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Effects of meta-human characteristics on user acceptance: from the perspective of uncanny valley theory

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ABSTRACT
Despite the potential of meta-humans in the virtual space, research on how consumers react to meta-humans is scarce. This study investigates the effects of meta-human characteristics on user acceptance. 280 responses from the online survey were analysed using structural equation modelling. Findings revealed that meta-humans outshine digital humans in terms of performance and user acceptance. Users encountering digital humans are affected by the uncanny valley in terms of appearance and function. However, users encountering meta-humans are affected only in terms of function. Social presence and perceived novelty are additional factors affecting user acceptance. Theoretically, this study contributes to the literature by confirming the existence of the uncanny valley effect in meta-humans and by expanding human likeness to appearance and behaviour. Although meta-humans have surpassed the uncanny valley in appearance, they still lack familiarity in terms of behaviour. Practically, meta-humans and meta-human modelling tools have been found to surpass existing digital human technology both in performance and user acceptance. However, behavioural human likeness must continue to be developed in order to further increase user acceptance. Furthermore, familiarity does not directly affect user acceptance but mediates satisfaction. As user acceptance follows satisfaction, marketers should investigate user satisfaction rather than improving human likeness.

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Metaverse; digital human; meta-human; uncanny valley; human likeness; user acceptance

1. Introduction

In a survey conducted in the US in 2022, 82% of business executives from diverse industries stated that they plan on incorporating the Metaverse into their business operations in the next 3 years (PwC 2022). The proliferation of extended reality (XR) and Metaverse technologies necessitates a higher quality of virtual experiences (Suzuki et al. 2020). In order to create memorable experiences for users, the content must be made more realistic, human-machine interactions more immersive and interactive, and the sense of presence more immediate (Barreda-Ángeles, Aleix-Guillaume, and Pereda-Baños 2020). The use of realistic immersive content is already increasing in popularity in many sectors, such as theatre performances (Salihbegovic 2020), tourism (Noh and Ro 2021), education (Leow and Ch'ng 2021), and e-commerce (Ssin et al. 2021).

Immersive experiences include virtual avatars. Currently, digital humans are already widely used. In this study, digital humans refer to photorealistic AI-powered virtual avatars that are capable of communicating and connecting with humans through realistic features and expressions (Silva and Bonetti 2021). Most recently, meta-humans, hyper-realistic digital humans that are very similar to real humans in both appearance and movement, have been introduced. On the contrary, meta-humans refer to a much more advanced digital human with greatly enhanced visual and functional capabilities (Gawand and Demirel 2020b). Meta-humans are able to move in ways and perform functions that humans cannot (Dean 2013). Whereas creation of digital humans can take several months, modern modelling tools such as the MetaHuman Creator can create meta-humans in just a few hours. The strength of the MetaHuman Creator lies in their ability to generate hyper-realistic images compared to conventional Digital Human Modelling (DHM) techniques, which has aimed to depict more realistic human appearances and behaviours. In this sense, the use of meta-humans is expected to increase cost efficiency greatly for businesses (Dharma and Suryadinatha 2019; MetaHuman Creator 2022). Meta-humans have the potential to improve the quality of services significantly. Their ability to enhance human-machine

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interactions makes it very likely that they will be widely adopted by user interface developers.

However, despite the emergence of these hyper-realistic meta-humans and their potential to replicate body appearance and motions closely, there is still uncertainty as to how consumers will react to this novel technology.

One early study on humanoids found that as they became more humanlike, user familiarity also increased. However, when their human likeness reached a certain point, users began to feel that this resemblance was uncanny, which made them feel uncomfortable. At this point, user familiarity rapidly declined, as did user acceptance (Mori 1970). However, as developers continued to create humanoids that were less distinguishable from real humans, user familiarity began to rise again. This dip in familiarity and user acceptance caused by uncanniness is what is known as the uncanny valley (Mori 1970). It is uncertain as to whether this effect of the uncanny valley also applies to meta-humans. If so, it is highly likely to hinder the adoption of this technology, although the lack of empirical research in this area makes it difficult to predict whether or not the uncanny valley will affect users' acceptance of meta-humans. This study explores the factors affecting user familiarity and acceptance of meta-human technology, posing the following research question:

> In light of the uncanny valley effect, does the use of meta-humans increase user acceptance when compared to digital humans? What are the factors that influence overall user acceptance of these two technologies?

In order to answer this question, the study will focus on three key objectives. Firstly, in order to compare the effectiveness of meta-humans to digital humans, the study will investigate their relative impacts on user acceptance. Secondly, with the advancement of modelling tools, developers are now able to greatly enhance both visual and behavioural capabilities of avatars. Therefore, the study will investigate whether there is a difference in impacts on user acceptance between visual human likeness and behavioural human likeness. Lastly, the study will investigate whether the uncanny valley effect applies to meta-humans, and whether meta-humans have overcome this effect. The study will also identify various factors that affect user familiarity and acceptance.

2. Theoretical background

2.1. Digital human simulation tools

Digital Human Modelling (DHM) is a technique used to create digital humans that resemble humans in terms of both appearance and movement (Hanson, Högberg, and Brolin 2020). These digital humans are then used to simulate and evaluate interactions between humans and products/objects. Studies have shown that DHM is an effective tool for integrating human factors during the process of designing digital humans (Ahmed et al. 2021).

DHM simulation tools have been used in many areas, such as aerospace, the military, healthcare (Gawand and Demirel 2020, July; Malek et al. 2006; Mohammed et al. 2020) and mobility (Steffan, Geigl, and Moser 1999). DHM increases the time and cost efficiency of creating simulations that involve humans (Gawand and Demirel 2020b). Recently, DHM tools have also been used in conjunction with digital twin technologies in fields related to human safety to boost its effectiveness further (Raschke and Cort 2019). Many different DHM simulation tools, such as IPS IMMA, AnyBody and OpenSim (Delp et al. 2007), have been developed to create virtual environments (Gaisbauer et al. 2020). They are used to replicate the human musculoskeletal structure and respiratory systems in detail. Other DHM tools, such as Unity3D (https://unity.com), Unreal Engine (www.unrealengine.com) and CryEngine (https://www.cryengine.com), include games. These tools provide game-related platforms that allow users to animate human movements more realistically with ease.

Although various DHM simulation tools exist, very few produce digital humans that replicate human expressions accurately whilst also functioning in various environments (Suda and Oka 2021). To alleviate this problem, meta-human modelling tools have recently been developed (Siddiqui 2022). Compared to DHM tools, meta-human modelling tools can help developers to create hyper-realistic meta-humans in a much simpler, faster and more scalable manner (Higgins et al. 2018). Meta-humans created using meta-human modelling tools can accurately simulate human speech, facial expressions and movements. These tools not only reduce the time, costs and effort required in the production process, but also produce much higher-quality digital humans (Gawand and Demirel 2020b). Not only is the increased efficiency appealing to businesses, but the literature also states that an increase in familiarity that users feel towards technology increases their acceptance of the technology itself (Kim, Chua, and Han 2020; Pei, Wang, and Archer 2021; Rekswinkel 2020). Due to these new capabilities, it is likely that meta-human modelling tools will be more widely accepted than digital humans created using digital human modelling tools.

2.2. Extended uncanny valley theory: two human likeness factors

The uncanny valley theory states that at a certain point on the continuum of human likeness, there is a valley of negative emotions caused by a feeling of uncanniness. Existing studies on the uncanny valley theory are summarised in Appendix A. The main problems we identified in this literature are as follows.

First, most studies focused their research on undergraduate students. It is necessary to investigate the effect of meta-humans on adults with income in order to determine implications for businesses and their managers. Secondly, many of the stimuli used in the studies were not hyper-realistic; therefore, the results were affected by the uncanny valley effect. In Mori's (1970) original experiment on the uncanny valley, the humanoids investigated were not very similar to humans. Although more recent studies have used more realistic stimuli, these stimuli cannot yet be considered hyper-realistic. Thirdly, the evaluation of human likeness has been mainly based on appearance. However, emotional responses are caused by both appearance and behaviour (i.e. motion and voice). Therefore, it is necessary to expand the definition of human likeness to determine the applicability of this technology for business purposes. In addition, to investigate motion and voice, the stimuli should be presented in 3D video form rather than via 2D images. Finally, similar concepts in the literature were labelled differently (e.g. human likeness = realism; affinity = familiarity = eeriness) and familiarity and eeriness were commonly labelled as emotional responses. Consistent terminology is necessary for applicability of research findings to the marketplace.

According to uncanny valley theory, a nonlinearity exists between human likeness and familiarity, as shown in Figure 1. As digital humans become more similar to real humans in terms of appearance, familiarity also increases. However, when human likeness reaches a certain point, the appearance of digital humans begins to cause feelings of uneasiness in users, resulting in a sharp drop in familiarity (Mori 1970). Therefore, although meta-humans are more realistic compared to digital humans, meta-humans may also cause the uncanny valley effect. Accordingly, the following hypothesis is proposed:

> **H1**: In the context of digital/meta-humans, the uncanny valley effect applies in the relationship between visual human likeness and user familiarity.

In Mori's (1970) experiment, human likeness was measured only in terms of appearance. However, as previously mentioned, human likeness must be measured in terms of both appearance and behaviour because digital humans are used in a wide variety of ways. They are designed specifically to perform their intended tasks and to replicate human behaviour in different ways. Some uses include increasing the realism of interaction between users and products (Reed et al. 2006), increasing product design quality (especially clothing) (Scataglini et al. 2019), and performing complex tasks in manufacturing (Khayer, Patel, and Ningthoujam 2019; Zhu, Fan, and Zhang 2019). Digital humans are often used to perform tasks that humans usually perform, but in a more efficient manner. Meta-humans have similar uses to digital humans, and therefore it is likely that their behavioural and functional resemblance to humans will have a significant impact on user familiarity. Accordingly, the following hypotheses are proposed:

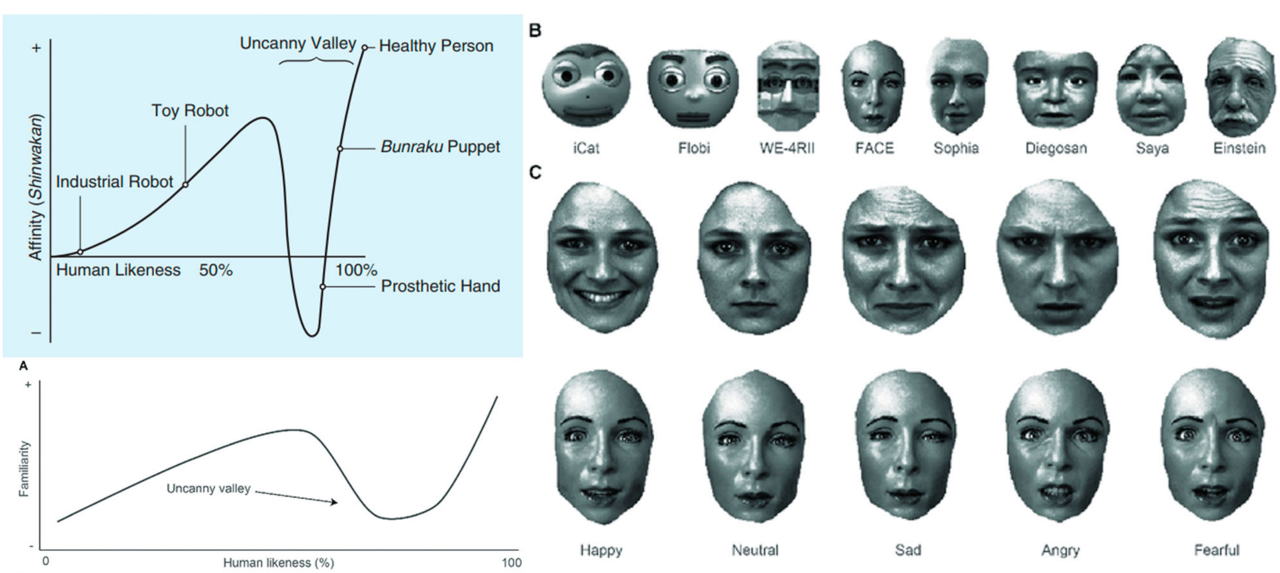


Figure 1. Uncanny valley effect (figure adapted from Reuten, Van Dam, and Naber 2018).

H2: In the context of digital/meta-humans, the uncanny valley effect applies in the relationship between user familiarity and behavioural human likeness.

Similar to experiences with digital humans, experiences with meta-humans may be subject to the uncanny valley effect. However, compared to digital humans, user experiences with meta-humans may differ because of their greater sense of realism in terms of appearance and behaviour. In this study, we compare user experiences with both digital humans and meta-humans, examining the uncanny valley effect in terms of human likeness and familiarity. Figure 2. depicts 3 potential scenarios of whether the two technologies (digital humans and meta-humans) have overcome the uncanny valley. If both have advanced to the point where they can overcome the uncanny valley effect (case B), their relationship is expected to be linear. However, if one of the technologies has overcome the uncanny valley effect whilst the other has not (case C), their relationship is expected to be nonlinear (see Figure 2).

2.3. Social presence, perceived novelty, familiarity and satisfaction

In the following sections, we identify additional factors that can potentially affect user familiarity and acceptance in the context of digital humans and meta-humans. Of course, the two technologies are likely to have varying impacts.

Social presence refers to the degree to which users feel a personal connection with each other through the use of digital media (Short, Williams, and Christie 1976). These days, more and more companies are using digital technologies to diversify customer services. Previous research revealed that social presence has a positive effect on customer satisfaction in various contexts, including financial services (Gimpel, Huber, and Sarikaya 2016), online learning (Andel et al. 2020; Horzum 2017; Hostetter and Busch 2006) and virtual reality-based services (Hodge et al. 2008). Research on immersive virtual worlds has also shown that social presence has a positive effect on satisfaction (Jung et al. 2018). Therefore, in the context of digital/meta-humans in virtual worlds, we expect that the social presence of digital/meta-humans will positively affect satisfaction. Therefore, we hypothesise as follows:

H3: The social presence of digital humans/meta-humans has a positive impact on user satisfaction.

Perceived novelty is the interest or curiosity evoked in a user when encountering a novel product/experience (Choi, Lee, and Kim 2017). Perceived novelty is felt when users encounter new products (Chong 2018), and it is known to affect both user satisfaction and familiarity positively (Toyama and Yamada 2012).[open-strick]

[close-strick]If perceived novelty causes a positive reaction in users, it is likely that it will also positively impact user satisfaction, as is widely evident in areas such as education/training (Fierro-Suero et al. 2020; Stoa and Chu 2020), marketing (Toyama and Yamada, 2012) and various other services (Truong et al. 2020). We believe the same effect can be expected in the context of digital/meta-humans, which are also used for education, marketing and information purposes. The following hypothesis is therefore proposed:

H4: The perceived novelty of digital humans/meta-humans has a positive impact on user satisfaction.

2.4. Familiarity, user satisfaction and purchase intention

The familiarity that users feel when using IT products or services positively impacts their purchase intention. This effect has been documented in contexts such as electronic payments (Pei, Wang, and Archer 2021), voice/music-related services (Rekswinkel 2020) and online reservation services (Kim, Chua, and Han 2020). Thus, we expect that the familiarity that users feel towards digital/meta-humans will affect their willingness to use the technology. In the context of

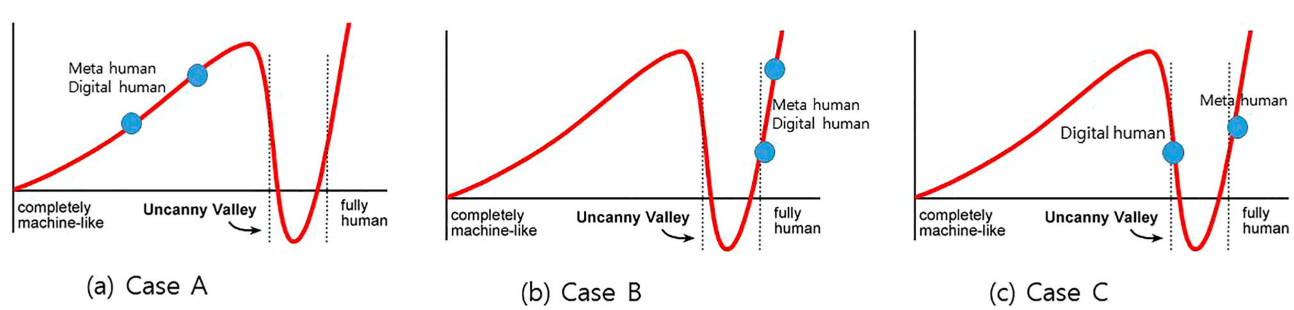


Figure 2. Three potential relationships between human likeness of digital human/meta-human technologies and familiarity.

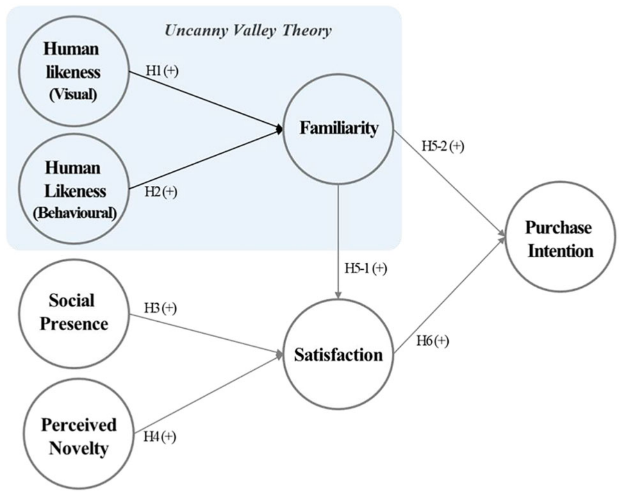


Figure 3. Research model.

marketing activities on SNS (Chun, Lee, and Park 2020) and Korean cosmetics (Augusta, Mardhiyah, and Widiastuti 2019) studies, we found the same results of a positive impact on familiarity and purchase intention. Therefore, the following hypotheses are proposed:

> **H5-1**: User familiarity towards digital humans/meta-humans has a positive impact on user satisfaction.

> **H5-2**: User familiarity towards digital humans/meta-humans has a positive impact on purchase intention.

Finally, the positive effect of satisfaction on the purchase intention has been widely observed in business research. Most recently, the positive impact of user satisfaction on the intention to use has been confirmed in contexts such as digital personal stores (Mariani, Styven, and Teulon 2021), mobile shopping (Gharaibeh and Gharaibeh 2021) and gaming (Abou-Shouk and Soliman 2021). Consequently, it is likely that the same pattern will be seen for digital/meta-humans, which are also used for digital personalisation, commercial services and gaming. The following hypothesis is therefore proposed:

> **H6**: User satisfaction with digital humans/meta-humans has a positive impact on purchase intention.

These hypotheses can be aggregated into a research model shown in Figure 3.

3. Methods

3.1. Study design

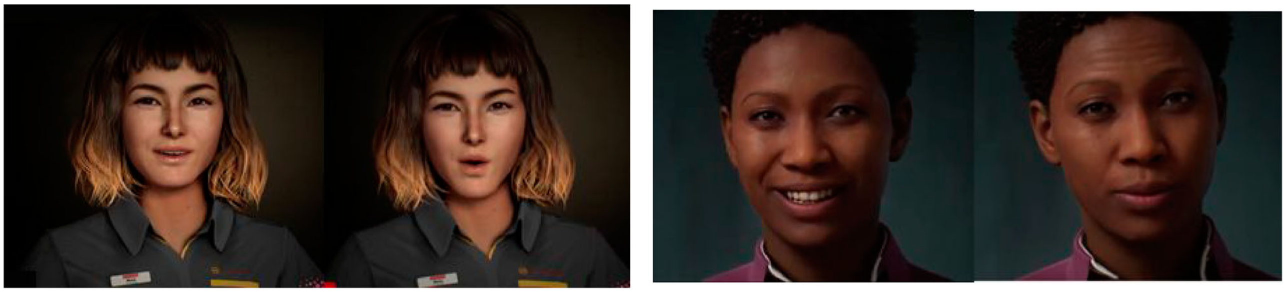
A quantitative study using an online questionnaire was conducted with adult participants who viewed videos featuring digital humans or meta-humans. The survey was conducted from May 22–27, 2021 by a survey company in Korea. The total number of surveys sent was 1,551,944; follow-up emails were sent to 2,949 panel members (0.19% of all respondents) who expressed willingness to participate in the survey. In total, 551 panel members accessed the survey emails (corresponding to 18.7% of emails sent), and the number of recipients who actually responded was 330, comprising 59.8% of the users who accessed the email. Gender and age ratios were ensured using a stratified sampling method, and \$4 incentives were provided to respondents to induce active participation. Those wishing to participate in the survey were asked first to check whether the requested video viewing environment was possible. After the system check, they were asked to watch the demonstration video for about 40 s.

To understand the existence of the uncanny valley phenomenon, we selected representative digital/meta-humans with different quality from the perspective of human likeness (visual/behavioural) as demonstration videos. Subjects were randomly divided into two groups: a group that watched a video featuring digital humans and a group that watched a video featuring meta-humans (Figure 4). The sample was divided into two groups as this has been shown to help isolate and emphasise the specific effects of each digital/meta-human (Shadish, Cook, and Campbell 2020), enable simple and direct comparisons across groups (Cooper and Campbell 2018), and reduce biases that can impact the evaluation of the participants (Dawes, Singer, and Lemons 1972). After watching the video, they answered questions about the digital/meta-human in the video (Appendix B). A reverse question was included for one item to discriminate inattentive respondents. Based on this test, 50 insincere responses were excluded from the total 330 responses, leaving us with a final sample of 280 responses (corresponding to 84.8% of respondents) for use in the analysis.

Demographic characteristics were confirmed with SPSS 28.0, and PLS-based structural equation modelling analysis was performed using Smart PLS 4.0 (please see Table 1). After verifying the measurement model (outer model) of the reflective model, hypothesis testing was performed by evaluating the structural model (inner model) and conducting bootstrapping (boot strapping).

3.2. Measures

Questionnaire items from previous studies based on the uncanny valley theory were modified to fit this study. For example, two constructs, human likeness and familiarity, both of which have been used in research on humanoids or digital actors since Mori (1970), were modified for this study. In particular, for human



(a) Digital human
https://www.youtube.com/watch?v=WarQGUK2Wo4

(b) Meta-human (B)
https://www.youtube.com/watch?v=HuAAdsZPLlE

Figure 4. Sample demo images for digital/meta-human experiment: (a) Digital human (b)Meta-human (B).

likeness, the humanness index proposed by Ho and MacDorman (2010) was used. Some of the social presence scales proposed by Gefen and Straub (2004) were also used. Familiarity was measured as one item on a scale ranging from strange to familiar in the study of MacDorman (2006, July); however, for this study, the familiarity index of Bouwer, Human, and de Lange (2019) was used. Bouwer, Human, and de Lange (2019) used sub-indices such as Eeriness, Attractiveness, Pleasure, and Warmth as components of their Familiarity Index. On the other hand, the construct intention to use was borrowed from technology acceptance models such as the UTAUT (Venkatesh et al. 2003).

In previous studies, in order to identify differences in evaluation according to the context of use for digital humans, two dimensions were most often considered: hedonic value and utilitarian value. However, in this study, the utilisation context was divided into three dimensions; we included normative value in addition to hedonic value and utilitarian value because the uncanny valley involves social and psychological characteristics such as the mental health of users. Thus, survey participants were asked to answer questions that digital/meta-humans are likely to ask (Cho, Molina, and Wang 2019).

To verify the content validity of the derived questionnaire items, one professor of media studies and two graduate students were asked to review it prior to implementation, after which a preliminary survey was conducted using non specialists as subjects. Survey responses were scored using a 7-point Likert scale (1 = not agree at all ~ 7 = strongly agree). A factor analysis was conducted based on the results, which are shown in Table 2.

Table 1. Demographic characteristics of study subjects.

Category		Number (%)
Gender	Male	143 (51.1)
	Female	137 (48.9)
Age	20s	84 (30.0)
	30s	84 (30.0)
	40s	62 (22.1)
	50s	50 (17.9)
Education	High school graduate	30 (10.7)
	College registration	38 (13.6)
	College graduate	183 (65.4)
	Graduate student or above	29 (10.4)
Profession	Student	35 (12.5)
	Office worker	104 (37.1)
	Employee	9 (3.2)
	Professional	47 (16.8)
	Self-employed	13 (4.6)
	Housewife	31 (11.1)
	Others	41 (14.6)
Stimulus	Digital human	139 (49.6)
	Meta-human	141 (50.4)

3.3. Reliability and validity of the measurement model

SmartPLS 4.0 was used to verify the research model and hypotheses of this study. First, the suitability and discriminant validity of the measurement model were investigated. After confirming the fit and discriminant validity of the model, we verified the research hypotheses through structural analysis of the model.

Before testing the hypotheses of this study, we examined the validity and suitability of the measurement model. First, as shown in Table 3, the average variance extracted (AVE) value was 0.831 or higher, thereby indicating satisfactory convergent validity (Bagozzi and Yi 1988). Composite reliability (CR), an index to measure the convergent validity of the measurement model, was 0.937 or higher, thereby indicating satisfactory reliability (Bagozzi and Yi 1988). In addition, reliability (Cronbach's alpha) as tested using the PLS algorithm was 0.864 or higher, ensuring internal consistency and high reliability (Bagozzi and Yi 1988; Hair et al. 2012). When it comes to $R^{2,}$ the value of R^2 of familiarity (0.142) indicates the presence of the uncanny valley effect rather than linearity between human likeness (visual) and human likeness (behavioural) with familiarity. Therefore, it cannot be

Table 2. Factor analysis.

Variable	Items	Factor Loadings 1	2	3	4	5	6	7	Eigen Value	Explained Variance (%)	Confidence Coefficient
Purchase Intention	**PI1**	**0.868**	0.088	0.075	0.201	0.207	0.228	0.157	**3.196**	**15.981**	**0.951**
	PI2	**0.867**	0.110	0.131	0.186	0.171	0.178	0.207			
	PI3	**0.822**	0.141	0.073	0.160	0.206	0.262	0.243			
Human Likeness (Visual)	**HLV2**	0.099	**0.858**	0.293	0.181	0.210	0.116	0.094	**2.839**	**14.197**	**0.966**
	HLV3	0.125	**0.854**	0.273	0.173	0.226	0.140	0.065			
	HLV1	0.124	**0.852**	0.289	0.229	0.223	0.138	0.052			
Human Likeness (Behavioural)	**HLA1**	−0.034	0.175	**0.884**	0.077	0.076	0.151	0.087	**2.697**	**13.484**	**0.898**
	HLA2	0.124	0.247	**0.882**	0.102	0.096	0.078	0.084			
	HLA5	0.180	0.267	**0.808**	0.129	0.108	0.002	0.090			
Social Presence	**SP1**	0.209	0.124	0.040	**0.823**	0.192	0.171	0.166	**2.614**	**13.068**	**0.890**
	SP2	0.172	0.241	0.212	**0.785**	0.135	0.191	0.148			
	SP3	0.180	0.238	0.129	**0.778**	0.176	0.120	0.315			
Perceived Novelty	**PN2**	0.169	0.215	0.140	0.160	**0.863**	0.180	0.077	**2.508**	**12.538**	**0.902**
	PN1	0.227	0.330	0.069	0.185	**0.770**	0.181	0.085			
	PN3	0.325	0.184	0.165	0.226	**0.682**	0.373	0.170			
Satisfaction	**SF1**	0.399	0.194	0.109	0.245	0.322	**0.707**	0.194	**2.049**	**10.244**	**0.953**
	SF3	0.390	0.220	0.144	0.236	0.311	**0.703**	0.218			
	SF2	0.398	0.162	0.154	0.273	0.319	**0.684**	0.234			
Familiarity	**FM4**	0.292	0.085	0.108	0.247	0.090	0.199	**0.838**	**1.832**	**9.159**	**0.901**
	FM5	0.285	0.077	0.172	0.324	0.149	0.172	**0.797**			

Note: KMO (Kaiser-Meyer-Olkin measure of sample adequacy) = 0.913; total variance = 88.67%; Bartlett's test of sphericity = 5834.316 (df = 190, p = 0.000).

Table 3. PLS-SEM overall model fit.

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)	R^2
Human Likeness (Visual)	0.966	0.966	0.978	0.936	
Human Likeness (Behavioural)	0.898	0.905	0.937	0.831	
Social Presence	0.892	0.892	0.933	0.822	
Perceived Novelty	0.903	0.918	0.939	0.837	
Familiarity	0.901	0.903	0.953	0.910	0.142
Satisfaction	0.953	0.953	0.970	0.914	0.664
Purchase Intention	0.952	0.952	0.969	0.912	0.583

solely explained by $\boldsymbol{R^2}$, rather it indicates the presence of the uncanny valley effect.

In order to confirm discriminant validity, the value of the square root of the AVE of each factor must be greater than the correlation coefficient between variables (Fornell and Larcker 1981). In this study, as shown in Table 4, the values were all greater than the correlation coefficients between the variables, confirming that this requirement was satisfied.

3.4. Fitness of the structural model

In addition, the average value for the fitness of the structural model was determined using the R^2 value of the endogenous variable and classified according to the size of the R^2 effect (lower: 0.02∼0.13, middle: 0.13∼0.26, upper: 0.26 or more), which is lower than that of other variables. Values for familiarity were higher than 0.438, confirming the fitness of our structural model (Tenenhaus et al. 2005).

4. Results

4.1. Digital human vs. meta-human

In this study, an independent samples t-test was performed to verify differences between factors before we investigated factors affecting the intention to use the

Table 4. Correlation analysis.

Constructs	Mean	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Human Likeness (Visual)	**4.64**	**1.50**	**0.967**						
(2) Human Likeness (Behavioural)	**3.48**	**1.39**	.576**	**0.912**					
(3) Social Presence	**3.60**	**1.30**	.524**	.368**	**0.907**				
(4) Perceived Novelty	**4.52**	**1.33**	.584**	.367**	.547**	**0.915**			
(5) Familiarity	**3.61**	**0.68**	−0.084	−0.061	.145*	−0.032	**0.954**		
(6) Satisfaction	**4.33**	**1.34**	.511**	.375**	.622**	.738**	−0.115	**0.956**	
(7) Purchase Intention	**3.66**	**1.36**	.374**	.293**	.520**	.582**	0.040	.740**	**0.955**

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 5. Independent t-test results by subject.

Variables	Type	n	M	SD	t	df	p
Human Likeness (Visual)	Digital human	139	3.76	1.31	−10.706 ***	276.800	0.000
	Meta-human	141	5.40	1.25			
Human Likeness (Behavioural)	Digital human	139	2.71	0.91	−11.131 ***	278.000	0.000
	Meta-human	141	4.25	1.37			
Social Presence	Digital human	139	2.96	1.26	−6.960 ***	277.813	0.000
	Meta-human	141	4.00	1.24			
Perceived Novelty	Digital human	139	4.25	1.39	−4.681 ***	278.000	0.000
	Meta-human	141	4.96	1.15			
Familiarity	Digital human	139	3.00	1.18	−4.052 ***	278.000	0.000
	Meta-human	141	3.62	1.39			
Satisfaction	Digital human	139	4.01	1.30	−4.058 ***	277.889	0.000
	Meta-human	141	4.65	1.30			
Purchase Intention	Digital human	139	3.39	1.34	−3.288 ***	278.000	0.001
	Meta-human	141	3.92	1.33			

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

existing digital humans and meta-humans as experimental subjects. The results, shown in Table 5, confirmed significant differences between factors by subject. It was confirmed that the meta-humans were evaluated more highly.

4.2. Hypotheses test results

The hypotheses were tested by determining the path coefficients, and the significance values of the path coefficients were confirmed using 5,000 bootstrapping samples (Hair, Ringle, and Sarstedt 2011). Figure 5 shows the results of the path analysis based on the high fitness of the path model.

4.3. Multigroup PLS-SEM test results

Table 5 confirms the differences between factors for each test subject. To check whether these differences were also evident in the path coefficients of the PLS-SEM, the results of the multigroup PLS-SEM test were confirmed. First, in order to examine the path coefficients and hypothesis test results for digital humans (n = 139), the significance of the path coefficients was confirmed using 5,000 bootstrapping samples (Hair, Ringle, and Sarstedt 2011). The results are shown in Figure 6.

Then, the path coefficients and hypothesis test results for meta-humans (n = 141) were investigated. The significance of the path coefficients was confirmed using 5,000 bootstrapping samples. The results are shown in Figure 7.

The results for hypothesis testing using PLS-SEM for each test subject were slightly different; thus, we statistically verified differences between groups in terms of the path coefficient for each test subject (Kock 2014). As shown in Table 6 and Table 7, the only significant difference was from satisfaction to intention to use (t = 2.167, $p = 0.05$), while other paths showed no difference in path coefficients by test subject.

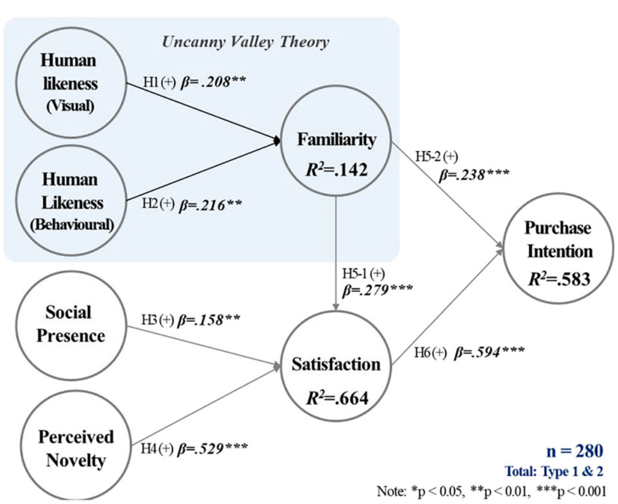


Figure 5. PLS-SEM test results.

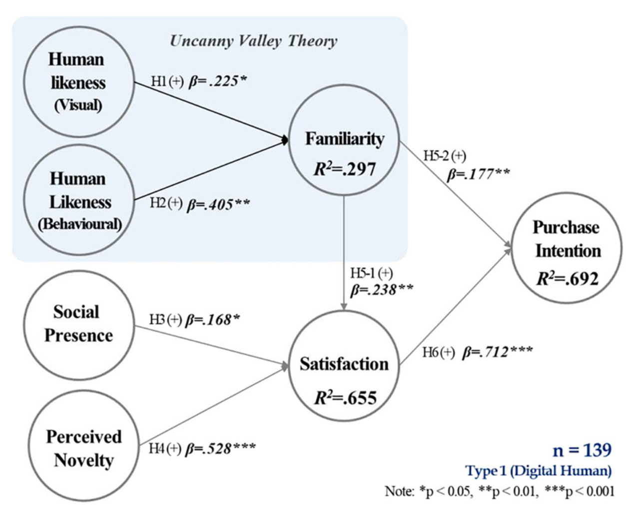


Figure 6. Multigroup PLS-SEM type 1 (digital human) test results.

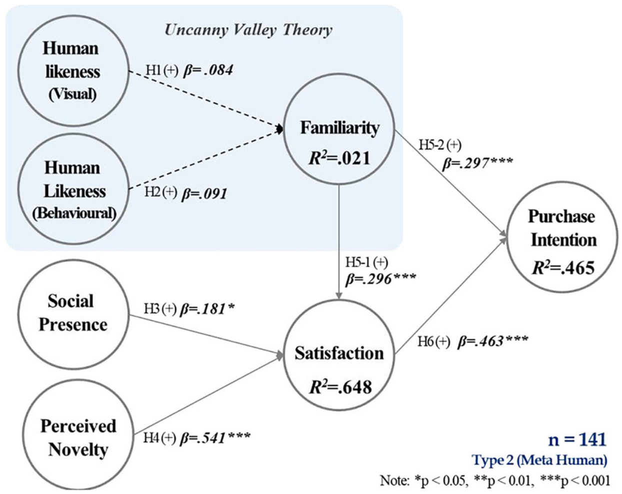


Figure 7. Multigroup PLS-SEM type 2 (meta-human) test results.

4.4. Scatter plot of uncanny valley effect

As shown in the research models and hypotheses, we assumed an uncanny valley effect in the relationship between human likeness (visual) and familiarity, and between human likeness (behavioural) and familiarity. Therefore, we assumed a nonlinear relationship between these variables using a scatter plot as an additional confirmation; the results are shown in Figure 8.

The scatter plot reveals that, for visual human likeness, digital humans scored low, while familiarity increased, which seems to be a typical phenomenon that occurs before the uncanny valley is reached. In contrast, meta-humans scored relatively high for human likeness and increased after familiarity decreased, which is also a typical phenomenon after the uncanny valley is reached. Therefore, in terms of appearance, it seems that digital humans and meta-humans are distributed on the left and right sides of the uncanny valley, respectively.

Table 7. PLS-SEM for test of multigroup differences

Hypothesis	Path Name	Multigroup comparison	Difference
H1	Human Likeness (Visual) → Familiarity	Digital = Meta	0.360
H2	Human Likeness (Behavioural) → Familiarity	Digital > Meta	0.050*
H3	Social Presence → Satisfaction	Digital = Meta	0.906
H4	Perceived Novelty → Satisfaction	Digital = Meta	0.930
H5-1	Familiarity → Satisfaction	Digital = Meta	0.619
H5-2	Familiarity → Purchase Intention	Digital = Meta	0.252
H6	Satisfaction → Purchase Intention	Digital > Meta	0.009**

Note: *p<0.05, **p<0.01, ***p<0.001.

On the other hand, in terms of human likeness (behavioural), that is, in terms of how similar the actions and conversations of digital/meta-humans are to actual humans, the results differ. In the case of digital humans, familiarity increased at a relatively low level of human likeness. Meta-humans received relatively higher scores for human likeness than digital humans, but with increased familiarity. Therefore, they fall on the right side of the uncanny valley, unlike digital humans (see Table 8). Overall, the nonlinearity between human likeness and familiarity assumed earlier was confirmed, as were differences between digital humans and meta-humans, and differences in terms of human likeness (visual) and human likeness (behavioural) were found in our tests of human likeness.

5. Discussion, contributions and limitations

5.1. Discussion

In this study, we investigated the effects of meta-human characteristics on user acceptance, asking whether users

Table 6. PLS-SEM for MGA test.

		Digital human		Meta-human			
Hyp.	Path Name	Path Coefficient	P value	Path Coefficient	P value	Path Coefficient Difference (|Digital − Meta|)	P value (|Digital − Meta|)
H1	Human Likeness (Visual) → Familiarity	0.225	0.011	0.084	0.425	0.141	0.298
H2	Human Likeness (Behavioural) → Familiarity	0.405	0.000	0.091	0.462	0.314	0.031
H3	Social Presence → Satisfaction	0.168	0.033	0.181	0.019	−0.013	0.899
H4	Perceived Novelty → Satisfaction	0.528	0.000	0.541	0.000	−0.013	0.932
H5-1	Familiarity → Satisfaction	0.238	0.003	0.296	0.000	−0.058	0.571
H5-2	Familiarity → Purchase Intention	0.177	0.009	0.297	0.000	−0.120	0.246
H6	Satisfaction → Purchase Intention	0.712	0.000	0.463	0.000	0.249	0.007

Note: *p < 0.05, **p < 0.01, ***p < 0.001.

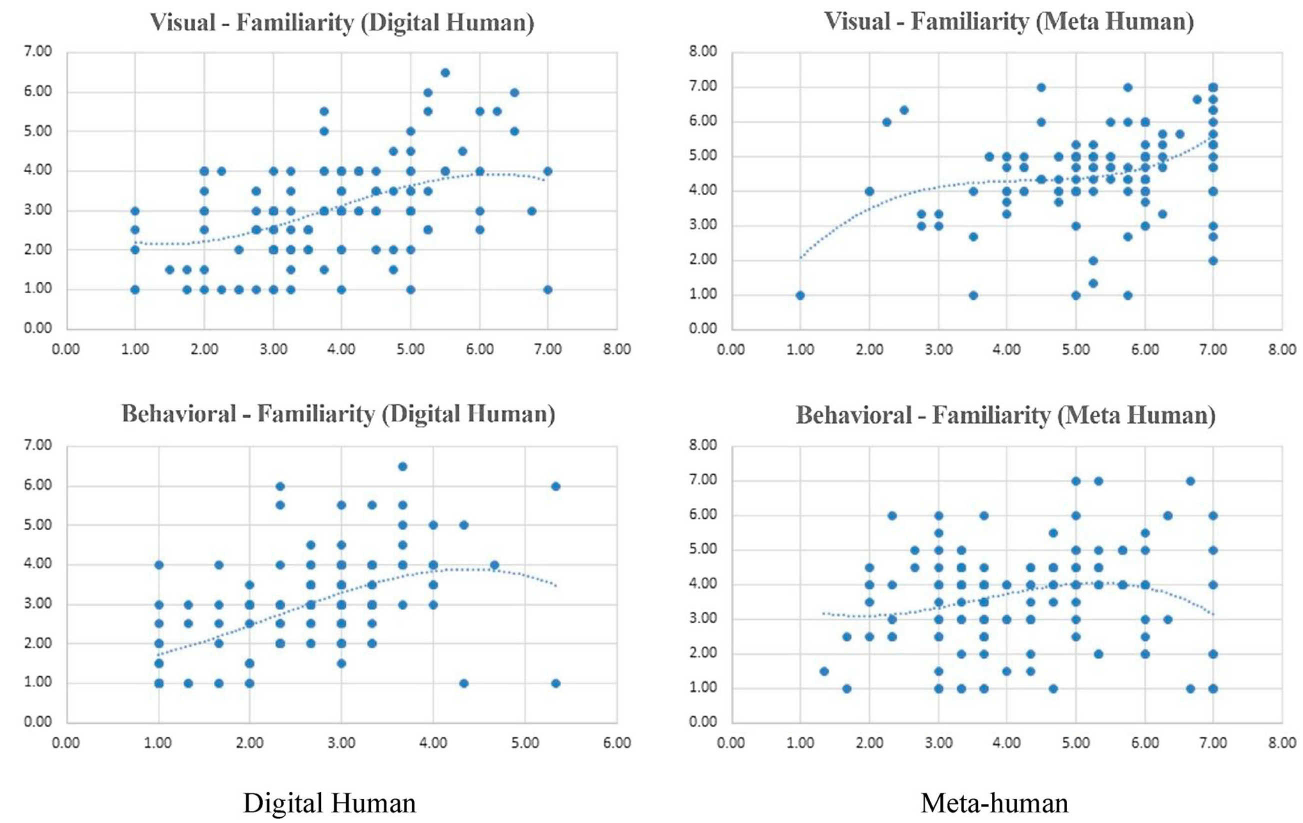


Figure 8. Scatter plot of the uncanny valley effect.

of technology featuring meta-humans are also affected by the uncanny valley effect. In particular, we set out to answer research questions, and this discussion is structured around them.

Objective 1: Are meta-humans superior to digital humans in terms of user acceptance?

Our findings showed (Table 5) that meta-humans had significantly higher user acceptance than digital humans. This is partly due to the greater satisfaction and purchase intention with meta-humans compared to digital humans. In addition, meta-humans were also rated higher than digital humans in terms of human likeness (visual and behavioural, social presence, intention to use and perceived novelty), which confirms the findings of Higgins et al. (2018). In fact, with the introduction of meta-human modelling tools, the creation of highly accurate and hyper-realistic meta-humans has been made possible. It is not unexpected that the use of meta-human modelling tools would produce a much higher-quality version of digital humans; the results of this study confirmed this (Gawand and Demirel 2020b). Considering the lack of empirical research on the use of meta-humans and its potential to enhance the current capabilities of digital technologies (Dean 2013; Dharma and Suryadinatha 2019), these results provide valuable information.

Objective 2: Does the human likeness of meta-humans in terms of appearance play a different role to that of human likeness in terms of functionality? How do these two types of human likeness affect user acceptance?

The findings of this study revealed that the level of human likeness (visual) of meta-humans was higher than that of digital humans (Table 8 and Figure 8). Moreover, the relationship between human likeness (visual) and user familiarity was strongest on the right side of the uncanny valley. These results show that meta-humans have overcome the uncanny valley effect in terms of appearance. Although there is scepticism as to whether developers of digital humans can

Table 8. Comparison of uncanny valley effect between digital humans and meta-humans as measured on the human likeness scale.

	Digital Humans	Meta Humans
Human likeness (Visual)	Relatively low human likeness The left side of the uncanny valley	Relatively high human likeness The right side of the uncanny valley
Human likeness (Behavioural)	Relatively low human likeness The left side of the uncanny valley	Relatively high human likeness The left side of the uncanny valley

overcome the uncanny valley effect (Bartneck et al. 2007; Burleigh, Schoenherr, and Lacroix 2013), our results indicate that the use of deep learning technology has enabled meta-human technology to overcome the uncanny valley effect by an acceptable margin. This is highly significant, as the uncanny valley effect drastically reduces acceptance of such technologies (Mori 1970), thereby hindering potential business applications. This study therefore serves as a meaningful turning point for developers of digital and meta-human technology.

On the other hand, although the level of human likeness (behavioural) of meta-humans was higher than that of digital humans, the relationship between human likeness (behavioural) and user familiarity for meta-humans was similar to that of digital humans in relation to the uncanny valley effect; it was strongest on the left side of the valley. This indicates that the behavioural aspects of meta-humans, such as movement and human interaction, are not yet sufficiently realistic to overcome the uncanny valley effect. Thus, compared to using the previous definition of human likeness (Ho and MacDorman 2010; Mori 1970; Mori et al., 2012), our approach of evaluating visual human likeness and behavioural human likeness separately has provided a better understanding of the relationship between human likeness and user familiarity.

Objective 3: Have meta-humans overcome the uncanny valley effect? When human likeness surpasses the uncanny valley, what factors affect user familiarity and acceptance?

Furthermore, our findings show that social presence and perceived novelty have a significant effect on familiarity with both meta-humans and digital humans. This confirms the findings of previous research (Borup, West, and Graham 2012; Gefen and Straub 2004; Toyama and Yamada 2012), which identified positive relationships between social presence/perceived novelty and user familiarity. A positive correlation between human likeness and familiarity was confirmed in this study, as was the existence of the uncanny valley effect. The fact that meta-humans could partially overcome the uncanny valley effect seems to have contributed to their levels of social presence and perceived novelty (Mori 1970).

Moreover, as shown in the multigroup difference test (Table 6), there was no significant difference in the intensity of causality between meta-humans and digital humans for all factors except for the relationship between satisfaction and intention to use. This suggests that social presence and perceived novelty likely play a positive role for both meta-humans and digital humans in surpassing the uncanny valley effect.

As expected, there was a significant relationship between user satisfaction and familiarity (Pei, Wang, and Archer 2021; Rekswinkel 2020). Moreover, since neither visual nor behavioural human likeness were found to affect user satisfaction directly, the uncanny valley effect was confirmed between human likeness and user satisfaction. In addition, perceived novelty was found to have a direct effect on satisfaction (Toyama and Yamada 2012). However, social presence had no direct effect on satisfaction. Instead, social presence indirectly affected satisfaction through familiarity. In order for businesses to improve user satisfaction when using digital/meta-humans, they must take perceived novelty into consideration. Social presence, however, must also be taken into consideration, as it still impacts user satisfaction in terms of increasing their familiarity with the technology (Andel et al. 2020; Gimpel, Huber, and Sarikaya 2016; Jung et al. 2018).

5.2. Theoretical contributions

This study provides a number of theoretical contributions. This is the first empirical study to find a significant difference between digital humans and meta-humans in the context of the uncanny valley effect (Ho and MacDorman 2010; Mori 1970). Although previous studies have evaluated and discussed the use of digital humans from the perspectives of design and ergonomics (Ahmed et al. 2021; Gaisbauer et al. 2020; Gawand and Demirel 2020b; Khayer, Patel, and Ningthoujam 2019), few studies have investigated the use of meta-humans, despite their significantly improved appearance and behaviour. In this study, meta-humans were found to be significantly superior to conventional digital humans in all aspects, including human likeness, social presence, perceived novelty, familiarity, satisfaction, and purchase intention. In this way, our empirical study showed that meta-humans are superior in terms of user behavioural intention.

Secondly, we verified the existence of the uncanny valley effect in the relationship between human likeness and familiarity, confirming the results of previous studies (Ho and MacDorman 2010; Mori 1970). We also found that whilst the level of human likeness of digital humans was measured as being before the uncanny valley, the human likeness of meta-humans, in terms of appearance, had surpassed the uncanny valley. Therefore, it is likely that meta-humans, in terms of appearance, can be used effectively in multiple contexts involving media services.

Thirdly, this study contributed to the literature on uncanny valley theory by expanding the definition of human likeness into two constructs: appearance and behaviour. For meta-humans, there was a significant difference between human likeness in terms of appearance and human likeness in terms of behaviour. Although developers of meta-humans have been successful in making them hyper-realistic and overcoming the uncanny valley effect in terms of appearance, they have not yet been successful in terms of behaviour. Therefore, we recommend that future research on the uncanny valley effect in the context of humanoids and digital humans should investigate these two types of human likeness separately.

Fourthly, our results confirmed that social presence and perceived novelty, in addition to human likeness, are also impactful factors when investigating user familiarity, user satisfaction and purchase intention of digital/meta-humans. Familiarity and satisfaction positively impacted users' intention to use products introduced to them by digital/meta-humans.

5.3. Practical contributions

This study also provided several practical contributions. First, it suggests that managers who plan to provide services/products using digital human simulation tools in companies should consider the uncanny valley effect and make efforts to improve the quality of human likeness (visual) and familiarity at the same time. While human likeness (visual) is a technical performance improvement, familiarity is connected to services or messages, so it is important to reflect elements that can make consumers feel familiar.

Secondly, this study provided empirical evidence that behavioural human likeness is also significant in the acceptance of digital/meta-humans. In addition to their appearance, designers should also focus on improving the facial expressions, movements, and interactions of digital/meta-humans to increase user acceptance. In this study, the lack of acceptance of digital/meta-humans with realistic appearances was based on the lack of behavioural similarity.

Thirdly, we also found that familiarity does directly affect purchase intention. Recently, companies are increasingly using digital/meta-humans in their metaverse or platforms to provide services and content. This suggests that corporate marketers should consider the familiarity factor in their marketing strategies if they want to provide experiences that reinforce the familiarity factor from digital/meta-humans, as it will increase the intention to purchase products/services recommended by digital/meta-humans, which will help corporate performance.

Lastly, the results of this study also have significant implications for developers of digital human modelling tools. In particular, although modelling tools have been confirmed to impact user satisfaction and purchase intention positively through the creation of visually hyper-realistic meta-humans, designers must go further to replicate human behaviour accurately. In particular, social presence and perceived novelty influence satisfaction, so it is important to design experiences that reflect the characteristics of social presence and perceived novelty that can be experienced in digital/meta-humans experiences. Adding features for improving behavioural likeness to future modelling tools can greatly increase the effectiveness of the digital/meta-humans and ensure their acceptance.

5.4. Limitations and future research

There are a few limitations of this study. First, accurate measurement of the location of digital humans and the uncanny valley on the human likeness scale and familiarity are difficult solely using the face. However, most previous studies were limited to the face, which is the most important and universal factor for the evaluation of humanoids and digital/meta-humans (Mori 1970; Mori, MacDorman, and Kageki 2012; Schindler et al. 2017). Unlike previous studies, this study included voice as well as facial appearance, enabling a richer evaluation. Nevertheless, human likeness is also affected by posture, gesture and motion. Therefore, a more refined scale development for Human Likeness (Visual/Behavioral) and familiarity are also necessary in future research. Further empirical research is needed to verify the location of digital/meta-humans on this scale and address the uncanny valley effect more accurately by examining the whole body.

Secondly, digital humans or meta-humans can be evaluated differently by different users depending on their backgrounds. For example, older people might value human likeness more than younger people (Tu, Chien, and Yeh 2020). Furthermore, the use of digital/meta-humans from varied ethnic groups may also have an impact on user evaluations. Therefore, the evaluation of digital humans or meta-humans according to different user groups is a useful indicator for future adoption by consumers and also provides insight into the direction of future development of avatars in the context of the Metaverse environment.

Thirdly, in this experiment, the effect of the gender of the digital humans or meta-humans used in the stimuli on users' evaluations (especially for the constructs familiarity, satisfaction and purchase intention) was not considered. There are also limitations in that we did not separately consider the different ethnic groups of the digital/meta-humans as stimuli, so caution should be exercised when interpreting the results of this study. In robotics research, the effect of homophily between humans and humanoids on user acceptance is often discussed (Lim, Rooksby, and Cross 2021). Clearly, homophily is a factor to consider in technology acceptance (Farrell, Pammer, and Drebert 2021, August). Moreover, the relationship between homophily and user acceptance is rather complex, as it involves elements of the user's culture (e.g. collectivism) (Farrell, Pammer, and Drebert 2021, August). However, in this study, homophily and cultural dimensions were omitted because the focus of this study was to analyse differences in the location of meta-humans on the human likeness scale concerning the uncanny valley compared to digital humans and introduce a new definition of human likeness. In a future study, we hope to address these factors. Furthermore, future research evaluating the differences between digital and meta-humans should seek to limit the variables of the avatars of each technology concerning gender, ethnicity, and general appearance as these factors may affect the perceptions of the users.

Fourthly, it should be noted that the current study does not investigate specific contexts. The current study provides a general and introductory insight into the differences between digital humans and meta-humans in terms of user acceptance and familiarity (given the lack of studies on meta-humans), and also provides an analysis of some of the key factors that affect acceptance and other relevant impacts. However, these effects will likely vary depending on the research context. Future research should aim to identify the contextual differences in the impact of meta-humans on user acceptance by comparing the use of the technology in different industries such as theatre performance, tourism, education, and theatre performances (Salihbegovic 2020), tourism (Noh and Ro 2021), education (Leow and Ch'ng 2021), and e-commerce (Ssin et al. 2021) where the use of immersive content is increasing.

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Appendices

Appendix A. Literature on digital humans based on uncanny valley theory

Authors (Year)	Study Context	Key Variables	Method	Pilot Study (Yes / No)	Stimulus	Sample	Key Findings
Hanson et al. (2005)	Robotic systems	humanlike facial expressions, engagement	experiment	No	video, animated human face	not reported	*For realistic robots to be appealing to people, robots must attain some level of integrated social responsivity and aesthetic refinement*
MacDorman (2006, July)	Robot development	human likeness, familiarity, eeriness	experiment: rating videos ('*Participants were asked to rate 13 robots and 1 human shown in video clips*'), using images of androids	No	2D, still images, from nonhuman robot to real human	Total n = 56 (100%), males n = 43 (76.8%), females n = 13 (23.2%); college students and government workers	*Perceived human likeness of a robot is not the only factor determining the perceived familiarity, strangeness or eeriness of the robot*
Bartneck et al. (2007)	Robot development	human likeness, likeability	empirical study ('*We conducted a 3 (framing) x 4 (anthropomorphism) within-participant experiment*')	No	2D still images, from nonhuman robot to humanoid	Total n = 58 (100%), males n = 30 (51.7%), females n = 28 (48.3%); university students in the Kyoto district of Japan (age: 18∼41)	*Anthropomorphism had a significant influence on the measurements, but not even pictures of real humans were rated as likeable as the pictures of humanoids or toy robots*
Ho and MacDorman (2010)	Computer-animated characters and robots	anthropomorphism, animacy, likeability, perceived intelligence, perceived safety	empirical study (5 out of 10 video clips were randomly selected)	No	video, from nonhuman robot to computer-animated human characters	Total n = 384 (100%), males n = 223 (58.1%), females n = 187 (48.7%); undergraduate students	*New humanness and eeriness indices facilitate plotting relations among rated characters of varying human likeness*
Burleigh, Schoenherr, and Lacroix (2013)	Computer digital models' development	prototypicality, human likeness, pleasantness, eeriness, realism, affect	experiment: examining the relationship between human likeness and eeriness using digital human faces	No	2D, still images, digital humans	Total n = 47 (100%), males n = 19, females n = 28; undergraduate students	*Human likeness affects eeriness using digital human faces*
Schindler et al. (2017)	Creat the cartoon characters	human likeness, appeal, realism, intensity, emotion	experiment		2D, still images, human character	Total n = 32 (100%), males n = 10, females n = 22; college students	*Face realism has a strong influence on the acceptance of digital humans*
Rosenthal-Von Der Pütten and Krämer (2014)	40 robots evaluation	human likeness, likeability, familiarity	empirical study		2D, still images, from nonhuman robot to humanoid	Total n = 151, males n = 42, females n = 109; campus members	*In contrast to humanoid robots, the android robots were rated higher on familiarity and likeability*
Thepsoonthorn, Ogawa, and Miyake (2021)	Robot's nonverbal behaviour	human likeness, affinity	experiment: rate robots with different nonverbal behaviours		demo, NAO (humanoid) robot	Total n = 20, males n = 11, females n = 9; students	*Different nonverbal behaviours (gestures, speaking, face tracking, etc.) influence the u-shaped relationship between human likeness and affinity*
Seymour et al. (2021)	Avatars in a virtual reality	realism, affinity, trustworthiness	empirical study		2D, VR avatar	Total n = 50 employees of Amazon Mturk	*Hyper-realistic character portrayals can cross the uncanny valley*

Appendix B. Survey Items

Variable		Items	Source
Human Likeness (Visual)	HLV1	The shape of the digital human (meta-human) I experienced is similar to that of a real person.	Ho and MacDorman (2010) revised
	HLV2	I have experienced that the appearance of the digital human (meta-human) is similar to that of a real human.	Ho and MacDorman (2010) revised
	HLV3	My experience of the digital human (meta-human) is similar to that of a real human.	Ho and MacDorman (2010)
	HLV4	I experienced that the digital human (meta-human) looked like a real human.	Ho and MacDorman (2010) revised
Human Likeness (Behavioural)	HLA2	I experienced that the digital human (meta-human) felt synthetic.	Ho and MacDorman (2010)
	HLA1	I experienced that the digital human (meta-human) seemed artificial.	Ho and MacDorman (2010)
	HLA5	I experienced that the digital human (meta-human) had mechanical expressions and movements.	Ho and MacDorman (2010); MacDorman (2006, July)
Social Presence	SP2	When experiencing the digital human (meta-human), I felt human warmth.	Gefen and Straub (2004)
	SP1	When I experienced the digital human (meta-human), I felt that the (digital human / meta-human) was sociable.	Gefen and Straub (2004)
	SP3	When I met the digital human (meta-human), I realised it has human emotions.	Gefen and Straub (2004)
Perceived Novelty	PN1	The digital human (meta-human) I experienced was new.	Tokunaga (2013); Vitaliano et al. (1993)
	PN2	My experience with the digital human (meta-human) was a feeling I had never felt before.	Tokunaga (2013); Vitaliano et al. (1993)
	PN3	I felt that the digital human experience was differentiated from other content experience	Tokunaga (2013); Vitaliano et al. (1993)
Familiarity	FM4	I feel attached to the digital human I have experienced	Stevens et al. (2016)
	FM5	I feel emotionally close to the digital humans I have experienced	MacDorman (2006, July)
Satisfaction	SF1	I am generally satisfied with my experience meeting a digital human (meta-human).	Bae et al. (2020); Hosany and Witham (2010); Mehmetoglu and Engen (2011); Quadri-Felitti and Fiore (2013)
	SF2	I am satisfied with the digital human (meta-human) experience.	
	SF3	After experiencing the digital human (meta-human), I'm more satisfied than before.	
Purchase Intention	PI1	I want to buy a product guided by an experienced digital human.	Lu, Chang, and Chang (2014)
	PI2	I would like to recommend to my acquaintances the purchase of a product guided by an experienced digital human.	Lu, Chang, and Chang (2014)
	PI3	I intend to buy items guided by an experienced digital human.	Nam, Dong, and Lee (2017)