Individual differences predict sensitivity to the uncanny valley

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Abstract

It can be creepy to notice that something human-looking is not real. But can sensitivity to this phenomenon, known as the uncanny valley, be predicted from superficially unrelated traits? Based on results from at least 489 participants, this study examines the relation between nine theoretically motivated trait indices and uncanny valley sensitivity, operationalized as increased eerie ratings and decreased warmth ratings for androids presented in videos. Animal Reminder Sensitivity, Neuroticism, its Anxiety facet, and Religious Fundamentalism significantly predicted uncanny valley sensitivity. In addition, Concern over Mistakes and Personal Distress significantly predicted android eerie ratings but not warmth. The structural equation model indicated that Religious Fundamentalism operates indirectly, through robot-related attitudes, to heighten uncanny valley sensitivity, while Animal Reminder Sensitivity increases eerie ratings directly. These results suggest that the uncanny valley phenomenon may operate through both sociocultural constructions and biological adaptations for threat avoidance, such as the fear and disgust systems. Trait indices that predict uncanny valley sensitivity warrant investigation by experimental methods to explicate the processes underlying the uncanny valley phenomenon.

Introduction

Masahiro Mori (1970/2012) identified the uncanny valley phenomenon: a feeling of eeriness and discomfort with android robots and other realistic human figures. Affinity for a robot typically increases as it is made to look more human. However, at some point the robot may become sufficiently realistic that its remaining nonhuman features become noticeable and disturbing. Thus, entities of intermediate perceived humanness, such as androids, appear eerier than those of low or high perceived humanness, such as mechanical-looking robots or real human beings (Figure 1). Empirical research has found evidence of this phenomenon for both androids and computer-animated human characters (Burleigh, Schoenherr, & Lacroix, 2013; Lewkowicz & Ghazanfar, 2012; MacDorman, Green, Ho, & Koch, 2009; MacDorman & Ishiguro, 2006; Mitchell, Ho, Patel, & MacDorman, 2011; Seyama & Nagayama, 2007; Steckenfinger & Ghazanfar, 2009; Tinwell, Abdel Nabi, & Charlton, 2013; Tinwell, Grimshaw, & Williams, 2011). The uncanny valley is a concern not only in social robotics regarding people's acceptance of robots but also in the computer-animated film and video game industries; for example, if audiences cannot relate to human characters in animated narratives because of the uncanny valley, the title could flop and, as a result, the studio could go bankrupt (e.g., ImageMovers Digital, Butler & Joschko, 2009; Freedman, 2012; Syrdal, Dautenhahn, Koay, & Walters, 2009; Walters, Dautenhahn, Boekhorst, Koay, Syrdal, & Nehaniv, 2008).
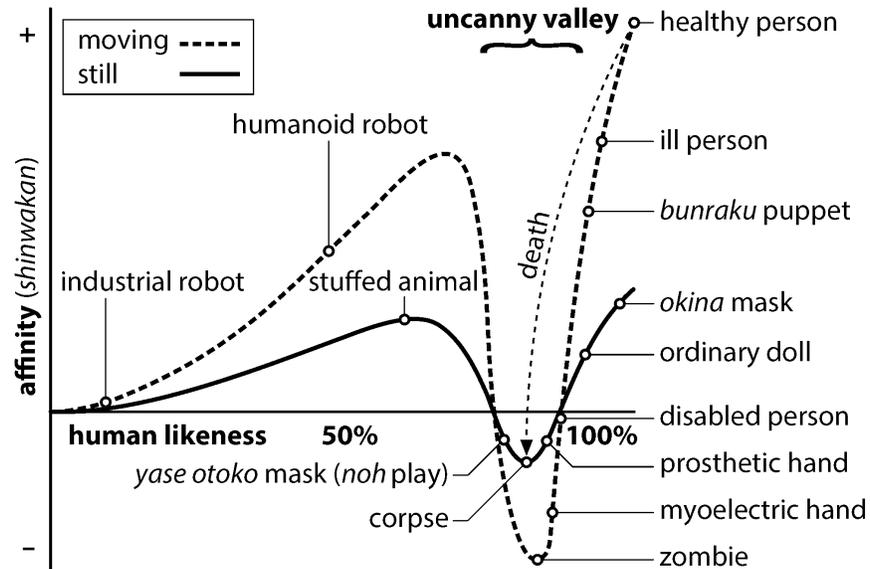
Figure 1. Mori's (1970/2012) graph illustrates his observations concerning the relation between human likeness and affinity: Affinity increases with human likeness until a point is reached at which the figure appears so human that its remaining nonhuman features become salient and unnerving. Thus, the figure tumbles into a valley of eeriness. Affinity increases once again, pulling the figure out of the valley, as it becomes indistinguishable from a real human being. Movement is said to amplify the effect.

This study aims to explore how differences among individuals could affect their sensitivity to the uncanny valley phenomenon. Specifically, its purpose is to determine the relation between individuals' traits and their emotional state while perceiving potentially uncanny androids. Individual differences have been considered in past research on human–robot interaction (Tapus, Tapus & Matarić, 2008; Tsui, Desai, Yanco, Cramer, & Kemper, 2011; Turkle, Taggart, Kidd, & Dasté, 2006; Syrdal et al., 2009; Walters et al., 2008). However, no attempt has been made to investigate empirically the relation between individual traits and uncanny valley sensitivity. We have selected the following nine traits for examination: Perfectionism, Neuroticism and Anxiety, Animal Reminder Sensitivity, Personal Distress, Human–Robot Uniqueness, Human–Android Uniqueness, Religious Fundamentalism, and

Negative Attitudes Toward Robots. The nine traits are motivated by current and proposed theories of the uncanny valley (Burleigh, Schoenherr, & Lacroix, 2013; Hanson, 2005; Ho, MacDorman, & Pramono, 2008; MacDorman et al., 2009; MacDorman & Ishiguro, 2006; Moore, 2012; Moosa & Ud-Dean, 2010; Ramey, 2005; Tondu & Bardou, 2011; Yamada, Kawabe, & Ihaya, 2012). The results of this exploratory study on individual differences may assist researchers in determining which theories on the causes of the uncanny valley are plausible and, thus, worthy of further investigation.

For the purposes of this study, we operationalize uncanny valley sensitivity as higher ratings of eeriness and lower ratings of warmth (vs. coldness) for androids (Ho & MacDorman, 2010). A warmth dimension serves as an empirically justifiable analogue for what Mori (1970/2012) calls affinity (*shinwakan* in the original Japanese). Warmth has been found to be the primary dimension of human social perception (Fiske, Cuddy, & Glick, 2007; competence is the secondary dimension). However, coldness, the negative pole of warmth, is conceptually distinct from eeriness (*bukimi*), because we can feel cold toward someone without finding that person creepy (e.g., someone envied for gaining a promotion solely based on good looks). Thus, it is necessary to measure both eeriness and warmth. A limitation of a number of studies on the uncanny valley is that they do not measure eeriness—the *uncanny* in the uncanny valley. Whether eeriness and warmth ratings for androids are sufficient to operationalize uncanny valley sensitivity, or other behavioral or physiological variables are necessary, remains an open question.[1]

We propose that the uncanny valley cannot be fully explained solely by a general cognitive theory, such as processing fluency (Yamada, Kawabe, & Ihaya, 2012), perceptual

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[1] Dimensions for warmth and eeriness should arguably be complemented by a *rightness* dimension, that is, assonance vs. dissonance (Mangan, 2001). Even eeriness can feel right in certain contexts (e.g., seeking thrills at a haunted house) but not others (e.g., touching a prosthetic limb).

tension (Burleigh, Schoenherr, & Lacroix, 2013; Moore, 2012), or cognitive dissonance (Hanson, 2005; Tondu & Bardou, 2011). What none of these theories explain is the characteristic eerie feeling associated with human-looking entities that incorporate nonhuman features. We identify this feeling with specific biological adaptations for threat avoidance rooted in the fear and disgust systems (Ho, MacDorman, & Promono, 2007; MacDorman & Ishiguro, 2006; MacDorman et al., 2009). The structural equation model derived from data collected in this study indicates some provisional conclusions: First, Religious Fundamentalism may heighten uncanny valley sensitivity by operating through related sociocultural constructions, such as the conviction that human beings are unique—set apart from robots and the rest of creation (i.e., Human-Robot Uniqueness). Second, an individual's sensitivity to the vulnerability and impermanence of the physical body may directly and viscerally heighten the perceived eeriness of androids. This sensitivity, confusingly called Animal Reminder Sensitivity (Olatunji et al., 2007), is likely to operate through the fear and disgust systems.

Theoretical perspective and hypotheses

Each of the nine trait indices is examined below in relation to theories of the uncanny valley and their predictions.

Perfectionism

Perfectionists' excessive concern with making mistakes may predict the uncanny valley phenomenon. Nonhuman features in human figures are typically perceived as mistakes—eyes that look dead, movements unnatural (Tinwell, Abdel Nabi, & Charlton, 2013; Matsui, Minato, MacDorman, & Ishiguro, 2005); perfectionists are more likely than others to attend to details, to find flaws in them, and to feel worse when they do (Rice, Bair, Castro, Cohen, & Hood, 2003).

We invoke MacDorman and Ishiguro's (2006) *expectation violation* theory of the

uncanny valley to explain why concern with making mistakes predicts uncanny valley sensitivity. MacDorman and Ishiguro (2006) propose that an entity is experienced as uncanny when it elicits the brain's model of a human being but possesses features that violate the model's predictions (MacDorman et al., 2009). Saygin and colleagues (2012) found evidence of model prediction error in the form of increased cortical activation when observing a mechanical-looking movement in a human-looking robot. Failed predictions may result in a stronger orienting response in perfectionists, leading to a higher defect detection rate. This would make perfectionists acutely susceptible to the paradox of the uncanny valley: As an entity is made to look more human, its remaining nonhuman features become more noticeable and disturbing (MacDorman et al., 2009; MacDorman, Srinivas, & Patel, 2013; Mitchell et al., 2011).

To measure excessive concern for making mistakes, this study uses the Concern over Mistakes subscale of the Multidimensional Perfectionism Scale (MPS; Frost, Marten, Lahart, & Rosenblate, 1990). Concern over Mistakes and Doubts about Actions constitute the primary dimension of MPS, and because androids embody mistakes (nonhuman features), Concern over Mistakes is theoretically more relevant to the uncanny valley than the remaining dimensions (i.e., Parental Expectations/Parental Criticism, Personal Standards, and Organization; Stöber, 1998). The subscale includes nine 7-point Likert items, such as the following: "I should be upset if I make a mistake." "If I do not do as well as other people, it means I am an inferior human being."

> *Hypothesis 1:* Individuals who rate higher on the Concern over Mistakes dimension of the MPS will perceive androids with nonhuman features as eerier and less warm than others.

Neuroticism and Anxiety

Neuroticism, which is a "big five" personality trait indicating emotional instability (Digman, 1990), may predict uneasiness with androids. The reason is as follows: Androids identified as creepy or

eerie are elicitors of fear, anxiety, and disgust (Ho, MacDorman, & Pramono, 2008), and emotionally unstable individuals are more likely than others to experience these emotions when exposed to their elicitors (Druschel & Sherman, 1999; Haidt, McCauley, & Rozin, 1994; Larsen & Ketelaar, 1991). Anxiety and fear are closely related but distinguishable: Fear is an adaptive mechanism that drives the individual to escape and avoid the eliciting stimulus, whereas anxiety is unresolved fear caused by anticipation of the stimulus, an inability to avoid it, or the stimulus remaining subconscious (Öhman, 2000).

Neuroticism has been found to correlate with a preference for mechanical-looking robots as opposed to human-looking ones (Syrdal et al., 2009; Walters et al., 2008). However, it has not yet been determined whether neuroticism predicts a heightened perception of eeriness in androids (Ho & MacDorman, 2010). To measure neuroticism, this study adopts the Neuroticism Scale from 23BB5 (Duijsens & Diekstra, 1995), which has six 7-point semantic differential items: *anxious–not anxious, insensitive–sensitive, tense–relaxed, emotional–unemotional, panicky–imperturbable,* and *temperamental–even tempered.*

Hypothesis 2a: Individuals who rate higher on the Neuroticism Scale of 23BB5 will perceive androids with nonhuman features as eerier and less warm than others.

Costa and McCrae (1992) decompose neuroticism into six facets: anxiety, angry hostility, depression, self-consciousness, impulsiveness, and vulnerability to stress (McCrae, 2002). We next examine the anxiety facet, because a defining characteristic of neuroticism is heightened sensitivity to stimuli that elicit fear and anxiety (Eysenck, 1992)—two emotions that are of theoretical and empirical significance to the uncanny valley (Ho, MacDorman, & Pramono, 2008; MacDorman et al., 2009; MacDorman & Ishiguro, 2006). Examining the uncanny as a source of anxiety dates back to the roots of the psychoanalytic tradition. An anxious disposition Jentsch (1906/1997) links to an abnormal sensitivity to the uncanny. According to Freud (1919/2003), the uncanny elicits morbid anxiety, a phenomenon he identifies with the recurrence of

something once familiar but estranged by repression. Drawing on the work of Freud's colleague Rank (1930/1998) and others, Becker (1973) proposed that culture and religion provide a symbolic defense mechanism against the individual's cognizance of mortality. Pyszczynski, Greenberg, and Solomon (1999) and their colleagues have extensively elaborated and tested Becker's ideas in terror management theory.

Applying terror management theory, MacDorman (2005) hypothesized that an uncanny android would elicit subconscious mortality-related fears and culturally-supported defense mechanisms for coping with death's inevitability. The study found that exposure to an uncanny android induced in participants mortality salience and terror management defenses, such as a heightened preference for supporters of their worldview and a diminished preference for detractors of their worldview. We propose that the anxiety facet of neuroticism could predict uncanny valley sensitivity based on the following assumption: Those rating high on anxiety are more sensitive to its elicitors and an uncanny android is one such elicitor.

Androids could also heighten social anxiety because of missing affective cues that resolve social ambiguity in human interactions. Individuals with high levels of social anxiety are more likely to interpret ambiguity in facial expressions and social interactions as threatening (Constans, Penn, Ihen & Hope, 1999; Yoon & Zinbarg, 2007). An individual's preexisting anxiety in conjunction with an inability to predict another's behavior has been found to lead to aversion (Samochowiec & Florack, 2010). A lack of emotional expression in the upper parts of a virtual character's face has also been found to increase the character's uncanniness, possibly because of the viewer's inability to predict its behavior (Tinwell, Grimshaw, Nabi & Williams, 2011).

To measure trait anxiety, this study adopts the Anxiety facet of the International Personality Item Pool (IPIP; Goldberg, 1999; cf. Kulas, Stachowski, & Haynes, 2008; Uliaszek et al., 2009), which has ten 7-point items, with responses varying from *very accurate* to *very inaccurate*. Sample items include the following: "Am afraid of many things." "Get stressed out easily." "Adapt easily to new situations" (reverse scaled). The Anxiety facet is designed to

measure the same construct as the NEO-PI-R N1 (Costa and McCrae, 1992; McCrae, 2002) but is in the public domain.

> *Hypothesis 2b:* Individuals who rate higher on the IPIP Anxiety facet will perceive androids with nonhuman features as eerier and less warm than others.

Personal Distress

The uncanny valley phenomenon may be intensified for individuals who, when seeing others in negative situations, experience personal distress—that is, anxiety and paralysis. Both personal distress and sympathy are considered forms of empathy, the ability to project one's self into the circumstances of another individual (de Vignemont & Singer, 2006). However, personal distress differs from sympathy in that the elicited feelings of anxiety are self-oriented and impede helping behavior (Davis, 1980, 1983; Preston & de Waal, 2002).

In relation to androids, personal distress could increase uncanny valley sensitivity through several empathetic processes. First, the android could operate as a human analogue. Thus, the android would elicit personal distress, if it had features that would be considered disturbing abnormalities in people, such as thrashing movements reminiscent of epilepsy (Freud, 1919/2003), or if it appeared incomplete or not fully assembled relative to a healthy person (MacDorman & Ishiguro, 2006). Second, uncanny androids could elicit anxiety by activating subconscious fears of replacement, dismemberment, soullessness, or mortality (MacDorman & Ishiguro, 2006; MacDorman, Vasudevan, & Ho, 2009). (As already noted, Jentsch, 1906/1997, identifies sensitivity to the uncanny with trait anxiety.) Third, because an android looks human but the perceiver typically knows it is not human, its perception could successively activate the concept *human* and then its conscious suppression, thus interfering with empathy (Misselhorn, 2009). To elaborate, *we propose that this alternation simultaneously elicits anxiety while suppressing empathy.* The perceiver feels the android's "suffering" but cannot attribute the suffering to the android owing to an inability to identify with the soulless machine.

This study uses the Personal Distress subscale of the Interpersonal Reactivity Index (IRI) to measures self-oriented anxiety in tense interpersonal situations (Davis, 1980, 1983). The scale includes seven 7-point Likert items, such as the following: "When I see someone who badly needs help in an emergency, I go to pieces." "I sometimes feel helpless when I am in the middle of a very emotional situation." "When I am with a friend who is depressed, I become so uncomfortable that I can't really talk to him."

Hypothesis 3: Individuals who rate higher on the Personal Distress subscale of the IRI will perceive androids with nonhuman features as eerier and less warm than others.

Animal Reminder Sensitivity

Individuals who are disturbed by reminders of their own creatureliness, such as their mortal body and bodily functions, may have a greater aversion to androids, perceiving them as eerier than those less easily disturbed. Mori (1970/2012) proposed that underlying the uncanny valley phenomenon is an instinct for self-preservation that causes aversion to corpses, dangerous animals, and other threats. MacDorman and Ishiguro (2006) elaborated on this idea, proposing that the uncanny valley phenomenon could reflect an evolved cognitive and affective mechanism for the avoidance of potential threats, such as pathogens or unfit mates (Moosa & Ud-Dean, 2010). According to the theory of pathogen avoidance, we are more sensitive to abnormalities in human-looking entities, because their physical and behavioral similarity indicate genetic relatedness and, thus, a higher risk of disease transmission (Ho, MacDorman, & Pramono, 2008; MacDorman et al., 2009). According to the theory of mate selection, abnormalities could indicate low fitness in potential mates (MacDorman & Ishiguro, 2006; MacDorman et al., 2009). For both pathogen avoidance and mate selection theories, aversion to abnormalities enhances fitness.

Two candidate systems underlying aversive behavior are fear and disgust. Fear and disgust differ in their elicitors (e.g., bear vs. cockroach), experiential qualities, evolutionary origin,

elicited facial expressions, areas of brain activity, and other physiological responses (Davey et al., 1998; Jabbi, Bastiaansen, Keysers, 2008; Öhman, 2000; Rozin, Haidt, & McCauley, 2008). Fear motivates flight from immediate, life-threatening dangers, whereas disgust, as a behavioral prophylaxis, motivates the oral rejection and avoidance of potential toxins and pathogens (Curtis, Aunger, & Rabie 2004; Fessler & Navarrete, 2005; Öhman, 2000; Rozin & Fallon, 1987). Animal reminders may elicit fear, disgust, and horror by bringing to mind our creatureliness and animal origins (Olatunji et al., 2007; Cox, Goldenberg, Pyszczynski, & Weise, 2007). Human–android comparisons could engage the same cognitive and affective systems for threat avoidance as human–animal comparisons.

A third candidate mechanism is terror management (MacDorman, 2005; MacDorman & Ishiguro, 2006). Reminders of our creatureliness are also reminders of our mortality, because all animals die. Terror management research has found animal reminders heighten the accessibility of death-related thoughts, disgust sensitivity, and a preference for arguments favoring human uniqueness to those favoring human continuity with the animal realm (Cox et al., 2007; Goldenberg, Pyszczynski, Greenberg, Solomon, 2000; Goldenberg et al., 2001).

Animal Reminder is the disgust sensitivity subfactor most closely related to humanity's aversion to its animality. Sensitivity to animal reminders has been measured reliably (Olatunji et al., 2007, derived from Haidt, McCauley, & Rozin 1994). The Animal Reminder subscale includes eight 7-point items: five Likert items and three disgust intensity items. Given that only three of the eight items mention disgust and the subscale thematically overlaps with the bodily injury–illness–death subfactor of the Fear Survey Schedule-III (Arrindell et al., 2003), the subscale likely also detects fear sensitivity to animal reminders. Compellingly, several of Freud's (1919/2003) examples of the uncanny—dead bodies, losing one's eyes, a hand cut off at the wrist—match the Likert items from the animal reminder subfactor: "It would bother me tremendously to touch a dead body." "It would not upset me at all to watch a person with a glass eye take the eye out of the socket" (reverse scaled). "It would bother me to be in a science class,

and see a human hand preserved in a jar."

> *Hypothesis 4:* Individuals who rate higher on the Animal Reminder subfactor of the Disgust Scale-Revised will perceive androids with nonhuman features as eerier and less warm than others.

Human–Robot and Android–Robot Uniqueness

We propose that an individual who conceptualizes the categories *robot* and *human* as more mutually exclusive will also tend to feel more disturbed by ambiguous entities, such as androids. Jentsch (1906/1997) was first to observe that uncanny sensations could be caused by uncertainty about the category to which an entity belongs and especially by uncertainty about whether the entity is living or nonliving, human or nonhuman (MacDorman & Ishiguro, 2006), or sentient or insentient (Gray & Wegner, 2012; Waytz, Gray, Epley, & Wegner, 2010). Ramey (2005) further proposes that an uncanny valley arises whenever two qualitatively distinct learned categories are linked by a quantitative metric that challenges their prior separation. For example, Mori's (1970/2012) graph depicts a continuum of entities of increasing human likeness, from the industrial robot to a healthy person. At the bottom of the valley lies the walking corpse, presumably on the boundary between nonliving human doubles and living human beings. Uncanny sensations may be eliminated by resolving uncertainty about the ambiguous entity; for an android, this can be achieved either by learning a new cognitive category, *android,* to cover the ambiguous entity or by no longer conceiving of the categories *robot* and *human* as mutually exclusive (Ramey, 2005). For example, robots and human beings could be viewed as instances of the same kind of thing: complex physical mechanisms.

Category uncertainty may result either when it is unclear to which category an entity's features belong or when some features appear to belong to one category and other features to a different, incompatible category. The latter, namely, perceptual tension among features, Moore (2012) identifies as the cause of the uncanny valley. Others have further qualified that

the conflicting features should be human and nonhuman (Burleigh, Schoenherr, & Lacroix, 2013; MacDorman et al., 2009). In his original essay, Mori (1970/2012) gave an example of this kind of perceptual tension: a myoelectric hand that looks human but feels robotic. Perceptual tension may result in contradictory beliefs concerning what an entity is and, thus, cognitive dissonance (Hanson, 2005; e.g., caused by entities at the boundary of the soulful and soulless, Tondu & Bardou, 2011). Cognitive dissonance is a form of psychological discomfort that people are motivated to reduce (Elliot & Devine, 1994; Festinger, 1957; Gawronski & Strack, 2012). However, unlike examples of cognitive dissonance from the social psychology literature, the origin of the discomfort is perceptual. Thus, it cannot be resolved by simply adjusting one's beliefs so that they no longer contradict each other.

To measure the extent to which individuals conceive of human beings as distinct from robots, in this study we developed and validated a Human–Robot Uniqueness (vs. Equivalence) Index. The index has eleven 7-point Likert items, such as "Human beings are fundamentally different from robots" (Appendix A). The more conceptually distinct an individual conceives of human beings and robots, the higher the expected rating on this index. Our assumption is that individuals who more strongly differentiate humans and robots will experience greater cognitive dissonance when presented with androids whose visual forms, movements, and sounds incorporate both human and robotic features. This psychological discomfort will be measurable as uncanny valley sensitivity.

> *Hypothesis 5a:* Individuals who rate higher on the Human–Robot Uniqueness Index will perceive androids with nonhuman features as eerier and less warm than others.

To measure the extent to which individuals conceive of androids as distinct from robots, we developed and validated an Android–Robot Uniqueness (vs. Equivalence) Index. Ratings on this index are expected to be higher the more conceptually distinct an individual conceives of androids and other kinds of robots. Distinctness indicates prior learning of the android category.

Thus, the individual should not feel eeriness when observing human-looking robots, because they should be perceived as androids and not as potential though ambiguous instances of humans or robots. The index has seven 7-point Likert items, such as "I would relate to androids differently than to robots that don't look human" (Appendix A).

> *Hypothesis 5b:* Individuals who rate higher on the Android–Robot Uniqueness Index will perceive androids with nonhuman features as less eerie and warmer than others.

Religious Fundamentalism

We propose that fundamentalists of the Abrahamic religions are more prone than other individuals to perceive androids as cold and eerie. The theoretical basis for this prediction is twofold. First, fundamentalists adhere to a worldview that divides humanity from the rest of existence (MacDorman, Vasudevan, & Ho, 2009; Vail et al., 2010; Vess, Arndt, & Cox, 2012). This division, which must be maintained in the face of increasing scientific evidence to the contrary (e.g., from physical cosmology, evolutionary biology, molecular genetics, social psychology), results in heightened outgroup derogation and negational categorization (Altemeyer, 2003; Tajfel, Billig, Bundy, & Flament, 1971; Zhong, Phillips, Leonardelli, & Galinsky, 2008). Fundamentalists tend to view both human outgroups (e.g., people of a different race, religion, political party, or sexual orientation; Altemeyer, 2003) and nonhuman animals less favorably (DeLeeuw, Galen, Aebersold, & Stanton, 2007). Androids as liminal objects appear to trespass the very boundary the fundamentalist worldview is determined to preserve, namely, between the realm of the human and the nonhuman. As a result, androids could elicit higher levels of cognitive dissonance among fundamentalists.

Second, androids may rekindle awareness of repressed fears that are especially pernicious to fundamentalists: A "soulless" machine assuming the role of a human being renders the soul functionally superfluous; a detached android head places the finality of human decapitation in grotesque contrast with the machine's potential for "immortality"; an android

excites fears of replacement, both as a double and as the continuation of the body's shell in the absence of its soul; and unnatural movements in an android arouse fears of losing mental and bodily control (MacDorman & Ishiguro, 2006). Thus, exposure to androids renders human mortality salient, elicits fear and anxiety as a result (Ho, MacDorman, & Pramono, 2008; MacDorman, 2005), and challenges the fundamentalist worldview. Terror management theory predicts that a fundamentalist worldview, which offers the literal transcendence of death (e.g., John 3:16; Acts 24:15), serves as a buffer against mortality-related fears, but needs to be shored up when an individual's mortality becomes salient (Vail et al., 2010; Vess, Arndt, & Cox, 2012). This need results in the increased derogation of outgroups—an effect MacDorman and Ishiguro (2006) elicited through the presentation of an android that resembled an unhealthy or dead person. From a fundamentalist perspective, "soulless" androids could be considered the ultimate outgroup.

This study measures religious fundamentalism with the Revised Religious Fundamentalism Scale (RRFS; Altemeyer & Hunsberger, 2004). This index is comprised of twelve 9-point Likert items, such as the following: "To lead the best, most meaningful life, one must belong to the one, fundamentally true religion." "When you get right down to it, there are basically only two kinds of people in the world: the Righteous, who will be rewarded by God; and the rest, who will not."

> *Hypothesis 6:* Individuals who rate higher on the the Revised Religious Fundamentalism
> Scale will perceive androids with nonhuman features as eerier and less warm than
> others.

Negative Attitudes towards Robots

Negative or ambivalent attitudes toward robots, especially those involving emotion, may predict the uneasiness elicited by uncanny androids. Negative attitudes lead to negative affective evaluations. For example, an individual who disparages robots in general is more likely to feel

uncomfortable around a particularly disturbing android. Nonhuman features in androids could also be treated as stigmata, identifying the android as an outgroup, and eliciting anxiety and threat avoidance—just as facial birthmarks do in humans (Blascovich, Mendes, Hunter, Lickel, & Kowai-Bell, 2001). Given that intergroup contact reduces prejudice and anxiety (Pettigrew & Tropp, 2008), those who have had more exposure to androids may also have fewer negative attitudes. However, negative attitudes toward robots could be caused by other factors, such as a worldview that sharply divides the human and the nonhuman.

Conflicting attitudes toward another group is ambivalent prejudice (e.g., Fiske, Xu, & Cuddy, 1999), such as when industrial robots are simultaneously viewed as freeing people from drudgery and taking away their jobs (MacDorman, Vasudevan, & Ho, 2009). These conflicting attitudes cause the psychological discomfort associated with cognitive dissonance (Ho, MacDorman, & Pramono, 2007; MacDorman et al., 2009).

The negative attitude towards robots scale (NARS) was designed to identify prejudice toward robots that is hard to infer from demographics, personality, and experience using technology (Nomura, Kanda, & Suzuki, 2006; Syrdal et al., 2009). Given that fear, anxiety, disgust, and other emotions have been found to predict the uncanny valley phenomenon (Ho, MacDorman, & Pramono, 2008), this study adopts the Emotions in Interactions subscale (Nomura, Kanda, & Suzuki, 2006; Tsui et al., 2011). The subscale consists of three 7-point Likert items: "If robots had emotions, I would be able to make friends with them." "I would feel relaxed talking with robots." "I feel comforted being with robots that have emotions" (reverse scaled).

> *Hypothesis 7:* Individuals who rate higher on the Emotions in Interaction subscale of
> NARS will perceive androids with nonhuman features as eerier and less warm than
> others.

Methods

Participants

A total of 563 participants (M_{age} = 23.3, SD_{age} = 6.6, 39% male) completed the trait indices part of this study, and 489 of those participants (M_{age} = 23.5, SD_{age} = 6.8, 38% male) went on to complete ratings of the figures in the videos. Because 14 participants quit during the trait indices part and 5 quit during the figure ratings part, in the results *n* varies from 563 to 577 and from 489 to 494. Participants were recruited by electronic mail from a randomized exhaustive list of undergraduate students attending a nine-campus Midwestern public university. Additional inclusion criteria were 18 or older, native English speaker, and 20/40 vision or better with correction. Participants in this study were 83.2% White (Non-Hispanic), 4.8% Asian, 3.5% African American, 3.0% Hispanic, 5.5% other/unclassified. The study was conducted in August 2012.

Materials and Procedure

To explore how individual differences influence uncanny valley sensitivity, this study examines the relation between trait indices and ratings of androids incorporating nonhuman features. After giving informed consent, participants completed a demographics questionnaire, the nine trait indices, and ratings of robots, androids, and human beings. The study was designed to have an equal number of android and other stimuli (three of each). The androids were selected because their past ratings were positive on an eeriness index; the other robots were selected because their past ratings were negative on the same index (Ho & MacDorman, 2010).

Details on each of the nine trait indices have already been presented in the introduction. All trait indices use Likert scales except the following: Neuroticism uses a semantic differential scale, Anxiety uses a scale ranging from *very inaccurate* to *very accurate,* and Animal Reminder Sensitivity uses both a Likert scale and an intensity scale, the later ranging from *not disgusting* to *very disgusting*. All trait indices use 7-point scales, ranging from –3 to +3, except Religious Fundamentalism, which uses a 9-point scale, ranging from –4 to +4. The order of the nine trait

indices and of the items within each trait index was randomized for each participant to prevent order effects.

After completing the trait indices, participants observed and rated each of the following six moving figures: (1) a mobile robot (iRobot's Roomba 570, leaving its charging stand and vacuuming the floor, 29 s); (2) a humanoid robot (JSK Laboratory's Kotaro, seated legs apart and swaying its shoulders, 22 s); (3–5) three androids (David Ng's Animatronic Head, making facial expressions while moving its eyes, 21 s; Le Trung's Aiko, protesting when her arm is being hurt, 31 s; Hanson Robotics' Jules, affirming to its creator the pain of missing him before being shipped to the University of West England, 46 s); and (6) a human being (Bart Cummings in an unplanned 2008 interview on a cold, early morning before the Caulfield Cup thoroughbred horse race in which the trainer evades a question about his picks, 32 s). The androids possess the following nonhuman features: For the Animatronic Head, the back of the skull and neck are open, exposing wires, and some movements resemble bones moving under skin; for Aiko, the face is expressionless, the left hand wobbles like gelatin, and larger arm movements look and sound mechanical; for Jules, the back of the skull is open, exposing wires, and lip movements are not synchronized with the voice.

Each figure appeared in its own 20–46 s video clip (520×330 pixels, 4:3 aspect ratio). Each clip played continuously in a loop while the participant rated the figure on the following indices: humanness, eerie (a subfactor of eeriness), warmth, and competence (Ho & MacDorman 2010). Each index averaged the results of 7-point semantic differential scales, ranging from –3 to +3. The order of the videos and the scale items was randomized for each participant. Data analysis was performed in SPSS (version 20) and LISREL (version 8.5).

Results and discussion

Uncanny valley sensitivity is operationalized as higher eerie ratings and lower warmth ratings for

androids with nonhuman features.[2] For participants who completed both trait indices and figure ratings, Table 1 lists the correlation between each trait index and the average ratings of the three androids on the eerie and warmth indices. For all participants who completed the trait indices, Table 1 also lists the reliability, mean, and standard deviation of each index. For all nine trait indices, a significant correlation was found with either eerie, warmth, or both.

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[2] Although the decision to exclude the nonandroid ratings was made on theoretical grounds, namely, because they are not depicted in the uncanny valley of Mori's (1970/2012) graph, this decision was supported by the data. On average, the eerie or warmth ratings of an android was significantly correlated with six out of nine of the trait indices, but only three out of nine for the nonandroids. The eerie ratings of the human were not significantly correlated with any of the trait indices.

Table 1

Pearson's correlation between trait indices and android eerie and warmth ratings; trait index reliability,

number of participants, mean, and standard deviation

Trait Index	Eerie r	Warmth r	Cronbach's α	Mean	SD
Neg. Att. Robots: Emotions in Interaction	.41***	−.38***	.86 (n =575)	−0.11	1.65
Animal Reminder Sensitivity	.34***	−.21***	.83 (n = 571)	−0.22	1.38
Human–Robot Uniqueness	.28***	−.37***	.89 (n = 573)	0.93	1.31
Anxiety	.18***	−.13***	.87 (n = 563)	−0.20	1.10
Neuroticism	.16***	−.12***	.77 (n = 571)	−0.16	1.18
Perfectionism: Concern over Mistakes	.13**	.01	.88 (n = 576)	−0.38	1.30
Personal Distress	.12**	−.07	.83 (n = 577)	−1.01	1.10
Religious Fundamentalism	.12**	−.24***	.96 (n = 563)	−1.51	2.26
Android–Robot Uniqueness	−.03	.26***	.75 (n =570)	0.53	1.04

*p < .05. **p < .01. ***p < .001.

For participants completing the trait indices, the nine indices were found to be reliable (i.e.,

Cronbach's α ≥ .7 threshold). Human–Robot Uniqueness was negatively skewed, with

skewness of −.48 (SE = .11) and kurtosis of −.48 (SE = .22). Religious Fundamentalism was

positively skewed, with skewness of .66 (SE = .11) and kurtosis of −.71 (SE = .22). These results

reflect the fact that, although a relatively large percentage of participants were atheists (11.6%

scored the minimum on Religious Fundamentalism), participants on average slightly agreed with

statements asserting the uniqueness of human beings relative to robots (Appendix A).

Exploratory factor analysis was performed using maximum likelihood with varimax

rotation and Kaiser normalization, which in eight rotations converged on eight factors. All items

belonging to each of the following subscales loaded on its own factor: Religious

Fundamentalism (factor 1, 18% of variance explained), Perfectionism: Concern over Mistakes

(factor 4, 5%), Animal Reminder Sensitivity (factor 5, 4%), and Negative Attitudes toward Robots: Emotions in Interaction (factor 8, 2%). Anxiety and Neuroticism loaded on a single factor (factor 2, 13%). Human–Robot Uniqueness loaded on one factor (factor 3, 6%), except for the God's image item (9, Appendix A), which loaded on factor 1 (Religious Fundamentalism). The five Emotional Concern items relating to emergencies or getting hurt loaded on one factor (factor 6, 3%) and the two items relating to emotional situations loaded on factor 2 (Anxiety, Neuroticism). Five Android–Robot Uniqueness items loaded on their own factor (factor 7, 2%) and two items (6 and 7, Appendix A) loaded on factor 3 (Human–Robot Uniqueness).

Figure 2 graphs the mean humanness, eerie, and warmth ratings of each moving figure. The androids were rated more human than the mobile and humanoid robot but considerably less human than the human beings. The androids were rated eerier than the other figures. Jules, the most human among the androids, was also rated eeriest. The fact that Jules was also rated warmest among the figures is less surprising given the narrative in which the android longs for its creator. Although eerie was designed to be independent of warmth (Ho & MacDorman, 2010; both anchors of the semantic differential items are negatively valenced), there was a significant but small negative correlation between eerie and warmth ($r = -.11$, $p = .016$).
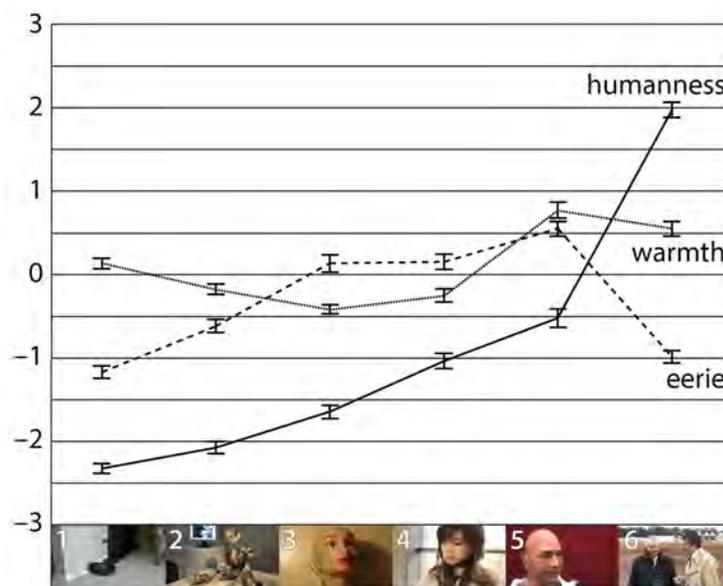
Figure 2. The six moving figures are arranged in increasing order of their mean humanness rating. The graph depicts the mean humanness, eerie, and warmth rating of each moving figure and its 95% confidence interval.

The humanness (10 items; α = .91), eerie (3 items; α = .78), warmth (7 items; α = .86), and competence (7 items; α = .90) indices were found to be reliable. Warmth was leptokurtic, with skewness of −.14 (*SE* = .11) and kurtosis of 1.75 (*SE* = .22).

Exploratory factor analysis was performed using maximum likelihood with varimax rotation and Kaiser normalization, which in six rotations converged on four factors. The humanness items exclusively loaded on factor 1 (35% variance explained). The competence items and the *unreliable–trustworthy* item of warmth loaded on factor 2 (9%). The remaining items of warmth loaded on factor 3 (8%). And the items of eeriness, including the eerie subfactor, loaded on factor 4 (5%).

Among these predominantly Midwestern undergraduates, android eerie ratings decreased with age. This inverse correlation was significant but the effect size was small

(n = 492, Pearson's r[490] = –.12, p = .006).[3] However, age was not significantly correlated with warmth. Death-related disgust sensitivity has been previously found to decline with age (Curtis, Aunger, & Rabie 2004). In this study Concern over Mistakes (n = 575, r[573] = –.08, p = .049), Anxiety (n = 563, r[561] = –.11, p = .004), Animal Reminder Sensitivity (n = 570, r[568] = –.13, p = .003), and Personal Distress (n = 575, r[573] = –.18, p < .001) were all inversely correlated with age.

The effect of gender on eerie ratings was more pronounced. Women (M = 0.88, SD = 0.92, n = 302) rated the androids as eerier than men (M = 0.37, SD = 0 .79, n = 186) rated them (t[486] = –6.24, p < .001). The correlation was significant and the effect size was small-to-medium (n = 488, r[486] = .28, p < .001). These results for gender confirmed in a US population a finding from an Indonesian population (Ho, MacDorman, & Pramono, 2008). However, gender was not significantly correlated with warmth. Women rated significantly higher on Animal Reminder Sensitivity (t[563] = –3.14, p = .002) and all other trait indices except Android–Robot Uniqueness. This agrees with previous research, which has found that women have greater disgust sensitivity than men (Tybur, Bryan, Lieberman, Caldwell Hooper, & Merriman, 2011).

Perfectionism

Concern over Mistakes was significantly correlated with android eerie ratings with a small effect size (n = 493, r[491] = .13, p = .004). However, it was not significantly correlated with warmth. Thus, given that uncanny valley sensitivity is operationalized as both higher eeriness and lower warmth ratings for androids, *Hypothesis 1 is unsupported.* Perfectionism was significantly correlated with Neuroticism, Anxiety, Personal Distress, and Negative Attitudes toward Robots (Table 2).

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[3] Pearson's correlation effect size convention: negligible: $|r|$ < .1; small: .1 ≤ $|r|$ < .2; small-to-medium: .2 ≤ $|r|$ < .3; medium: .3 ≤ $|r|$ <.4; medium-to-large: .4 ≤ $|r|$ <.5; large: .5 ≤ $|r|$.

Table 2

Pearson's correlation between trait index pairs

	Perfect.	Neurot.	Anxiety	Personal Distress	Animal Remind.	Human Unique.	Android Unique.	Relig. Fund.
Neurot.	.35***							
Anxiety	.42***	.72***						
Personal Distress	.23***	.40***	.54***					
Animal Remind.	.05	.19***	.30***	.38***				
Human Unique.	.02	.11**	.05*	.03	.30***			
Android Unique.	.05	.00	−.05	−.02	−.03	−.42***		
Relig. Fund.	.00	.03	.00	.03	.25***	.56***	−.19***	
Neg. Att. Robots	.12***	.17***	.21***	.14***	.36***	.57***	−.35***	.32***

*$p < .05$. **$p < .01$. ***$p < .001$.

Neuroticism and Anxiety

Neuroticism was significantly correlated with both android eerie ($n = 489$, $r[487] = .14$, $p = .002$) and warmth ratings ($n = 490$, $r[488] = −.12$, $p = .007$) with a small effect size. *Thus, Hypothesis 2a is supported.* Anxiety was significantly correlated with android eerie ratings with a small effect size ($n = 493$, $r[491] = .178$, $p < .001$) and inversely with android warmth ratings with a small effect size ($n = 494$, $r[492] = −.13$, $p = .005$). *Thus, Hypothesis 2b is also supported.* Anxiety was significantly correlated with Perfectionism, Neuroticism, Personal Distress, Animal Reminder Sensitivity, Human–Robot Uniqueness, and Negative Attitudes toward Robots.

Personal Distress

Personal Distress was significantly correlated with android eerie ratings with a small effect size (*n* = 493, *r*[491] = .123, *p* = .006). However, it was not significantly correlated with warmth. *Thus, Hypothesis 3 is unsupported.* Personal Distress was significantly correlated with Perfectionism, Neuroticism, Anxiety, Animal Reminder Sensitivity, and Negative Attitudes toward Robots.

Animal Reminder Sensitivity

Sensitivity to animal reminders was significantly correlated with android eerie ratings with a medium effect size (*n* = 491, *r*[489] = .34, *p* < .001) and inversely with android warmth ratings with a small-to-medium effect size (*n* = 492, *r*[490] = −.21, *p* < .001). *Thus, Hypothesis 4 is supported.* Animal Reminder Sensitivity was significantly correlated with Neuroticism, Anxiety, Personal Distress, Human–Robot Uniqueness, Religious Fundamentalism, and Negative Attitudes toward Robots.

Human–Robot and Android–Robot Uniqueness

Human–Robot Uniqueness was significantly correlated with android eerie ratings with a small-to-medium effect size (*n* = 491, *r*[489] = .28, *p* < .001) and inversely with android warmth ratings with a medium effect size (*n* = 492, *r*[490] = −.37, *p* < .001). *Thus, Hypothesis 5a is supported.* Android–Robot Uniqueness was not significantly correlated with android eerie ratings. It was significantly correlated with android warmth ratings with a small-to-medium effect size (*n* = 492, *r*[490] = .26, *p* < .001). *Thus, Hypothesis 5b is unsupported.*

Human–Robot Uniqueness was significantly inversely correlated with android humanness ratings with a medium effect size (*n* =492, *r*[490] = −.35, *p* < .001) and android competence ratings with a small effect size (*n* =492, *r*[490] = −.19, *p* < .001). Android–Robot Uniqueness was significantly correlated with android humanness ratings with a medium effect size (*n* = 492, *r*[490] = −.31, *p* < .001) and android competence ratings with a small-to-medium effect size (*n* = 492, *r*[490] = −.20, *p* < .001). Human–Robot Uniqueness was significantly correlated with Neuroticism, Anxiety, Animal Reminder Sensitivity, Android–Robot Uniqueness,

Religious Fundamentalism, and Negative Attitudes toward Robots. Android–Robot Uniqueness was significantly correlated with Human–Robot Uniqueness, Religious Fundamentalism, and Negative Attitudes toward Robots.

Religious Fundamentalism

Religious Fundamentalism was significantly correlated with android eerie (n = 491, r[489] = .12, p = .007) and warmth (n = 490, r[488] = –.24, p < .001) ratings with a small-to-medium effect size. *Thus, Hypothesis 6 is supported.*

Religious fundamentalism was significantly correlated with android humanness ratings with a small effect size (n =492, r[490] = –.19, p < .001) and android competence ratings with a small effect size (n =492, r[490] = –.13, p = .005). Religious fundamentalism was significantly correlated with Animal Reminder Sensitivity, Human–Robot and Android–Robot Uniqueness, and Negative Attitudes toward Robots.

Negative Attitudes toward Robots

Emotions in Interaction was significantly correlated with android eerie ratings with a medium-to-large effect size (n = 492, r[490] = .41, p < .001) and inversely with android warmth ratings with a medium effect size (n = 493, r[491] = –.38, p < .001). *Thus, Hypothesis 7 is supported.*

Emotions in Interaction was significantly correlated with android humanness ratings with a medium effect size (n =493, r[491] = –.30, p < .001) and android competence ratings with a small effect size (n =493, r[491] = –.19, p < .001). Emotions in Interaction was significantly correlated with all other trait indices.

Table 1 identifies the five unique traits that have significant correlations with both eeriness and inversely with warmth at the .01 or .001 level: Negative Attitudes toward Robots (Emotions in Interaction), Animal Reminder Sensitivity, Human–Robot Uniqueness, Anxiety, and Religious Fundamentalism. These traits, which predict uncanny valley sensitivity, have some significant and tantalizingly large intercorrelations (Table 2).

To explore relations among these five traits and eeriness and warmth, a structural equation model (SEM) was calculated. In the initial model, indices in the first column (Causes) were fully connected by directed edges to those in the second (Effects) and third columns (Uncanny Valley Sensitivity), and indices in the second column were fully connected by directed edges to those in the third column. The model is based on the assumption that robot-related traits (i.e., Human-Robot Uniqueness, Negative Attitudes toward Robots) do not cause other, more basic traits (i.e., Religious Fundamentalism, Animal Reminder Sensitivity, Trait Anxiety), which presumably are rooted in an individual's upbringing, development, and heredity.

In model 1, seven directed edges had nonsignificant standardized gammas. The four least significant were Religious Fundamentalism $\rightarrow$ Warmth ($\gamma = -.06$, two-tailed $p = .29$), Animal Reminder Sensitivity $\rightarrow$ Warmth ($\gamma = -.00$, $p = .98$), Trait Anxiety $\rightarrow$ Human-Robot Uniqueness ($\gamma = .02$, $p = .66$), and Trait Anxiety $\rightarrow$ Eerie ($\gamma = .01$, $p = .91$). Model 2 omits these four edges with the expectation that the remaining three nonsignificant directed edges may reach significance. However, the remaining three failed to reach significance in model 2 but continued to show trend: Religious Fundamentalism $\rightarrow$ Eerie ($\gamma = -.11$, $p = .053$), Human-Robot Uniqueness $\rightarrow$ Eerie ($\gamma = .14$, $p = .066$), and Trait Anxiety $\rightarrow$ Warmth ($\gamma = -.08$, $p = .056$). Model 3 omits all six nonsignificant directed edges. The difference in the normal theory weighted least squares χ^2 between model 1 and model 2 and between model 2 and model 3 was not statistically significant (Table 3).

Table 3

Summary of specifications and fit statistics for the structural equation models

Model	df	χ^2	$\Delta\chi^2$	RMSEA	ECVI	NNFI	CFI
1	1014	3296.51		.059	5.44	.96	.96
2	1017	3296.98	0.47	.059	5.43	.96	.96
3	1021	3306.08	9.10	.059	5.43	.96	.96

Figure 3 presents model 2. For simplicity, the figure omits the measurement items of each index. The model straddles the threshold of good fit (df = 1017, normal theory weighted least squares χ^2 = 3296.98, p < .001, RMSEA = 0.059, NNFI = .96, GFI = 0.82, AGFI = 0.80). Although the CFI, NNFI, and RMSEA are acceptable (RMSEA < .06, CFI ≥ .9, NNFI ≥ .95; Hu & Bentler, 1999), the GFI and AGFI are not (GFI and AGFI ≥ .9; Baumgartner & Hombur, 1996).
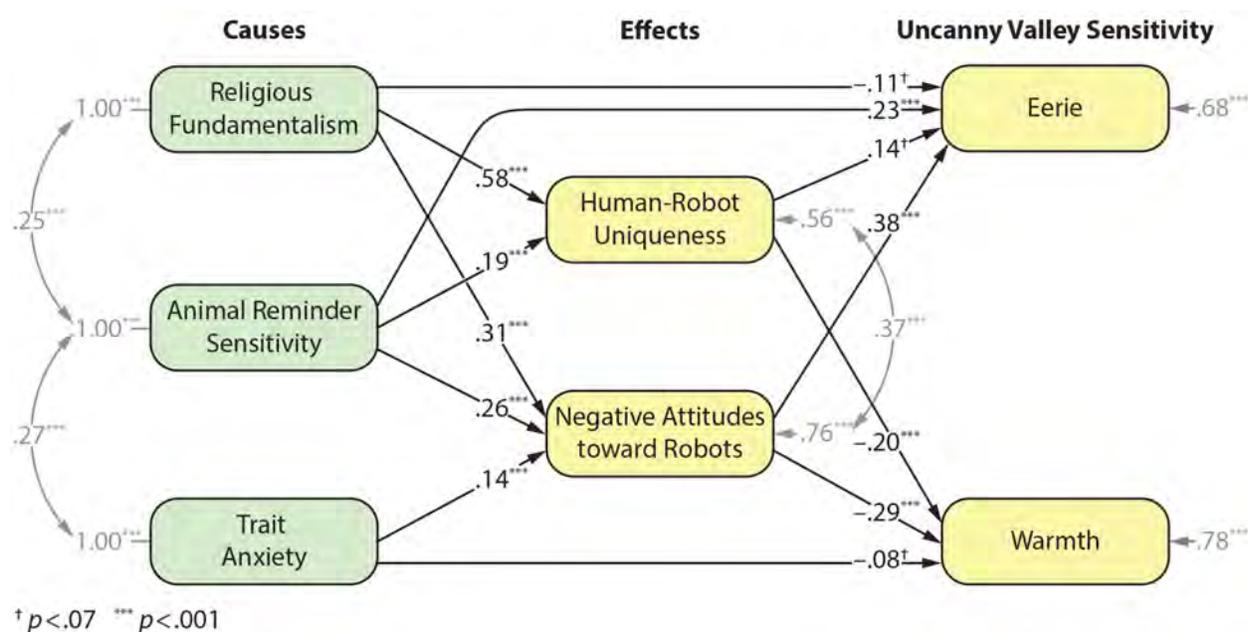

$^\dagger p$<.07 $^{***}p$<.001

Figure 3. Three structural equation models were calculated with five distinct traits for predicting uncanny valley sensitivity. In the models, directed edges (arrows) depict causal relations along left-to-right pathways. The values on the directed edges are the standardized gammas. The figure depicts model 2, which includes three nonsignificant but trending directed edges.

General discussion and conclusion

Eight of the nine traits had significant positive correlations with android eerie ratings. Only Android–Robot Uniqueness had no significant correlation. In addition, age and gender correlated significantly with android eerie ratings; female or younger undergraduates rated the androids eerier. Seven of the nine traits were found to correlate inversely with android warmth

ratings. Only Concern over Mistakes and Personal Distress had no significant correlation.

These findings indicate how individual differences may influence uncanny valley sensitivity. For example, fundamentalists of the Abrahamic religions teach their children early in life to identify strongly with their religion; this in turn leads them to adopt a worldview that treats the human and nonhuman as separate realms of existence (Altemeyer, 2003; Vail et al., 2010; Vess, Arndt, & Cox, 2012). The large and significant correlation between Religious Fundamentalism and Human-Robot Uniqueness ($r = .56$, $p < .001$) indicates the plausibility of our theoretical claim that fundamentalism leads to the belief that human beings are unique and different from robots and the rest of creation (MacDorman, Vasudevan, & Ho, 2009). Nevertheless, both Religious Fundamentalism and Human-Robot Uniqueness are more strongly correlated with warmth than eeriness, while Animal Reminder Sensitivity and Anxiety are more strongly correlated with eeriness than warmth (Table 1). We suspect that this is because the former are learned sociocultural constructions, while the latter are biological adaptations for threat avoidance.

These hypotheses are supported by the three structural equation models. In the models, Religious Fundamentalism heightens uncanny valley sensitivity indirectly, through robot-related attitudes. In particular, Religious Fundamentalism has a strong influence on Human–Robot Uniqueness ($\gamma = .58$, $p < .001$). Surprisingly, the direct influence of Religious Fundamentalism on eerie is negative and approaching significance ($\gamma = -.11$, $p = .053$). Based on this result, we speculate that belief in salvation and an eternal life would in fact lessen uncanny valley sensitivity were it not for the Christian worldview that human beings are distinct from robots and the rest of creation. To explore the relations among these variables, it would be useful to perform a crosscultural comparison with fundamentalists of religions that do not stress the human–nonhuman distinction (e.g., neo-Confucianism, Taoism, Buddhism, and Shinto).

In the structural equation models, Animal Reminder Sensitivity directly increases eerie ratings, while Religious Fundamentalism only indirectly increases eerie ratings through robot-

related attitudes. We suspect this result reflects a key point neglected by those who claim the uncanny valley is caused by a general cognitive mechanism (Burleigh, Schoenherr, & Lacroix, 2013; Hanson, 2005; Moore, 2012; Ramey, 2005; Tondu & Bardou, 2011; Yamada, Kawabe, & Ihaya, 2012). These researchers acknowledge the uncanny valley's relation to learned categories without acknowledging its characteristic macabre coloring and the sometimes visceral aversive responses it elicits. Although cultural and other learned constructions may amplify or attenuate the uncanny valley, evidence from studies with infants and primates indicate the phenomenon is also rooted in more specific biological adaptations (Lewkowicz & Ghazanfar, 2012; Steckenfinger & Ghazanfar, 2009). We have previously proposed the fear and disgust systems as candidate mechanisms (Ho, MacDorman, & Promono, 2007; MacDorman & Ishiguro, 2006; MacDorman et al., 2009).

Limitations

This is an exploratory study despite its relatively large sample size. Although the choice of traits were theoretically motivated, no serious attempt was made to evaluate the theories to determine which are more probable. For example, Neuroticism, Trait Anxiety, and Religious Fundamentalism were related to terror management theory in the introduction, and yet no measurement was made of mortality salience, terror-management effects on attitudes, and other relevant variables such as self-esteem. Human Uniqueness, Android Uniqueness, Religious Fundamentalism, and Negative Attitudes toward Robots (Emotions in Interaction) were related to uncertain or conflicting judgments about category membership (e.g., human vs. robot), which may induce cognitive dissonance; nevertheless, no attempt was made to induce cognitive dissonance or to measure the psychological discomfort and arousal it elicits and its effect on beliefs and attitudes. Although we have argued that the uncanny valley phenomenon involves more than cognitive dissonance, we have not made a comparison with domains that induce cognitive dissonance without inducing eeriness and a reduction in warmth. We have left

a theoretical exploration of the relation between theories of uncanny valley and uncanny valley sensitivity to planned experiments.

This study found that Religious Fundamentalism strongly predicts Human–Robot Uniqueness, which in turn predicts the uncanny valley phenomenon. However, a broader principle may be at play, namely, a preference for things to be "black and white," which fundamentalists share with other groups, such as those rating high in right-wing authoritarianism (Altemeyer, 2003). Thus, it would be useful to include in future studies a measure of intolerance for ambiguity (e.g., dichotomous thinking, Oshio, 2009; ambiguity intolerance, McLain, 1993; Norton, 1975; or uncertainty intolerance, Freeston, Rhéaume, Letarte, Dugas, & Ladouceur, 1994) and right-wing authoritarianism (Altemeyer, 1996).

This study focuses on how an individual's traits predict uncanny valley sensitivity to android videos. Although the videos have ecological validity in the sense that they are videos of robots in actual use, videos are mere depictions, once removed from reality. Interactions with physically present, embodied androids could produce different, perhaps stronger effects. (For example, Kose-Bagci et al., 2009, and other research groups have found that embodiment enhances enjoyment during human–robot interaction.)

A further limitation is that the relation between the robots' formal properties (e.g., their morphology, motion quality) and their experiential properties (e.g., eeriness, diminished warmth) cannot be inferred, because the formal properties were not varied systematically as independent variables (as in, e.g., Burleigh, Schoenherr, & Lacroix, 2013; Cheetham, Pavlovic, Jordan, Suter, & Jäncke, 2013; Cheetham, Suter, & Jäncke, 2011; Looser & Wheatley, 2010; MacDorman et al., 2009). However, the fact that we cannot identify which formal properties of the android robots elicited the uncanny valley phenomenon does not prevent us from identifying provisional relations between trait indices and uncanny valley sensitivity. These relations should be confirmed in future studies that manipulate formal properties systematically and incorporate a broader array of robots and other stimuli.

This study examines individual differences as they relate to the uncanny valley in robotics; however, the financial impact of the uncanny valley on the video game and animated film industries has been far greater. It has yet to be determined what bearing, if any, this study has on the uncanny valley in computer animation, given its reliance on robots as stimuli and on robot-related indices. In particular, the study does not address the impact of the uncanny valley on empathy in visual narratives, which has been identified as a major problem for computer-animated films with human characters (e.g., *Mars Needs Moms,* 2011, *A Christmas Carol,* 2009, *The Polar Express,* 2004, and *Final Fantasy: The Spirits Within,* 2001; Butler & Joschko, 2009; Freedman, 2012; Hodgins, Jörg, O'Sullivan, Park, & Mahler, 2010; MacDorman, Srinivas, & Patel, 2013).

Appendix A. Questionnaires

Listed below are the two indices developed for this study; the remaining indices were published previously.

Human–Robot Uniqueness (vs. Equivalence) Index

The items load on a single factor and are ordered by their factor loadings, listed in parentheses. Removing the last one or two items slightly improves the reliability of the index with the Cronbach's α rising from .89 to .90.

1. Someday robots will be able to feel pain and heartache just like human beings do.[R] (.79)

2. It is absurd to consider a human being and a robot to be the same kind of thing. (.78)

3. Human beings have a soul, which a robot could never have. (.77)

4. Even if a robot might one day seem human, it would never be anything like a real human being. (.77)

5. Reproduce human brain processes in a robot, and the robot would be conscious.[R] (.74)

6. In a sense, human beings are nothing more than highly sophisticated, self-replicating robots.[R] (.73)

7. It would be alright if someday we could not tell robots from human beings.[R] (.72)

8. Human beings are fundamentally different from robots. (.72)

9. Since only human beings are created in God's image, no robot could ever be. (.70)

10. The internal workings of human beings and robots are governed by the same physical processes.[R] (.56)

11. When taking on human occupations, robots also take on moral responsibility for their actions.[R] (.35)

Factor analysis by principal components analysis.

[R] Reverse scaled

Android–Robot Uniqueness (vs. Equivalence) Index

Items 1–5 loaded on the first factor, and items 6 and 7 loaded on the second factor. These final two items will be revised or replaced in future studies. The items are ordered by their factor loadings on the first factor.

1. Androids are fundamentally different from other kinds of robots. (.73)

2. I feel differently about androids than about other kinds of robots. (.73)

3. I would relate to androids differently than to robots that don't look human. (.69)

4. Androids deserve a different level of legal protection than other kinds of robots. (.65)

5. Shaking hands with a factory robot is no more or less meaningful than shaking hands with an android.[R] (.61)

6. Although an android has a human-looking face and body, it is still a robot.[R] (.48)

7. Although people may engage in human role-play with an android and not with another kind of robot, they're just pretending.[R] (.48)

Factor analysis by principal components analysis.

[R] Reverse scaled

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