficulty in the classification of targets as natural human or artificial human triggers uncanny valley perceptions (Pollick, 2010; Ramey, 2005).	Mathur and Reichling (2016)
Perceptual mismatch	Negative affinity is triggered by inconsistency in the mechano-humanness of targets' sensory cues (Kätsyri et al., 2015).	Seyama and Nagayama (2007)
Theory of mind agency	The apparent ability of near-human entities to plan and conduct action is unnerving (Gray et al., 2007).	Kim et al. (2019)
Theory of mind emotion	Synthetic beings' perceived capacity to feel and sense trigger the uncanny valley effect (Gray et al., 2007).	Gray and Wegner (2012)
Movement fidelity	The display of movement by humanoid entities will produce negative reactions in line with the uncanny valley hypothesis (Kätsyri et al., 2015).	Saygin et al. (2011)
Audio fidelity	Manipulations of humanlike voices will produce negative reactions in line with the uncanny valley hypothesis (Scott et al., 2020).	Scott et al. (2020)
Morbidity	Human replicas remind of death on a subconscious level, and thereby generate uncanny valley effects through the deeply rooted anxiety regarding mutilation and mortality (Jonte-Pace, 2001).	Poliakoff et al. (2013)
Doppelgänger	Synthetic recreations of the self elicit of anxieties involving identity, the repressed subconscious, and the fear of being replaced (Freud, 1919).	Weisman and Peña (2021)

Table 2

Studies Included in the Meta-Analysis

Study No.	Study	Number of effects coded	Causal mechanism	Outcome	Message channel	Message target
1	Appel, Weber, Krause, & Mara (2016)	4	ToM agency, ToM experience	Attitudes	Text	Vignette
2	Bartneck, Kanda, Ishiguro, & Hagita (2009)	5	Categorization ambiguity	Affect	Direct contact	Single real robot
3	Brink, Gray, & Wellman (2017)	2	Categorization ambiguity, ToM experience	Affect, Attitudes	Real video without audio	Single real robot
4	Broadbent, Kumar, Li, Sollers, Stafford, MacDonald, & Wegner (2013)	16	Categorization ambiguity	Affect, Attitudes	Direct Contact	Single real robot
5	Burleigh & Schoenherr (2015)	7	Categorization ambiguity	Affect, Behavior, Cognition	Computer-generated image	Morph
6	Burleigh, Schoenherr, & Lacroix (2013)	2	Categorization ambiguity	Affect, Attitudes	Computer-generated image	Morph
7	Cafaro, Lyons, Roberts, & Radinsky (2014)	5	Movement fidelity	Attitudes	Computer-generated video without audio	Virtual human
8	Chattopadhyay & MacDorman (2016)	6	Categorization ambiguity	Attitudes	Computer-generated image	Morph
9	Cheetham & Jäncke (2011)	3	Categorization ambiguity	Behavior	Computer-generated image	Morph
10	Cheetham & Jäncke (2013)	1	Categorization ambiguity	Behavior	Computer-generated image	Morph

11	Cheetham, Pavlovic, Jordan, Suter, & Jäncke (2013)	2	Categorization ambiguity	Behavior	Computer-generated image	Morph
12	Cheetham, Suter, & Jäncke (2014)	12	Categorization ambiguity	Behavior	Computer-generated image	Morph
13	Cheetham, Wu, Pauli, & Jäncke (2015)	8	Categorization ambiguity	Affect, Behavior, Attitudes	Computer-generated image	Morph
14	Ciechanowski, Przegalinska, Magnuski, & Gloor (2019)	6	Perceptual mismatch	Affect, Attitudes	Text	Text-based chat
15	Clayton & Leshner (2015)	6	Categorization ambiguity	Affect, Behavior, Cognition	Computer-generated video with audio	Virtual human
16	Destephe, Brandao, Kishi, Zecca, Hashimoto, & Takanishi (2015)	1	ToM experience	Attitudes	Real video with audio	Single real robot
17	Destephe, Zecca, Hashimoto, & Takanishi (2014)	2	ToM experience	Affect	Real video without audio	Single real robot
18	Ferrey, Burleigh, & Fenske (2015)	10	Categorization ambiguity	Affect	Text, Computer-generated image	Morph
19	Gray & Wegner (2012)	7	Categorization ambiguity, ToM agency, ToM experience	Affect, Attitudes	Text, Real photo, Real video without audio	Single real robot, Vignette
20	Groom, Nass, Chen, Nielsen, Scarborough, & Robles (2009)	12	Movement fidelity	Affect, Behavior, Attitudes	Computer-generated video with audio	Virtual human
21	Herberg, Behera, &	1	Categorization ambiguity	Attitudes	Real photo	Image continuum

	Saerbeck (2013)					
22	Kätsyri, Mäkäräinen, & Takala (2017)	32	Categorization ambiguity	Affect, Attitudes	Computer-generated video with audio	Image continuum
23	Kim, Kwak, Hyun, Kim, & Kwak (2012)	2	ToM experience	Attitudes	Direct Contact	Single real robot
24	Kim, Schmitt, & Thalmann (2019)	7	Categorization ambiguity, ToM agency, ToM experience	Affect, Attitudes	Text, Real photo, Real video with audio	Image continuum, Single real robot, Vignette
25	Koschate, Potter, Bremner, & Levine (2016)	6	Categorization ambiguity, ToM experience	Affect, Cognition, Attitudes	Real photo	Image continuum, Single real robot
26	Lewkowicz & Ghazanfar (2012)	2	Categorization ambiguity	Behavior	Computer-generated video without audio	Image continuum
27	MacDorman & Chattopadhyay (2017)	5	Categorization ambiguity	Affect, Attitudes	Computer-generated image	Morph
28	MacDorman, Green, Ho, & Koch (2009)	9	Perceptual mismatch	Affect, Attitudes	Computer-generated image	Morph
29	MacDorman, Srinivas, & Patel (2013)	3	Categorization ambiguity	Behavior	Computer-generated image	Image continuum
30	Mara & Appel (2015)	12	ToM agency	Affect, Cognition, Attitudes	Text	Vignette
31	Mathur & Reichling (2009)	2	Categorization ambiguity	Behavior	Real photo	Morph
32	Mathur & Reichling (2016)	5	Categorization ambiguity	Affect, Behavior, Attitudes	Real photo	Image continuum
33	Mitchell, Szerszen, Lu, Schermerhorn, Scheutz, &	5	Categorization ambiguity, Audio fidelity	Affect, Attitudes	Real video with audio	Single real robot

	MacDorman (2011)					
34	Nitta & Hashiya (2021)	4	Categorization ambiguity, Doppelgänger	Behavior	Computer-generated image	Morph
35	Paetzel & Castellano (2019)	5	Categorization ambiguity	Affect, Cognition, Attitudes	Direct contact	Single real robot
36	Paetzel-Prüsmann, Perugia, & Castellano (2021)	19	Categorization ambiguity, ToM experience	Affect, Attitudes	Direct contact	Single real robot
37	Palomäki, Kunnari, Drosinou, Koverola, Lehtonen, Halonen, Repo, & Laakasuo (2018)	36	Categorization ambiguity	Affect	Real photo, Computer-generated image	Image continuum, Morph
38	Patel & MacDorman (2015)	13	Categorization ambiguity, Perceptual mismatch, ToM agency	Affect, Attitudes	Computer-generated video with audio	Virtual human
39	Piwek, McKay, & Pollick (2014)	3	Categorization ambiguity, Movement fidelity	Attitudes	Computer-generated image, Computer-generated video without audio	Image continuum
40	Rosenthal-von der Pütten & Krämer (2014)	7	Categorization ambiguity	Affect, Attitudes	Real photo	Image continuum
41	Rosenthal-von der Pütten, Krämer, Becker-Asano, Ogawa, Nishio, & Ishiguro (2014)	6	Movement fidelity	Behavior	Direct contact	Single real robot
42	Rosenthal-von der Pütten,	3	Morbidity	Affect, Attitudes	Real photo	Image continuum

	Krämer, Maderwald, Brand, & Grabenhorst (2019)					
43	Sasaki, Ihaya, & Yamada (2017)	3	Categorization ambiguity	Affect, Behavior	Computer-generated image	Morph
44	Schein & Gray (2015)	3	Perceptual mismatch	Affect, Attitudes	Real photo	Morph
45	Seyama & Nagayama (2007)	2	Categorization ambiguity	Attitudes	Computer-generated image	Morph
46	Seyama & Nagayama (2009)	11	Perceptual mismatch	Attitudes	Computer-generated image	Morph
47	Shimada, Minato, Itakura, & Ishiguro (2006)	51	Categorization ambiguity	Behavior	Direct Contact	Single real robot
48	Shin, Kim, & Biocca (2019)	10	Categorization ambiguity, Movement fidelity	Affect, Cognition, Attitudes	Computer-generated image	Virtual human
49	Shin, Song, & Chock (2019)	2	Categorization ambiguity, Movement fidelity	Affect	Computer-generated image	Virtual human
50	Skjuve, Haugstveit, Følstad, & Brandtzaeg (2019)	6	Categorization ambiguity	Affect, Attitudes	Text	Text-based chat
51	Stein & Ohler (2017)	6	ToM agency, ToM experience	Affect, Attitudes	Computer-generated video with audio	Virtual human
52	Stein, Appel, Jost, & Ohler (2020)	5	ToM experience	Affect, Attitudes	Text, Real video with audio	Vignette, Virtual human
53	Strait & Scheutz (2014)	14	Categorization ambiguity	Affect	Real photo	Image continuum
54	Strait, Aguillon,	3	Categorization ambiguity	Affect, Behavior	Real video with audio	Image continuum

	Contreras, & Garcia (2017)					
55	Strait, Urry, & Muentener (2019)	7	Categorization ambiguity	Affect, Behavior	Real photo	Image continuum
56	Thaler, Schlögl, & Groth (2021)	24	Categorization ambiguity	Affect, Attitudes	Computer-generated video without audio	Virtual human
57	Tinwell & Sloan (2014)	3	Movement fidelity	Affect, Attitudes	Computer-generated video without audio	Virtual human
58	Tinwell, Grimshaw, Nabi, & Williams (2011)	36	ToM experience	Affect, Attitudes	Computer-generated video with audio	Virtual human
59	Tinwell, Nabi, & Charlton (2013)	3	ToM experience	Affect	Computer-generated video with audio	Virtual human
60	Tschöpe, Reiser, & Oehl (2017)	5	Categorization ambiguity, ToM agency	Affect, Attitudes	Real video with audio	Image continuum
61	Tu, Chien, & Yeh (2020)	6	Categorization ambiguity	Affect, Attitudes	Real photo	Image continuum
62	Urgen, Kutas, & Saygin (2018)	3	Movement fidelity	Cognition	Real video without audio	Single real robot
63	Veletsianos (2012)	6	ToM agency	Cognition, Attitudes	Computer-generated video with audio	Virtual human
64	Wang & Rochat (2017)	30	Categorization ambiguity	Affect, Behavior, Attitudes	Real photo	Image continuum
65	Wang, & Quadflieg (2015)	5	ToM agency	Affect, Cognition, Attitudes	Real photo	Single real robot
66	Weisman & Peña (2021)	9	Doppelgänger, ToM agency	Affect	Computer-generated	Virtual human

					video with audio	
67	Wiese & Weis (2020)	9	Categorization ambiguity	Cognition, Attitudes	Real photo, Computer-generated image	Image continuum, Morph
68	Woods (2006)	2	Categorization ambiguity	Attitudes	Real photo	Image continuum
69	Yamamoto, Tanaka, Kobayashi, Kozima, & Hashiya (2009)	1	ToM agency	Behavior	Direct contact	Single real robot
70	Złotowski, Sumioka, Nishio, Glas, Bartneck, & Ishiguro (2015)	9	Categorization ambiguity, ToM experience	Affect, Attitudes	Direct contact	Single real robot

Table 3

Descriptive Statistics for H1.

	Scale Values	Self-face morphs		Stranger-face morphs	
		M	SD	M	SD
Likeability	1-7	2.95	1.72	3.02	1.73
Resource Allocation	0-100	24.64	25.38	22.82	23.15
Uncanny Perceptions	1-7	5.16	1.71	5.09	1.76
Human Perception	-100 – 100	-34.58	69.51	-34.87	69.40
Identification	1-7	2.75	1.88	2.09	1.43
ToM Emotion	1-7	3.12	2.15	3.08	2.17
ToM Agency	1-7	3.69	2.15	3.69	2.17

Table 4

Descriptive Statistics for Contrasts Performed in Analysis of Significant Two-Way Interactions Between the Self- and Stranger-Morph Manipulation with the Mechano-Anthropomorphic Manipulation

	Mechanical Self-Face Morph		Mechanical Stranger-Face Morph					
Measured Outcome	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Resource Allocation	13.80	44.30	13.80	44.30	4132	.03	.98	0
Identification	1.35	2.43	1.27	2.43	4132	.40	.16	.03
ToM Agency	2.52	5.13	2.54	5.13	4132	-.26	.80	<.001
	Anthropomorphic Self-Face Morph		Anthropomorphic Stranger-Face Morph					
Measured Outcome	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Resource Allocation	35.50	44.30	31.80	44.30	4132	3.76	<.001	.08
Identification	4.15	2.43	2.92	2.43	4132	23.12	<.001	.51
ToM Agency	4.87	5.13	4.84	5.13	4132	.41	.68	.01
	Anthropomorphic Stranger-Face Morph		Mechanical Stranger-Face Morph					
Measured Outcome	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Resource Allocation	31.80	44.30	13.80	44.30	4132	18.43	<.001	.41
Identification	2.92	2.43	1.27	2.43	4132	30.76	<.001	.68
ToM Agency	4.84	3.63	2.54	3.63	4132	28.80	<.001	.63
	Anthropomorphic Self-Face Morph		Mechanical Self-Face Morph					
Measured Outcome	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Resource Allocation	35.50	44.30	13.80	44.30	4132	22.21	<.001	.49
Identification	4.15	2.43	1.35	2.43	4132	52.49	<.001	1.15
ToM Agency	4.87	3.63	2.52	3.63	4132	29.47	<.001	.65

Table 5

Descriptive Statistics for RQ2

	Scale Values	Female Participants		Male Participants	
		M	SD	M	SD
Likeability	1-7	3.01	1.84	2.96	1.61
Uncanny Perceptions	1-7	5.10	1.83	5.15	1.64
Human Perception	-100 – 100	-32.95	70.03	-36.46	68.85
Resource Allocation	0-100	23.03	23.00	24.42	25.52
Identification	1-7	2.38	1.74	2.46	1.67
ToM Emotion	1-7	3.09	2.16	3.10	2.16
ToM Agency	1-7	3.66	2.16	3.72	2.15

Table 6

Descriptive Statistics for Contrasts Analyzing Significant Two-Way Interactions of Participants' Biological Sex and the Self- and Stranger-Face Morph Manipulation

	Male Self-Face Morph		Male Stranger-Face Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Likeability	2.94	3.44	2.98	3.44	4132	-.54	.59	.01
Uncanny Perceptions	5.16	3.49	5.13	3.49	4132	.28	.78	.01
	Female Self-Face Morph		Female Stranger-Face Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Likeability	2.96	3.44	3.07	3.44	4132	-1.50	.13	.03
Uncanny Perceptions	5.16	3.49	5.04	3.49	4132	.58	.11	.03
	Female Stranger-Face Morph		Male Stranger-Face Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Likeability	3.07	3.47	2.98	3.44	4132	1.22	.22	.03
Uncanny Perceptions	5.04	3.49	5.13	3.45	4132	-1.23	.22	.03
	Female Self-Face Morph		Male Self-Face Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Likeability	2.96	3.47	2.94	3.44	4132	.25	.80	.01
Uncanny Perceptions	5.16	3.49	5.16	3.45	4132	.09	.93	0

Table 7

Descriptive Statistics for Contrasts Analyzing Significant Two-Way Interactions of Participants' Biological Sex and the Mechano-Anthropomorphic Morph Manipulation

	Male Anthropomorphic Morph		Male Mechanical Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	20.50	114.45	-93.40	114.45	4132	64.15	<.001	1
	Female Anthropomorphic Morph		Female Mechanical Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	22.80	114.45	-88.70	114.45	4132	62.09	<.001	.97
	Female Mechanical Morph		Male Mechanical Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	-88.70	81.66	-93.40	81.01	4132	2.66	.008	.06
	Female Anthropomorphic Morph		Male Anthropomorphic Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	22.8	81.66	20.50	81.01	4132	1.27	.20	.03

Table 8

Descriptive Statistics for Contrasts Analyzing Significant Two-Way Interactions of the Self- and Stranger-Face Morph Manipulation with Participants' SF&T Affinity

	Stranger-Face Morph High SF&T affinity		Stranger-Face Morph Low SF&T affinity					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	-32.20	138.88	-37.50	138.88	4132	1.73	.08	.04
Likeability	3.10	3.45	2.95	3.45	4132	1.92	.06	.04
Uncanny	5.03	3.47	5.15	3.47	4132	-1.63	.10	.03
Perceptions								
ToM Emotion	3.23	4.31	2.94	4.31	4132	3.05	.002	.07
ToM Agency	3.84	4.30	3.54	4.30	4132	3.20	.001	.07
Identification	2.16	3.34	2.03	3.34	4132	1.70	.09	.04
	Self-Face Morph High SF&T affinity		Self-Face Morph Low SF&T affinity					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	-34.70	138.88	-34.50	138.88	4132	-.07	.94	.001
Likeability	3.04	3.45	2.85	3.45	4132	2.52	.01	.06
Uncanny	5.12	3.47	5.20	3.47	4132	-1.09	.28	.02
Perceptions								
ToM Emotion	3.28	4.31	2.95	4.31	4132	3.47	.001	.08
ToM Agency	3.78	4.30	3.60	4.30	4132	1.88	.06	.04
Identification	2.87	3.34	2.63	3.34	4132	3.21	.001	.07
	Self-Face Morph Low SF&T affinity		Stranger-Face Morph Low SF&T affinity					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	-34.50	196.10	-37.50	196.10	4132	1	.32	.01
Likeability	2.85	4.88	2.95	4.88	4132	-1.32	.19	.02
Uncanny	5.20	4.91	5.15	4.91	4132	.65	.51	.01
Perceptions								
ToM Emotion	2.95	4.31	2.94	4.31	4132	.14	.89	<.001
ToM Agency	3.60	4.30	3.54	4.30	4132	.73	.47	.01
Identification	2.63	3.34	2.03	3.34	4132	8.16	<.001	.18

	Self-Face Morph High SF&T affinity		Stranger-Face Morph High SF&T affinity					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	-34.70	196.10	-32.2	196.10	4132	-.80	.42	.01
Likeability	3.04	4.88	3.10	4.88	4132	-.72	.47	.01
Uncanny	5.12	4.91	5.03	4.91	4132	1.20	.23	.02
Perceptions								
ToM Emotion	3.28	4.31	3.23	4.31	4132	.56	.57	.01
ToM Agency	3.78	4.30	3.84	4.30	4132	-.60	.55	.01
Identification	2.87	3.34	2.16	3.34	4132	9.67	<.001	.21

Table 9

Descriptive Statistics for Contrasts Analyzing Significant Two-Way Interactions of Participants' SF&T Affinity with the Mechano-Anthropomorphic Manipulation

	High SF&T affinity Mechanical Face Morph		Low SF&T affinity Mechanical Face Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Uncanny Perceptions	6.32	2.40	6.34	2.40	4134	-2.21	.03	.01
ToM Emotion	1.80	3.16	1.46	3.16	4134	4.94	<.001	.11
Identification	1.41	2.58	1.20	2.58	4134	3.67	<.001	.08
	High SF&T affinity Anthropomorphic Face Morph		Low SF&T affinity Anthropomorphic Face Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Uncanny Perceptions	3.83	2.40	3.92	2.40	4134	-1.72	.09	.04
ToM Emotion	4.70	3.16	4.43	3.16	4134	3.96	<.001	.09
Identification	3.61	2.58	3.46	2.58	4134	2.70	.007	.06
	Low SF&T affinity Anthropomorphic Face Morph		Low SF&T affinity Mechanical Face Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Uncanny Perceptions	3.92	3.40	6.43	3.40	4132	-47.57	<.001	.74
ToM Emotion	4.43	4.46	1.46	4.46	4132	42.81	<.001	.67
Identification	3.46	3.65	1.20	3.65	4132	39.74	<.001	.62
	High SF&T affinity Anthropomorphic Face Morph		High SF&T affinity Mechanical Face Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Uncanny Perceptions	3.83	3.40	6.32	3.40	4132	-47.08	<.001	.73
ToM Emotion	4.70	4.46	1.80	4.46	4132	41.83	<.001	.65
Identification	3.61	3.65	1.41	3.65	4132	38.77	<.001	.60

Table 10

Descriptive Statistics for Contrasts Analyzing Significant Three-Way Interactions of Participants' SF&T Affinity with the Mechano-Anthropomorphic Morph Manipulation and Self- and Stranger-Face Manipulation on the Human Perception of Target Morphs

	Anthropomorphic Face Morph, Low SF&T affinity, Stranger-Face		Mechanical Face Morph, Low SF&T affinity, Stranger-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	15.80	114.39	-90.90	114.39	4130	42.28	<.001	.93
	Anthropomorphic Face Morph, High SF&T affinity, Stranger-Face		Mechanical Face Morph, High SF&T affinity, Stranger-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	25.60	114.39	-90.00	114.39	4130	45.81	<.001	1.01
	Anthropomorphic Face Morph, Low SF&T affinity, Self-Face		Mechanical Face Morph, Low SF&T affinity, Self-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	23.40	114.39	-92.30	114.39	4130	45.84	<.001	1.01
	Anthropomorphic Face Morph, High SF&T affinity, Self-Face		Mechanical Face Morph, High SF&T affinity, Self-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	21.70	114.39	-91.10	114.39	4130	44.69	<.001	.99

	Self-Face, Low SF&T affinity, Mechanical Face Morph		Stranger-Face, Low SF&T affinity, Mechanical Face Morph					
Measured Outcome	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	-92.30	114.39	-90.90	114.39	4130	-.58	.57	.01
	Self-Face, High SF&T affinity, Mechanical Face Morph		Stranger-Face, High SF&T affinity, Mechanical Face Morph					
Measured Outcome	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	-91.10	114.39	-90.00	114.39	4130	.41	.68	.01
	Self-Face, Low SF&T affinity, Anthropomorphic Face Morph		Stranger-Face, Low SF&T affinity, Anthropomorphic Face Morph					
Measured Outcome	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	23.40	114.39	15.80	114.39	4130	2.99	.003	.07
	Self-Face, High SF&T affinity, Anthropomorphic Face Morph		Stranger-Face, High SF&T affinity, Anthropomorphic Face Morph					
Measured Outcome	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	21.70	114.39	25.60	114.39	4130	1.53	.13	.03
	High SF&T affinity, Mechanical Face Morph, Stranger - Face		Low SF&T affinity, Mechanical Face Morph, Stranger-Face					
Measured Outcome	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	-90.00	114.39	-90.90	114.39	4128	.33	.74	.01

	High SF&T affinity, Anthropomorphic Face Morph, Stranger -Face		Low SF&T affinity, Anthropomorphic Face Morph, Stranger-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	25.60	114.39	15.80	114.39	4128	3.86	<.001	.09
	High SF&T affinity, Mechanical Face Morph, Self-Face		Low SF&T affinity, Mechanical Face Morph, Self-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	-91.10	114.39	-92.30	114.39	4128	.49	.62	.01
	High SF&T affinity, Anthropomorphic Face Morph, Self-Face		Low SF&T affinity, Anthropomorphic Face Morph, Self-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
Human Perception	21.70	114.39	23.40	114.39	4128	-.66	.51	.01

Table 11

Descriptive Statistics for Contrasts Analyzing Significant Three-Way Interactions of Participants' SF&T Affinity with the Mechano-Anthropomorphic Morph Manipulation and Self- and Stranger-Face Manipulation on the Tom Emotion of Target Morphs

	Self-Face, Low SF&T affinity, Mechanical Face Morph		Stranger-Face, Low SF&T affinity, Mechanical Face Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
ToM Emotion	1.45	4.46	1.47	4.46	4130	-.18	.86	.004
	Self-Face, High SF&T affinity, Mechanical Face Morph		Stranger-Face, High SF&T affinity, Mechanical Face Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
ToM Emotion	1.81	4.46	1.79	4.46	4130	.18	.86	.004
	Self-Face, Low SF&T affinity, Anthropomorphic Face Morph		Stranger-Face, Low SF&T affinity, Anthropomorphic Face Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
ToM Emotion	4.45	4.46	4.41	4.46	4130	.45	.65	.009
	Self-Face, High SF&T affinity, Anthropomorphic Face Morph		Stranger-Face, High SF&T affinity, Anthropomorphic Face Morph					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
ToM Emotion	4.75	4.46	4.66	4.46	4130	.91	.36	.02

	High SF&T affinity, Mechanical Face Morph, Stranger-Face		Low SF&T affinity, Mechanical Face Morph, Stranger-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
ToM Emotion	1.79	4.46	1.47	4.46	4128	3.31	.001	.07
	High SF&T affinity, Anthropomorphic Face Morph, Stranger-Face		Low SF&T affinity, Anthropomorphic Face Morph, Stranger-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
ToM Emotion	4.66	4.46	4.41	4.46	4128	2.57	.01	.06
	High SF&T affinity, Mechanical Face Morph, Self-Face		Low SF&T affinity, Mechanical Face Morph, Self-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
ToM Emotion	1.81	4.46	1.45	4.46	4128	3.67	.<.001	.08
	High SF&T affinity, Anthropomorphic Face Morph, Self-Face		Low SF&T affinity, Anthropomorphic Face Morph, Self-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
ToM Emotion	4.75	4.46	4.45	4.46	4128	3.03	.003	.07
	Anthropomorphic Face Morph, Low SF&T affinity, Stranger-Face		Mechanical Face Morph, Low SF&T affinity, Stranger-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
ToM Emotion	4.41	4.46	1.47	4.46	4128	29.95	<.001	.66

	Anthropomorphic Face Morph, High SF&T affinity, Stranger-Face		Mechanical Face Morph, High SF&T affinity, Stranger-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
ToM Emotion	4.66	4.46	1.79	4.46	4128	29.21	<.001	.64
	Anthropomorphic Face Morph, Low SF&T affinity, Self-Face		Mechanical Face Morph, Low SF&T affinity, Self-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
ToM Emotion	4.45	4.46	1.45	4.46	4128	30.57	<.001	.67
	Anthropomorphic Face Morph, High SF&T affinity, Self-Face		Mechanical Face Morph, High SF&T affinity, Self-Face					
*Mea*sured *Outcome*	*Mean*	*SD*	*Mean*	*SD*	*df*	*t*	*p*	Cohen's *d*
ToM Emotion	4.75	4.46	1.81	4.46	4128	29.93	<.001	.66

Supplemental Material

How Much Anthropomorphism is Necessary to Trigger an Uncanny Valley Effect?

Finally, my study seeks to identify at which steps of the human-robot face morph continuum significant differences between the self- and stranger-face morphs are observed. This will provide insights relevant to the study of the self-reference mechanism that underlies the doppelgänger hypothesis in the uncanny valley literature through enabling a fine-grained examination of the interaction between these two manipulations to elucidate the role of targets' visual self-proximity on the elicitation of doppelgänger-linked uncanny valley reactions. Specifically, I seek to explore if there is a category boundary in self-target identification on the enhancement of uncanny valley outcomes in line with the self-reference effect.

Individuals tend to assign stimuli to discrete categories (Calder et al., 1996). Currently, it is unknown how participants' allocation of targets to "self" or "not self" will impact the self-reference effects' enhancement of the uncanny valley. One possibility is that targets that elicit high levels of self- vs. not-self categorization ambiguity will trigger enhanced uncanny valley perceptions in similar mechanism to the categorization ambiguity hypothesis. In such case, differences between outcomes associated with the self-targets and stranger-targets are expected to be greatest among the more mechanical face morphs where self- vs not-self categorization proves most challenging. Alternatively, participants may not self-reference highly mechanical stimuli featuring their manipulated self-image, and instead view such aberrated recreations as belonging to a strange, separate individual. If so, the self-reference effect would be found to enhance uncanny valley perceptions for the least manipulated images. In investigation of these two proposed mechanisms of the self-reference effect on the uncanny valley, I pose:

RQ4 At which steps of the mechano-anthropomorphic manipulation will differences between the self- and stranger-photo manipulation on (a) mechano-human rating, (b) likability, (c) resource allocation, (d) uncanny valley perceptions, (e) theory of mind emotion, (f) theory of mind agency, (g) identification, and (h) perceived realism be observed?

RQ4 identified at which steps of the mechano-anthropomorphic manipulation differences between the self- and stranger-photo manipulation on the outcome variables emerged. Self-targets were rated as less likeable than stranger-targets at the 20% human face morph condition only. Uncanny valley perceptions were also greatest at the 20% human face morph condition. Additionally, participants identified more with self than the stranger-targets from the 30% and greater human face morph conditions. Further, participants attributed greater agency to the self-relative to the stranger-targets at the 70% human face morph condition. At the 90% and 100% human face morph conditions, self-morphs were bestowed a more altruistic resource allocation than stranger morphs. At the 100% human face morph condition, self-morphs were rated as significantly more uncanny than stranger morphs. No other differences between the self- and stranger-face morphs by step of the mechano-anthropomorphic manipulation were identified. RQ4 revealed that the self-reference effect was most reliable on the least-modified self-faces. Nevertheless, RQ4 demonstrated the unreliable nature of the self-reference effect for self-face morphs which presented modified anthropomorphism. For descriptive statistics, see Table 12.

Stepwise Examination of the Mechano-Anthropomorphic Manipulation

In analysis of RQ4, examination of the self- and stranger-face morph manipulation by stepwise comparison of the mechano-anthropomorphic manipulation revealed a singular robust effect on participants' identification with self-face morphs, relative to stranger-face morphs, when presented face morphs were 30% or greater human. This robust self-refence effect on

participants' identification for self-face morphs relative to stranger-face morphs that were at least 30% human echoes prior face morph research on the self-recognition bias. Take Chakraborty and Chakrabarti (2015), who presented participants with 21-image stranger- to self-face morph continuums to identify that half of participants correctly recognize their self-face at approximately the 40% self-face face morph step. Nevertheless, Chakraborty and Chakrabarti (2015) did not examine how participants' self-recognition with target-morphs impact self- or target-oriented outcome variables, allowing my present research to provide important expansion of the literature.

Significantly, I identified weak and unreliable evidence of the self-reference effect on participants' response to mechano-human face morph continuums for the remainder of the outcome variables, (likeability, theory of mind agency, simulated resource donation, and uncanny valley perceptions) to advance knowledge on the limitations of the self-reference effect on face morph-linked outcomes beyond identification. Likability of self-face morphs was significantly lower than the likeability of stranger-face morphs at the 20% human face morph step. In potential cause of this finding, participants' uncanny valley perceptions peaked for the 20% human face morphs. At the 70% human face morph step only, there was a significant if unreliable self-reference effect that enhanced participants' ToM agency for self-face morphs relative to stranger-face morphs. Participants were found to more altruistically donate resources to self-faces than stranger-faces that were at least 90% human, indicating the presence of a self-serving bias that occurred for the most human face morphs. Notably, the self-reference effect heightened participants' response on the uncanny valley scale for self-faces relative to stranger-faces for face morphs that were unmodified and 100% human. However, triggered by unmodified photos of humans, this effect fell outside the scope of the uncanny valley hypothesis.

Rather, participants were found to experience discomfort from viewing their self-images in laboratory settings.

As such, findings serve to inform that identification with images in face morph continuums alone is insufficient to trigger the self-reference effect on variables beyond identification. In explanation of this unexpected finding, I suggest that negative alterations to images featuring the self may inhibit the development of self-reference behavior. Indeed, Proteus effect research highlights that individuals distance themselves from negative avatars (Peña, 2020). McCain et al. (2018) demonstrate that female participants embodying an avatar of a narcissistic celebrity display reduced narcissism relative to female participants embodying a generic avatar (McCain et al., 2018). Future research would do well to determine the boundaries of continuum stimuli that trigger the self-reference effect, and how this effect interweaves with uncanny valley mechanisms. For instance, communication and linguistic scholars may wish to replicate and extend this present work's design with self and stranger mechano-anthropomorphic voice morph continuums to provide a stepwise examination of the self-reference effect on audio triggers of the uncanny valley.

Table 12

Pairwise Comparisons in Description of RQ4

Measure	Face Morph Percent Human	Mean Difference (Self - Stranger)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Human Perception	0%	0.00	0.00		0.00	0.00
	10%	-1.59	1.65	0.34	-1.69	4.87
	20%	-1.62	2.63	0.54	-3.60	6.83
	30%	-2.07	2.66	0.44	-3.22	7.35
	40%	-3.15	3.16	0.32	-3.12	9.41
	50%	-5.28	3.59	0.14	-1.83	12.40
	60%	-4.49	4.70	0.34	-4.84	13.81
	70%	2.81	5.02	0.58	-12.77	7.15
	80%	3.43	5.29	0.52	-13.92	7.06
	90%	5.81	4.37	0.19	-14.48	2.85
	100%	1.72	2.24	0.44	-6.17	2.72
Likability	0%	0.00	0.00		0.00	0.00
	10%	-0.05	0.09	0.62	-0.14	0.23
	20%	-0.17	0.08	0.04	0.01	0.33
	30%	0.12	0.11	0.28	-0.33	0.09
	40%	-0.14	0.09	0.15	-0.05	0.32
	50%	0.02	0.08	0.85	-0.18	0.15
	60%	-0.02	0.11	0.85	-0.21	0.25
	70%	0.01	0.12	0.94	-0.25	0.23
	80%	-0.15	0.13	0.26	-0.11	0.41
	90%	-0.28	0.15	0.06	-0.02	0.57
	100%	-0.22	0.12	0.08	-0.02	0.46
Resource Allocation	0%	0.00	0.00		0.00	0.00
	10%	0.11	0.98	0.91	-2.06	1.84
	20%	0.25	0.97	0.80	-2.17	1.67
	30%	-0.66	1.04	0.53	-1.41	2.73
	40%	0.51	1.07	0.63	-2.63	1.60
	50%	0.62	1.16	0.60	-2.93	1.69
	60%	-0.57	1.67	0.73	-2.75	3.89
	70%	2.39	1.71	0.17	-5.78	1.00
	80%	2.40	1.81	0.19	-5.98	1.18
	90%	4.09	1.91	0.03	-7.88	-0.29
	100%	8.84	2.14	0.00	-13.09	-4.60

Uncanny Perceptions	0%	0.00	0.00		0.00	0.00
	10%	0.03	0.06	0.59	-0.15	0.09
	20%	0.06	0.06	0.31	-0.17	0.06
	30%	0.03	0.07	0.70	-0.16	0.11
	40%	0.04	0.08	0.65	-0.20	0.12
	50%	0.05	0.07	0.44	-0.19	0.08
	60%	0.18	0.10	0.08	-0.39	0.02
	70%	0.11	0.12	0.36	-0.34	0.12
	80%	0.13	0.12	0.31	-0.37	0.12
	90%	0.14	0.10	0.18	-0.35	0.06
	100%	0.14	0.07	0.04	-0.27	0.00
ToM Emotion	0%	0.00	0.00		0.00	0.00
	10%	-0.04	0.09	0.68	-0.15	0.22
	20%	-0.16	0.08	0.05	0.00	0.33
	30%	0.03	0.09	0.77	-0.20	0.15
	40%	0.00	0.11	1.00	-0.22	0.21
	50%	-0.02	0.13	0.89	-0.23	0.27
	60%	0.12	0.14	0.42	-0.40	0.17
	70%	0.28	0.16	0.09	-0.59	0.04
	80%	0.04	0.15	0.78	-0.34	0.26
	90%	0.13	0.15	0.39	-0.42	0.16
	100%	-0.02	0.08	0.83	-0.14	0.17
ToM Agency	0%	0.00	0.00		0.00	0.00
	10%	-0.04	0.11	0.70	-0.17	0.26
	20%	-0.20	0.10	0.06	-0.01	0.40
	30%	-0.12	0.10	0.23	-0.07	0.31
	40%	-0.04	0.11	0.70	-0.18	0.26
	50%	0.12	0.15	0.43	-0.40	0.17
	60%	0.14	0.16	0.36	-0.46	0.17
	70%	0.36	0.17	0.04	-0.69	-0.02
	80%	0.08	0.13	0.55	-0.34	0.18
	90%	0.05	0.14	0.71	-0.32	0.22
	100%	0.03	0.09	0.75	-0.20	0.14
Identification	0%	0.00	0.00		0.00	0.00
	10%	0.01	0.07	0.83	-0.15	0.12
	20%	0.10	0.07	0.13	-0.24	0.03
	30%	0.26	0.07	0.00	-0.40	-0.11
	40%	0.40	0.09	0.00	-0.59	-0.22
	50%	0.48	0.08	0.00	-0.64	-0.31
	60%	0.62	0.11	0.00	-0.83	-0.40
	70%	0.87	0.12	0.00	-1.10	-0.64
	80%	1.16	0.14	0.00	-1.44	-0.88
	90%	1.34	0.16	0.00	-1.65	-1.03
	100%	2.03	0.13	0.00	-2.28	-1.78

Appendix

Scale A1

Science Fiction and Technology Affinity Scale: Adapted from Weisman and Peña (2021)

Please mark your agreement with the following statements.		
Positive Outlook 1	I have a positive outlook about the impact of robots, AI, and science & technology on the future of the world in general.	(1) Strongly disagree (2) Disagree (3) Somewhat disagree (4) Neither agree nor disagree (5) Somewhat agree (6) Agree (7) Strongly agree
Positive Outlook 2	I enjoy imaginative futuristic concepts involving robots, AI, and science & technology.	
Positive Outlook 3	I appreciate learning more about the future of the world as it is influenced by robots, AI, and science & technology.	
Positive Outlook 4	I stay up to date with the latest developments in robots, AI, and science & technology.	
Positive Outlook 5	I expect positive things of a future with more robots, AI, and science & technology.	
Positive Outlook 6	I would enjoy being driven by an AI controlled self-driving car.	
Positive Outlook 7	I welcome ever increasing automation as a product of advancements in robots, AI, and science & technology.	
Media Consumption 1	How frequently do you play video games with positive or utopian portrayal of robots? E.g. Titanfall 2.	(1) Very infrequently (2) Infrequently (3) Somewhat infrequently (4) Some of the time
Media Consumption 2	How frequently do you read books with positive or utopian portrayal of robots? E.g. My Friend the Robot.	
Media Consumption 3	How frequently do you watch science fiction movies with positive or utopian portrayal of robots? E.g. Chappie.	
Media Consumption 4	How frequently do you watch documentaries with positive or utopian portrayal of robots? E.g. More Than Robots.	
Media Consumption 5	How frequently do you play video games with negative or dystopian	

	portrayal of robots? E.g. Fallout, Portal.	(5) Somewhat frequently (6) Frequently (7) Very frequently
Media Consumption 6	How frequently do you read books with negative or dystopian portrayal of robots? E.g. Do Androids Dream of Electric Sheep.	
Media Consumption 7	How frequently do you watch science fiction movies with negative or dystopian portrayal of robots? E.g. Terminator.	
Media Consumption 8	How frequently do you watch documentaries with negative or dystopian portrayal of robots? E.g. Will Robots Steal Our Jobs.	
Virtual Assistant Use 1	How frequently do you use virtual assistants such as Amazon's Alexa, Apple's Siri, Google's Google Now, or Samsung's Bixby?	
Virtual Assistant Use 2	How much do you enjoy using virtual assistants such as Amazon's Alexa, Apple's Siri, Google's Google Now, or Samsung's Bixby?	(1) Greatly dislike (2) Dislike (3) Somewhat dislike (4) Neither dislike nor enjoy (5) Somewhat enjoy (6) Enjoy (7) Greatly enjoy
Virtual Assistant Use 3	How useful do you find virtual assistants such as Amazon's Alexa, Apple's Siri, Google's Google Now, or Samsung's Bixby?	(1) Extremely useless (2) Moderately useless (3) Slightly useless (4) Neither useful nor useless (5) Slightly useful (6) Moderately useful (7) Extremely useful
Novel AI Use 1	How frequently do you use novel chatbots such as OpenAI’s ChatGPT or Google’s Bard on a weekly basis?	(1) Very infrequently (2) Infrequently (3) Somewhat infrequently (4) Some of the time (5) Somewhat frequently (6) Frequently (7) Very frequently
Novel AI Use 2	How much do you enjoy using novel chatbots such as OpenAI’s ChatGPT or Google’s Bard?	(1) Greatly dislike (2) Dislike (3) Somewhat dislike (4) Neither dislike nor enjoy (5) Somewhat enjoy (6) Enjoy (7) Greatly enjoy

Novel AI Use 3	How useful do you find novel chatbots such as OpenAI's ChatGPT or Google's Bard?	(1) Extremely useless (2) Moderately useless (3) Slightly useless (4) Neither useful nor useless (5) Slightly useful (6) Moderately useful (7) Extremely useful