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Is Photorealism Important for Perception of Expressive Virtual Humans in Virtual Reality?

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Fig. 1. Experiment condition example: the realistic rendered character making eye-contact with the participant, immersed in the VR environment.

In recent years, the quality of real-time rendering has reached new heights - realistic reflections, physically based materials and photometric lighting are all becoming commonplace in modern game engines and even interactive virtual environments, such as virtual reality (VR). As the strive for realism continues, there is a need to investigate the effect of photorealism on users' perception, particularly for interactive, emotional scenarios in VR. In this paper, we explored three main topics, where we predicted photorealism will make a difference: the illusion of being present with the virtual person and in an environment, altered emotional response towards the character, and a subtler response - comfort of being in close proximity to the character. We present a perceptual experiment, with an interactive expressive virtual character in VR, which was designed to induce particular social responses in people. Our participant pool was large ($N = 797$) and diverse in terms of demographics. We designed a between-group experiment, where each group saw either the realistic rendering or one of our stylized conditions (simple and sketch style), expressing one of three attitudes: Friendly, Unfriendly or Sad. While the render style did not particularly effect the level of comfort with the character or increase the illusion of presence with it, our main finding shows that the photorealistic character changed the emotional responses of participants, compared to the stylized versions. We also found a preference for realism in VR, reflected in the affinity and higher place illusion in the scenario, rendered in the realistic render style.

CCS Concepts: • **Computing methodologies** → **Perception; Virtual reality; Animation.**

Additional Key Words and Phrases: virtual reality, proximity, render style, virtual humans

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1 INTRODUCTION

There has been a rapid improvement of real-time performance graphics in recent years. This development enabled the creation of photorealistic environments, seen in recent game releases, e.g., *Red Dead Redemption 2* (2018) or *Hellblade: Senua's Sacrifice* (2017). This development also made photorealistic rendering available in VR. The open source game engines, such as Unity and Unreal Engine 4 (UE4), are enabling creative developers free access to rendering effects, which mimic the appearance achieved with V-Ray and Mental Ray rendering engines. For these reasons, we anticipate photorealism will become commonplace in VR, and the virtual characters populating the environment will resemble actual people. This poses a question - will photorealism affect the way the user perceives and interacts with characters in VR? In particular, if they are more appealing to interact with, and if they induce a stronger and more close-to-real emotional response in people.

Virtual Reality is known for eliciting extraordinarily strong responses in the user. Even a very simple representation of a room can create an illusion of a real place (place illusion [33]) and make the user feel as if the virtual character is alive and right there in the room with the user (social presence [3, 34]). When studying social presence and place illusion, research has not found any consistent evidence that visual realism would intensify these illusions [13, 28]. However, it was also not possible to display interactive photorealistic environments in VR without significant loss in rendering speed. To estimate the importance of visual realism for the feeling of social presence and place illusion, we animated a current state-of-the-art photorealistic game character and created two stylized versions of it, which resembled the lower perceived levels of realism reported in McDonnell et al. [25].

In addition to the feeling of presence, visual realism could affect emotional responses of the user as well. Some previous studies investigated the link between realistic render style and emotional responses [37, 43] and found that the realistic style of the character affected the emotional response in negatively-charged emotional scenarios. In our study we were interested in the emotional reaction by investigating the response to three different scenarios, where one scenario was designed to introduce a character expressing strong negative emotions (sadness, guilt). We predicted that the people observing a realistically rendered version of this scenario will report more concern than the people observing the stylized versions of the same scenario.

The other two scenarios (friendly and unfriendly) were designed to test if people felt less comfortable standing close to the unfriendly than friendly character as previously reported by Bonsch et al. [7]. Our main hypothesis here was that the realistic render style in our scenario would make this discomfort even greater compared to other stylized versions of the character in the same scenario.

Our experiment was installed in a public setting in a museum called the Science Gallery, which is an international chain of art exhibition centres with a science outreach. Hundreds of visitors volunteered to take part in our experiment, and we retained data from a large sample. Visitors were members of the public from diverse backgrounds. A major advantage of having a large sample was that it enabled us to investigate the independent variables between-groups, which meant one participant saw only one combination of visual style (photorealistic or controls) and scenario (sad, friendly or unfriendly). This paradigm is typically used to reduce learning and transfer across the experimental conditions. If participants had seen multiple combinations of render style and scenario on the same character, this could have influenced their responses towards the characters. Seeing only one representation thus enabled a more ecologically valid response to the stimuli.

Our experiment is thus one of few large-scale experiments conducted in VR. We address a wide range of perceptual effects for a state-of-the-art expressive character, exhibiting complex and interactive behavior. We also explored novel measures, such as proximity in a constricted space. Our results show that, compared to stylization, photorealism increases place illusion, changes the emotional response, decreases the perceived movement realism, but does not affect comfort levels in close proximity to the character.

The results of this experiment are important for the design of interactive virtual characters (avatars or agents) in VR.

2 BACKGROUND

When studying artificial humans, either in computer graphics or robotics, attempting to design a highly realistic looking human can sometimes induce an aversive response in people, resulting in feelings of disgust, eeriness and even fear. This response was first described by Mori [27] as the “uncanny valley”, and the effect was even more intense when the robot was moving. Since then, many researchers have investigated this phenomenon, putting forward the mismatch in realism between elements of character design as the main cause [9, 24, 39, 41]. Some studies, however, showed that character realism can be created in different ways and is by itself not necessarily a predictor of affinity towards the character. In some studies, realistic render style of the character was found to be appealing, even when moving, as studies of McDonnell et al. [25] and Carter et al. [8] showed. Realistic render style of characters might have other perceptual effects, such as how trustworthy people find the character [25], which information they disclose to it [30], as well as emotional response and personality perception [37, 43].

Encountering characters in virtual reality can induce a feeling of social presence (sometimes referred to as co-presence) or the feeling that the user is present with real or imagined others [31]. The most important factor which increases social presence is interactive behavior of the character, which can be as simple as eye-contact with the user [2]. Social presence can be measured by using subjective reports or behavioral measures. The subjective responses are usually short questionnaires in a form of Likert-style scales [3, 14], and behavioral responses include analysis of physiological data, or examination of a variety of nonverbal and verbal behaviors [2, 12, 22].

The relationship between the character’s appearance and social presence has given conflicting evidence, where appearance realism had no effect on the viewer’s response, shown by Slater et al. [34] and Garau et al. [15] but increasing the anthropomorphism levels was positively correlated with co-presence, as shown by Nowak et al. [28]. However, a common result suggests that a mismatch between the realism of behavior and appearance lowers the feeling of co-presence [4]. Studies by Zibrek et al. [42, 43], comparing the effect of render style in virtual reality, found that a realistic render style was related to higher levels of appeal and was more acceptable than less realistic styles for certain personality expressions but did not affect social presence levels. It was suggested, however, that this was due to the lack of interactive behavior of the character - it did not respond to the user’s presence in VR [43].

In addition to having an illusion of character’s social presence, there is also a feeling of being in a place, a sense of a place illusion [33]. This illusion signifies an intense level of immersion into a virtual reality environment and can lead to user’s realistic response to the content. It corresponds to the traditional definition of presence as the sense of “being there”. There is no direct evidence that photorealism would elevate the feeling of place illusion, as the illusion is more related to the responsiveness of the environment to the user’s actions in this environment. However, photorealism could increase the user’s motivation to engage with the environment and in turn result in higher place illusion.

Proximity is one of the measures in VR which measures the behavioral response to virtual characters. The measure focuses on the comfort with the distance towards the virtual character. Minimum distance of approaching the character in VR and has commonly been used to study interpersonal relations observed in real human interactions, such as engagement [6], social status [21], and social presence with the virtual character [2]. One particular study has shown that the character’s attitude towards the user affects the proximity measure as well [7] - a threatening attitude will increase the proximity distance.

Realism of the virtual characters was found to be related to the emotional response of the observer. For example, Zibrek et al. [43] investigated the level of concern people expressed towards virtual characters in different render styles and found that in a particular scenario, when the character was expressing frustration, the concern for this character was higher if he was rendered in a realistic style. It was concluded that realism could induce a stronger feeling of empathy. A similar study by Volonte et al. [37] used a rigorous methodological approach to investigate emotional responses to a virtual patient, rendered in three different styles, who was exhibiting reactions to

different stages of his disease. A lack of appropriate emotions for the realistic character in critical moments of the scenario was found. They attributed this finding to the possibility of perceiving subtle expressions from the realistic render style, which would enable the perception of more complex traits of the character.

3 STIMULI CREATION

The virtual character which we chose for our task is one of the Epic Games freely accessible Paragon character assets with realistic materials from Marketplace [35]. We chose this model because it was the most human-like out of the available options and we removed some of the accessories, but kept her punk style hair and clothing. The photorealistic appearance of the female character (see Figure 1) was created using face scans from Otoy [29] and body scans from 3dscanstore [1]. It is equipped with a full body and facial rig (although with limited blendshapes), to which we applied body and facial animation.

We needed to avoid the potential aversive reaction to the mismatch between the environment and the character, so we ensured the environment matched the style of the virtual character, therefore we used the highly realistic environment from Marketplace [36] and rearranged the objects in the scene to suit the purpose of the experiment. The high level of realism of the room is created using physically based materials, with stationary photometric lights (using IES profiles for realism), environment maps for reflection, and pre-calculated bounce-light to replicate global illumination effects in real-time (Figure 2, bottom left).

3.0.1 Render Styles. In order to estimate the effect of photorealism, we created two control render styles of both the room and the virtual character, representing the stylized versions. For these controls, we abstracted the render style only, while all other elements, such as geometry and animated content, were kept the same. We attempted to replicate the styles in McDonnell et al. [25], as their study collected subjective responses on the perceived realism of a range of render styles. We were aiming for mid-range and lowest level of render style realism, specifically the “Human Basic” and “Toon Pencil”, respectively. The chosen Toon Pencil style needed to be modified for our task, since there was no shape information present for this style and we predicted this might disturb depth perception in virtual reality, therefore we added shading to this style. We created two styles for our task: a mid-range realistic character in “Simple” style, and the least realistic “Sketch” style (Figure 2). For Simple style, we removed the realistic lighting effects, shadows, and other shaders which created a realistic appearance of the virtual room and the virtual agent. We also removed all the material information (texture map, normal map, material functions, specular level adjusted to value 0) but retained the color appearance of the environment. The least realistic, Sketch style, was created by removing the colour information from the environment also, leaving only the grayscale range. We then used an inbuilt UE4 cel shader plugin to achieve a pencil sketch drawing effect.

3.0.2 Motion Capture Session. For the creation of the animations, one female actor was motion captured while performing a scripted scenario and her motion was retargeted offline onto the virtual character in the UE4 scene. We captured her body motion with a Vicon optical system, consisting of 13 Vantage and 8 MX T40 cameras. A marker-set of 53 markers were attached to the main joints. A Technoprops head-mounted video-based facial capture system was used for simultaneous facial capture, and a Sennheiser wireless microphone was placed near the actor’s mouth to record sound.

The actor was instructed to act out a script while being motion captured. We used scripts for the three scenarios used in the study. The sad scenario was expressing the character’s sadness and remorse over her friend’s accident:

“Oh, hi there... yeah, Caroline said you might be here, watering the plants. I just came back from the hospital visiting her and... she’s in so much pain. It’s horrible. You know, I was driving that night and I know the other driver was drunk but I can’t forgive myself for.. for the accident, am... (silence, sobbing). Anyway, thanks for coming.”

The unfriendly text was expressing the character's discomfort with the user's presence in the room and a slightly threatening attitude:

"Hi... who are you? Are you supposed to be here? Caroline never mentioned anyone having another set of keys to enter her apartment... I'm suppose to water her plants and what are you doing?"

The friendly character was expressing a welcoming attitude to the user's presence:

"Oh hi there! Caroline asked me to come and water the plants, but I see you have that covered so that's great! Yeah, she's away in Ibiza, she is so lucky. I wish I could go! But yeah, thanks for coming!"

She performed the texts several times and the best performance of each text was selected. The script represented three different attitudes the character will express towards the participant, who will observe it in VR. The attitudes created were: friendly, unfriendly and sad. The sad text was written to express a tragic situation, intended to induce the feeling of empathy in the participant. Friendly and unfriendly characters were supposed to create an un/comfortable situation, which would reflect in the participant's proximity comfort and emotional response.

The recorded body motion was exported from Vicon Shogun as fbx and applied to the virtual agent's skeleton. The video of the facial performance was analyzed using Faceware Analyzer and retargeted onto the virtual agent's rig with Faceware Retargeter plugin in Autodesk Maya.

3.0.3 Real-time. This experiment was conducted using the HTC Vive system, for which the tracking area was set to 2×1.5 metres. The equipment consisted of the Vive headset, controllers and headphones.

Spatialized audio was used to place the sound recording at the exact location of the agent's mouth. We also created an idle animation sequence consisting of the small movements in place after the actor finished with her monologue. This part of animation was cut and looped to serve as idle standing motion. The animation state machine started from this idle motion, until the participant's Head Mounted Display (HMD) position indicated that they were looking at her, which would then trigger the performance and when the performance ended, the character went back to idle.

Eye-gaze behavior was also implemented, since the character's eye contact with the user was found to be an important factor for the feeling that the user is in a room with another living entity, i.e., social presence [2], the character's head and eye motion rotated to follow the participant's HMD position. This was achieved by adding layered ease-in ease-out curves on top of the existing animation in the UE4, which changed the rotation of the head bone according to the HMD position in a natural way. The eyes were designed to follow the head rotation with a small delay in order to increase the naturalness of motion. Both rotations were limited to 180 degrees rotation angle and would not move after the participant passed the front of the virtual agent.

4 EXPERIMENT 1

For the present study, our aim is to investigate peoples' responses towards a photorealistic virtual character (realistic style) in an immersive environment of a corresponding render style, and compare to stylized versions (simple, sketch style) of it. We make the following hypotheses:

- **H1: Realistic style will increase place illusion and social presence.** We expect that the current advances in real-time graphics presented in the realistic style will increase people's sense of place illusion and social presence.
- **H2: Realistic style will increase the emotional response of participants in the empathetic scenario.** Based on previous findings [43], we expect participants will be more concerned for the realistic character in the sad scenario.
- **H3: An unfriendly realistically rendered character will increase the feeling of discomfort in people when in close proximity, compared to less realistic styles.** We predict that an unfriendly character will



Fig. 2. Render styles of the character (*top*) and room (*bottom*) used in the experiment: Realistic (*left*), Simple (*middle*) and Sketch (*right*) style.

be more uncomfortable to stand close to [7], and we extend this by predicting a realistic character will intensify this effect.

4.1 Measures

In order to measure the participant's responses, we designed a questionnaire measuring people's emotional response and other observations after being exposed to the character.

4.1.1 Subjective responses in the environment. In the virtual environment, we used a combination of subjective responses: one implicit measure and direct reports. We designed a questionnaire, which was put on a virtual TV in the environment. The questions (apart from the first one) were rated on a 7-point Likert scale, ranging from 1 – *Not at all* to 7 – *Extremely*. Table 1 shows the questions used in the experiment. We first asked if participants felt uncomfortable with the initial position of the character in the room when they first saw her (proximity). We posed the following question: “When I first saw the girl¹ in the room, I felt I was standing too close, I was in her intimate space.” Participants had to answer this question with either “Yes” or “No”.

The next three questions were related to the measures of emotional response – Concerned, Excited, Afraid and Calm. They were chosen to represent all combinations of emotional arousal (high vs. low) and valence (positive vs. negative), with the *Concerned* scale (low arousal and negative valence) taken from the study of Davis et al. [10], *Excited*, which is an emotion of positive valence and high arousal, signaling engagement with the virtual agent, taken from the PANAS questionnaire [38] and a negative emotion of high arousal: *Afraid* taken from the same questionnaire, and lastly *Calm*, taken from CAM battery [16], which is an example of positive emotion of low

¹We used a less formal term “girl” as we determined that it would fit better to her young appearance than more formal descriptors (woman, female, character, etc.)

Table 1. Questions arranged by group and variable name. Each statement could be answered on a scale from 1 – “Not at all” to 7 – “Extremely”.

Group	Variable Name	Statement
Emotional Response	Concerned	<i>“The girl I just observed made me feel concerned.”</i>
	Excited	<i>“The girl I just observed made me feel excited.”</i>
	Afraid	<i>“The girl I just observed made me feel afraid.”</i>
	Calm	<i>“The girl I just observed made me feel calm, at ease.”</i>
Affinity	Appeal	<i>“I found the girl appealing, likable.”</i>
	Eerie	<i>“I found the girl eerie, creepy.”</i>
	Familiar	<i>“I found the girl familiar, I have seen a similar person before.”</i>
Realism	Overall Realism	<i>“I found the girl realistic overall.”</i>
	Appearance Realism	<i>“I found the girl’s appearance realistic.”</i>
	Movement Realism	<i>“I found the girl’s movements realistic.”</i>
	Behavior Realism	<i>“I found the girl’s behavior realistic.”</i>
Place Illusion	Room	<i>“I have the sensation of being in a living room.”</i>
Social Presence	Item 1	<i>“It feels as if I am in the presence of another person in the room with me.”</i>
	Item 2	<i>“It feels as if the girl is watching me and is aware of my presence.”</i>
	Item 3	<i>“The thought that the girl isn’t real crossed my mind often.”</i>
	Item 4	<i>“The girl appears to be alive.”</i>
	Item 5	<i>“The girl is only a computerized image, not a real person.”</i>

arousal. The questions which follow are the Affinity and Realism groups (see Table 1), and are based on measures previously used by McDonnell et al. [25]. The Social presence questionnaire is taken from Bailenson et al. [3]. For Place Illusion, behavioral realism is the most common measure, according to Slater et al. [33]. However, due to the space limitations for our experiment, we could not measure behavioral responses. Therefore, we created a custom question, which asked the participant about being in the “living room”, relating to place illusion as presence, or “being there” in a virtual space [32].

4.2 Participants and Procedure

Participants were visitors to the Science Gallery exhibition and were introduced to the experiment by the gallery mediators, trained to give instructions for the task.

First, participants agreed to the statements of the electronic consent form and filled out a demographic questionnaire, where they were asked about their gaming experience, experience with CG characters, their native language, gender and age.

When finished, they were led to the VR booth, where they were given the HMD with headphones and a motion controller. They were instructed to stay in the blue circle, which appeared on the virtual floor due to space restrictions, and they were informed that they are allowed to receive help from the experimenter if they get stuck at any point with completing the tasks in the environment but that this support should be avoided, if possible. When they put on the HMD, they found themselves in a virtual living room where they were able to see a virtual television, instructing them about the task. They were told to listen to the character, and after, complete questions about it on a virtual questionnaire. Then, two examples of test questions appeared on the

television and the participants needed to use the controller to drag the slider on the scale. After these questions, the experiment started and they were transported into a bigger room with a character.

The participant was initially placed slightly to the side of the character, and the character started to speak only when the participant directed his gaze towards it. The character was expressing either a friendly, unfriendly, or sad response. When finished, the controller in the participant's hand vibrated which prompted the participant to look at it and see one of the buttons lighting up. When pressed, the virtual TV on the wall turned on, and the participant was asked to answer the questions about proximity comfort, character's traits, their own emotional response, perceived realism, affinity towards the character and their feeling of being present in space and with the character. After the last question was answered, the experiment self-terminated.

4.3 Analysis

Approximately 900 volunteers participated in the experiment. We first reviewed the data for possible exclusion. We had two major exclusion criteria: under 18 years of age and missing answers. Some participants mistakenly consented that they were 18 years old or older, but reported to be younger in the demographics questionnaire. Following data protection policy, such data was immediately deleted and excluded from analysis. The other exclusion criteria was missing answers - if the participant had equal or less than 50% of the questions answered, his or her data were not included in the analysis.

We further excluded data of some participants who had less than 50% missing answers as well, to get approximately equal N for each scenario-render style combination we were investigating ².

Following this procedure, we included responses of 622 participants in the final analysis, which was approximately 70 participants (SD: 5.3) for each scenario/render style combination. Participants were aged from 18-71 (average age = 26.6), of which 294 were male, and 328 were female. 62% were native speakers. 47% had no previous experience with CG characters and 32% did not report playing computer games. 6% of people reported to have expert knowledge on CG characters (are creating them), and a small percentage (14%) of people reported being passionate gamers.

5 RESULTS

To explore the most robust effects of render style (*Realistic, Simple, Sketch*) and scenario (*Sad, Friendly, Unfriendly*) on people's subjective responses, we analyzed the subjective scales separately. The measured scales were: Proximity, Concerned, Excited, Afraid, Comfortable, Appeal, Eerie, Familiar, Overall Realism, Movement realism, Appearance Realism, Social Presence and Place Illusion. We also analyzed possible effects of demographics (Familiarity with CG characters, Gaming Experience, Native speaker). We included gender in the main analysis for all scales.

Since the described scales (excluding Social Presence) are on an ordinal level, we analyzed the possible effects and interactions between the dependent variables and the grouping factors gender, scenario and render style by using a regression model based on the Wald statistics. The Wald test estimates to what extent the parameters (independent variables) predict the model of a dependent variable, and can be used on non-continuous data as well as asymmetric distributions, and can in addition give information about interactions between multiple factors. Since we used a Likert scale with 7 points, we predicted a multinomial ordinal distribution and a probit link function.

The 5 measured items of the Social Presence scale were tested for reliability (Cronbach's alpha: $\alpha = 0.81$) and due to sufficient correlation, we used a cumulative score of all 5 items as the final result and treated it as a continuous scale, as is custom. We analyzed the results by using ANOVA with between-subject factor scenario,

²Every participant was randomly assigned to view only one emotional scenario and one render style, and because of this, we did not get equal numbers of participants in each group.

render style and gender. We checked for homogeneity of variance, using Levene’s test and used Tukey’s HSD test for the post-hoc tests.

We display the detailed statistics, showing all significant effects in Table 2, and only discuss relevant results in the text. For all figures, we used stacked bars where the size of individual colors of the bar represent the percentages of answers on the individual scores of the Likert scale.

5.1 Realism Estimation

Unexpectedly, we found that participants’ ratings of realism did not vary between-groups, according to the rendering style the way it was reported by McDonnell et al. [25], as we did not get any effects of render style on Appearance Realism ratings.

Another unexpected finding was that Movement Realism appeared to be higher on the Sketch style compared to the Realistic style (see Figure 3). Scenario also affected Movement Realism ratings, where Sad was rated to have the highest Movement Realism, followed by Friendly and finally Unfriendly. The perceived Behavior Realism of the character was rated depending on the scenario, where participants rated that the character in the Sad scenario had the most realistic behavior, especially when compared to the Unfriendly scenario (see Figure 3).

There was also an effect of gender, where males were estimating Appearance and Overall Realism significantly higher than females in general (see Figure 3).

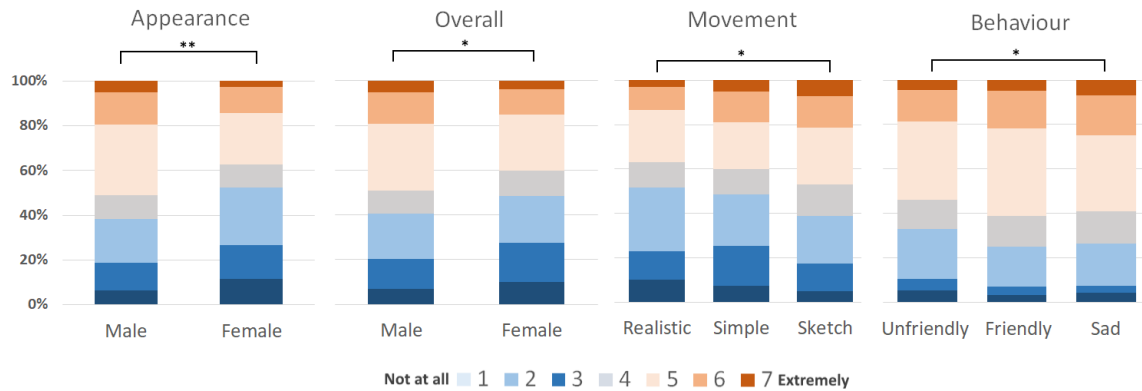


Fig. 3. Main effect of gender (*first two graphs*) and render style (*last two graphs*) on perceived realism. Star labeled lines point to significantly different medians according to the χ^2 test (* = $p < 0.05$, ** = $p < 0.001$). The % on the y-axis signify the percentages of an answer for each rating (1-7) on the Likert scale.

5.2 Place Illusion

As expected in **H1**, we found a significant effect of render style on Place Illusion, where the Realistic style was creating the highest illusion of being in an actual real space compared to both Sketch and Simple, but the Sketch created slightly higher ratings than Simple, even though we created the Sketch style to be further away from realism. The illusion was overall rated as high (more than half of the ratings from the participants were “6” and “7” on the 7-point Likert scale, see Figure 4).

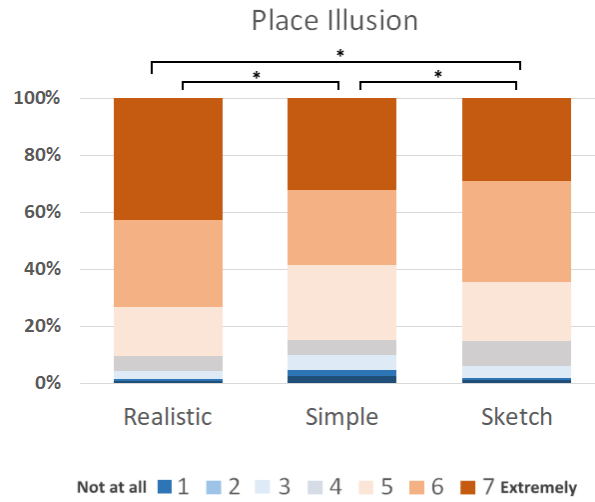


Fig. 4. Main effect of render style on Place Illusion.

5.3 Social Presence

Even though we predicted an effect of render style on Social Presence (**H1**), we found no main effects or interactions between render style or scenario on this dependent variable. The average result on this variable was $\bar{x} = 19.8$, ($SD : 5.04$), showing that Social Presence was not rated particularly high or low (highest rating is 35).

5.4 Emotional Response

As expected, the scenario had an effect on people's emotional response. Participants felt higher Concern for Sad, then Unfriendly and the least for Friendly (see Figure 5, top left graph). The character in the Friendly scenario received higher ratings for Excited than Sad, and Unfriendly was least exciting to observe. However, lower range ratings indicate that participants did not feel particularly excited by any scenario (see Figure 5, top right graph). Also, no scenario caused participants to report higher ratings on Afraid, while Friendly scenario received more ratings on Calm than Unfriendly or Sad scenario (see Figure 5, bottom graphs).

We predicted that an interaction between render style and scenario will exist (**H2**), where the Realistic style will increase the level of Concern. This was not the case, as participants reported more concern for the Sketch compared to Realistic style in the Sad scenario. The Realistic style did raise more concern than the other two styles in the Friendly scenario (Figure 6).

Some other interactions between scenario and render style were found as well: the character rendered in Sketch style made participants feel more Calm than the Realistic one in the Friendly scenario. Participants were also more excited for the Realistic render style compared to Sketch style. And there was also a main effect of gender on emotional responses, where male participants gave higher ratings for Calm, females gave higher ratings than males for Afraid and felt less Excited and more Concern for the character than males.

5.5 Proximity Analysis

We did not find an expected interaction between render style and scenario, where the Realistic style would increase discomfort in the Unfriendly scenario (**H3**). We did find that participants felt more comfortable standing

closer to a Sad character than Unfriendly or Friendly and females were less comfortable standing near the character than males (see Figure 7).

5.6 Affinity

To exclude a possible uncanny valley effect on the emotional response of participants, we investigated the questions of Affinity. We did not find any effects of render style or interactions between render style and scenario, which shows that the way the character was rendered did not have a considerable effect on the ratings of appeal.

We found a main effect of scenario on Appeal and Familiarity. For Appeal, the Friendly scenario was rated as more likeable than both Unfriendly and Sad. Familiarity was higher for the Friendly scenario as well but only when compared to Unfriendly.

Both Appeal and Familiarity were also affected by gender, where females gave lower scores on both scales, and also rated the character more Eerie than males in all scenario/style combinations. There was also an interaction between gender and render style for Appeal, where it was revealed that males gave significantly higher scores

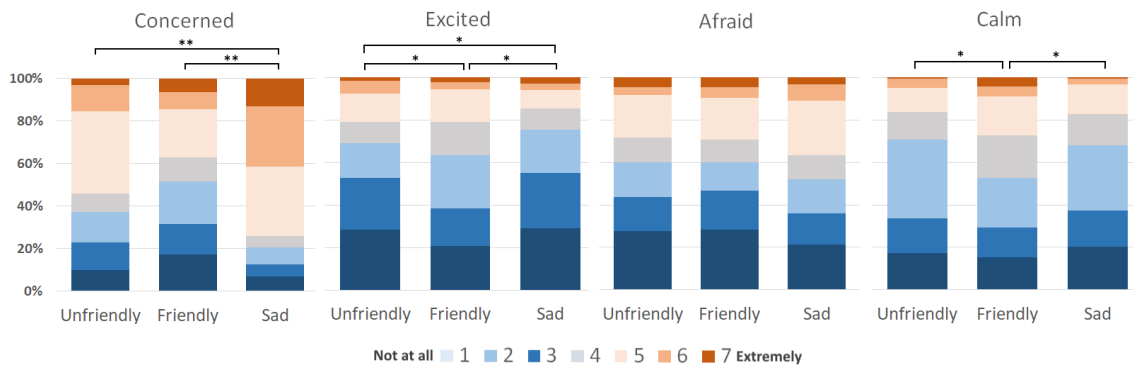


Fig. 5. Main effects of scenario on emotional responses Concerned, Excited, Afraid and Calm.

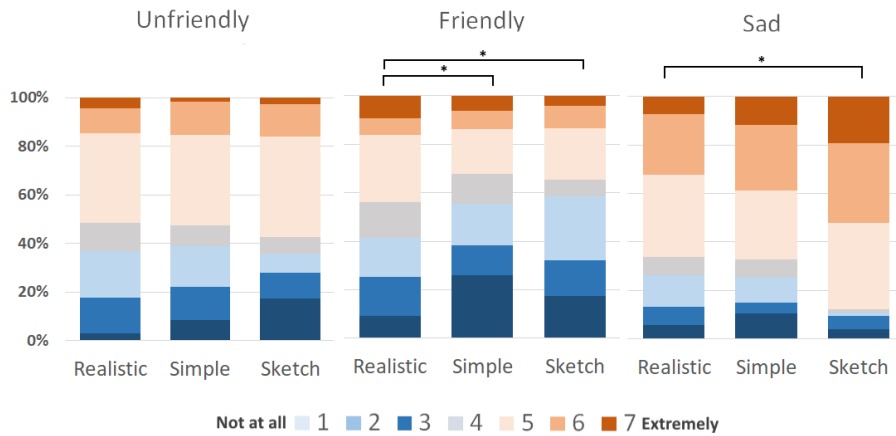


Fig. 6. Interaction between render style and scenario on the variable Concerned.

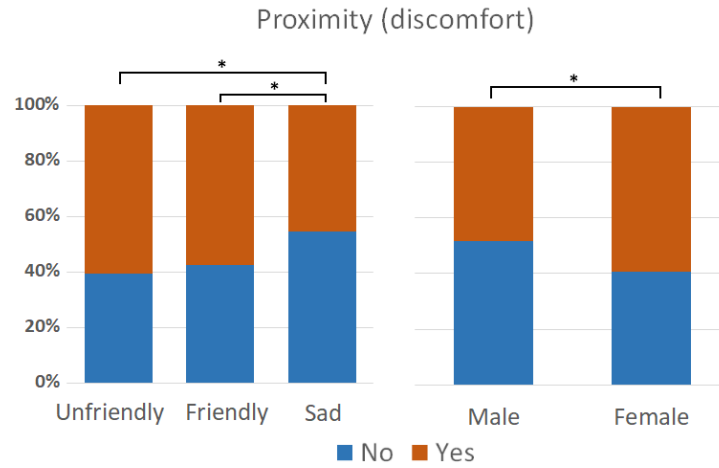


Fig. 7. Main effects of scenario (left graph) and gender (right graph) on Proximity.

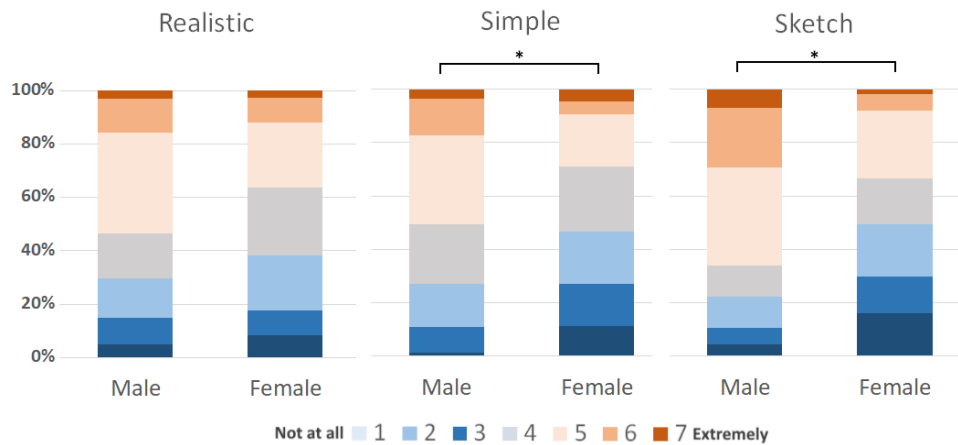


Fig. 8. Interaction between gender and render style on Appeal.

for the Sketch and Simple character compared to females. For the interaction between gender and render style on Appeal, see Figure 8).

6 ADDITIONAL EXPERIMENT: REALISM AND AFFINITY

In our previous experiment, participants’ ratings did not vary according to the render style. Since this was unexpected, we reformulated the question to be more specific on the term “appearance realism” by adding: “compared to a real photo/video of a person” (Table 3). We expected higher ratings for the photorealistic character compared to the stylized ones.

Additionally, we found some gender effects in the results of the previous experiment. We speculate that the lower affinity ratings of female participants (see Section 5.6) could have been related to the chosen character model, since it is a typical stereotypical game-industry female character, designed to be extremely visually

Table 2. Summary of all main effects and interactions with corresponding post-hoc analysis for Experiment 1.

Realism		
Effect	Wald Test	Post-hoc
APPEARANCE: Gender	$\chi^2 = 12.78, df = 1, p < 0.0004$	Males estimate higher than females.
OVERALL: Gender	$\chi^2 = 5.14, df = 1, p < 0.023$	Males estimate higher than females.
MOVEMENT: Scenario	$\chi^2 = 10.02, df = 2, p < 0.007$	Sad was rated to have the most realistic movement, followed by Friendly and last by Unfriendly ($p < 0.05$, for all)
MOVEMENT: Render Style	$\chi^2 = 5.09, df = 2, p < 0.024$	Movement more realistic on the Sketch style, compared to Realistic style.
MOVEMENT: Style*Gender	$\chi^2 = 6.20, df = 2, p < 0.013$	Male participants gave higher ratings of Movement Realism for the Sketch style than females.
BEHAVIOUR: Scenario	$\chi^2 = 9.65.2, df = 2, p < 0.008$	Sad scenario more realistic than Unfriendly ($p < 0.003$).
Emotional Response		
CONCERN: Scenario	$\chi^2 = 44.36, df = 2, p < 0.0001$	Higher concern for Sad, then Unfriendly and the least for Friendly ($p < 0.0001$, for all).
CONCERN: Gender	$\chi^2 = 4.62, df = 1, p < 0.031$	Females more concern than males.
CONCERN: Scenario*Render Style	$\chi^2 = 10.35, df = 4, p < 0.04$	Sketch style more concern than Realistic in Sad ($p < 0.02$). Realistic style more concern than the other two styles for the Friendly scenario ($p < 0.04$).
EXCITED: Scenario	$\chi^2 = 9.34, df = 2, p < 0.009$	Friendly higher ratings than Sad, and Unfriendly least exciting to observe ($p < 0.03$, for all).
EXCITED: Render Style	$\chi^2 = 13.05, df = 2, p < 0.002$	Realistic style rated higher compared to Sketch style ($p < 0.0007$).
EXCITED: Gender	$\chi^2 = 73.32, df = 1, p < 0.0001$	Females less excited than males.
AFRAID: Gender	$\chi^2 = 34.94, df = 1, p < 0.0001$	Females higher ratings than males.
CALM: Scenario	$\chi^2 = 12.33, df = 2, p < 0.002$	Friendly received more ratings on Calm than Unfriendly or Sad ($p < 0.0009$).
CALM: Gender	$\chi^2 = 22.97, df = 1, p < 0.0001$	Male participants gave higher ratings for Calm than females.
CALM: Scenario*Render Style	$\chi^2 = 12.69, df = 4, p < 0.013$	Sketch style more calm than the Realistic in the Friendly scenario ($p < 0.03$).
Place Illusion		
Render Style	$\chi^2 = 10.61, df = 2, p < 0.005$	Realistic style higher than Sketch and Simple ($p < 0.002$, for both). Sketch created higher ratings than Simple ($p < 0.05$).
Social Presence		
NO EFFECTS		
Proximity		
Gender	$\chi^2 = 7.61, df = 1, p < 0.006$	Females less comfortable than males ($p < 0.006$).
Scenario	$\chi^2 = 10.15, df = 2, p < 0.006$	More comfortable with Sad than Unfriendly or Friendly character ($p < 0.002$).
Affinity		
APPEAL: Scenario	$\chi^2 = 7.89, df = 2, p < 0.02$	Friendly scenario rated more likeable than both Unfriendly and Sad ($p < 0.006$).
APPEAL: Gender	$\chi^2 = 43.15, df = 1, p < 0.0001$	Females lower scores than males.
APPEAL: Gender*Render Style	$\chi^2 = 8.66, df = 2, p < 0.02$	Males higher scores for the Sketch and Simple character compared to females ($p < 0.0001$).
FAMILIAR: Scenario	$\chi^2 = 10.15, df = 2, p < 0.006$	Higher for the Friendly scenario as well but only when compared to Unfriendly ($p < 0.02$).
FAMILIAR: Gender	$\chi^2 = 9.42, df = 1, p < 0.003$	Females lower scores than males.
EERIE: Gender	$\chi^2 = 13.92, df = 1, p < 0.0002$	Higher ratings than males.

Table 3. Changes to the “Appeal” and “Appearance Realism” questions.

	Likability	<i>“I found the girl likable.”</i>
Affinity	Visual Appeal	<i>“I found the girl visually appealing.”</i>
Realism	Appearance Realism	<i>“I found the girl’s appearance realistic, compared to a real photo/video of a person.”</i>

appealing, especially to males. We therefore separated the appeal scale to “Visual Appeal” and “Likability” (see Table 3).

We repeated the experiment with three render styles but chose just one scenario (Sad), since the changes should mainly be related to render style and not scenario.

6.1 Participants

For this experiment, following the same exclusion criteria as described in Section 4.3, we collected responses of 175 people, aged from 18 - 76 (average age: 27.8, SD: 10.2), 93 females and 82 males. 70% of participants were native speakers, 41% had no previous experience with CG characters and 22% of participants reported they do not play video games. A small percentage 4% reported they work with CG characters and 17% were passionate gamers. The experiment procedure was exactly the same as described in Experiment 1.

7 RESULTS

We conducted the same analysis as in Experiment 1. We expected changes to the responses based on the changes to the questions for Appeal and Appearance Realism. We display the detailed statistics showing all significant effects in Table 4.

7.1 Realism Estimation

We expected that the revised question of Appearance Realism will result in a significant effect of render style on this scale. This was the case, since a significant main effect of Appearance Realism was found, indicating that participants could identify differences in realism levels of the styles (Figure 9, *left* graph), with the difference between Realistic and Sketch being significant. However, an interaction between gender and Appearance Realism showed males were more ‘accurate’ at estimating the level of visual realism than females - females were giving significantly lower scores on Appearance Realism for Realistic style compared to males and gave higher scores than males for the Simple style.

7.2 Affinity

We speculated that gender effects on Affinity in Experiment 1 might be related to visual appeal of the character. By investigating Visual Appeal and Likability separately in this experiment, we found Likability was rated higher again by males than females, but we found no effect of gender in Visual Appeal, therefore preference for the character by male participants was not determined by the model’s appearance. It was however related to render style: the Realistic character was perceived as more visually appealing, however, only when compared to the Sketch character (Figure 9, *right* graph).

8 GENERAL DISCUSSION

In this study, we investigated the effect of render style realism on the perception of a character, expressing different types of emotions. We anticipated that higher realism will raise the levels of social presence and place

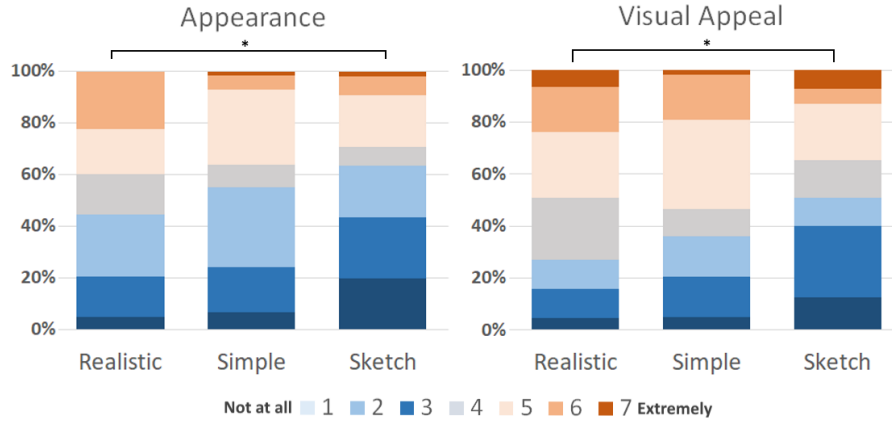


Fig. 9. Main effects of (left) render style on Appearance Realism and (right) Visual Appeal in the Additional experiment.

Table 4. Summary of main effects and interactions with corresponding post-hoc analysis for the Additional experiment.

Realism		
Effect	Wald Test	Post-hoc
APPEARANCE: Render style	$\chi^2 = 6.96, df = 2, p < 0.03$	Significant difference between Realistic and Sketch ($p < 0.03$).
APPEARANCE: Gender*Render style	$\chi^2 = 8.54, df = 2, p < 0.014$	Females lower scores for Realistic style compared to males and gave higher scores than males for the Simple style ($p < 0.02$, for both).
OVERALL: Gender*Render style	$\chi^2 = 5.03, df = 1, p < 0.025$	Females give lower ratings than males ($p < 0.025$), particularly for the Realistic render style ($p < 0.008$).
Affinity		
LIKABILITY: Gender	$\chi^2 = 6.15, df = 1, p < 0.02$	Rated lower by females than males.
VISUAL APPEAL: Render style	$\chi^2 = 7.46, df = 2, p < 0.03$	Realistic character was perceived as more visually appealing compared to the Sketch character ($p < 0.05$).
EERIE: Render style	$\chi^2 = 7.32, df = 2, p < 0.03$	No significant differences between individual render styles.

illusion (**H1**), change emotional response (**H2**) and also increase the proximity discomfort, particularly with the unfriendly character (**H3**), compared to other styles.

H1: We found that photorealism increased place illusion. This result indicated that place illusion could be directly related to render quality, which is an important result, since this was not found in previous studies and visual realism was usually ignored or deliberately reduced in order to increase the computational power for rendering immersive environments. It must be noted that for all the styles in this study a remarkably high place illusion was reported (mainly ratings of 6 and 7), even for the sketch style. The differences are therefore quite small. Further research would be needed to investigate if the illusion causes differences in participant behaviors (e.g., heart rate), as indicated by Slater [33].

Social presence was not affected by render style, as we expected. This confirms reports that appearance does not play as important role as interaction with the character [15, 34]. Our results showed, that the reported

social presence was in the mid-range on average, which means the character still exhibited a sufficient level of interactive behavior. Compared to a study of Zibrek et al [43], where social presence was lower than mid-range of the scale, we estimate that the added eye-gaze in our study might have increased the feeling of presence with the character, as proposed by Bailenson et al. [3].

H2: We did not find that concern was higher for the realistic style in the sad scenario, as expected based on the findings of Zibrek et al. [43]. In fact, the concern was higher for the sketch character. In addition, in the friendly scenario, people felt more concern for the realistic style compared to both other styles. This is an interesting finding, similar to the evidence presented in Volante et al. [37], where the emotions did not match the situation - more negative emotions in a neutral stage of the scenario and less in the negative stage of the scenario for the realistic style compared to the stylized versions. The explanation the authors gave could help in explaining our results as well, that due to texture details of the character's face, more subtle emotions could be perceived, making the participant's own emotional response more complex. A study by Hyde et al. [17] also suggested that a change in expression is more noticed on a realistic render style. However, these studies found the benefits of non-photorealistic rendering (NPR) techniques, where important information is actually better portrayed with NPR than realistic rendering [11]. Our results also showed more appropriate reactions to our stylized characters (lowest concern for friendly and highest for sad). We believe that the higher level of detail in photorealism increases the amount of information the viewer perceives, which could make it possible to recognize certain subtle expressions as well as obscure others.

Emotional responses we collected show us also that, in general, our scenarios were constructed properly, since the friendly scenario was at the same time more calming and more exciting than the other scenarios, and the character was also more likable and familiar in this scenario. The sad scenario made participants more concerned for the character. However, an unfriendly character did not make participants more afraid, which shows that this particular scenario was not seen as threatening.

H3: We predicted proximity comfort will be affected by style and scenario, however, it was only affected by scenario: participants did not feel as uncomfortable with the sad character as with the other scenarios. Emotion was found to have an effect on proximity as reported by Bonsch et al. [7], however, in our study we did not find that the unfriendly character was the most uncomfortable to be close to - but this character was also not found particularly threatening, as already mentioned. In addition, female participants were more uncomfortable with the characters in general. An effect of participant's gender on proximity was reported by Bailenson et al. [3], where females kept greater distance towards avatars, but not agents (for males there was no difference).

Another interesting finding was related to the way we measured proximity. By placing the participant in close proximity to the character and measuring how they felt with that initial position, we were able to measure the proximity comfort even with a limited room space. Another result which was obtained this way was the finding that people felt less discomfort when observing the sad character, which they perceived less threatening. Since they were also most concerned for this character, it could mean that close proximity could be a measure of empathy.

Additional to the proposed hypotheses, there were other findings as well. With the revised question for appearance realism, people rated the levels of render style realism as we initially intended: photorealism as the most, simple less and sketch the least realistic. The perceived difference between realistic and simple was small, even though we intended the realistic character to have a level of realism which was notably higher than the simplified version of it. The result could be attributed to many possible reasons, such is our experiment design (between-group), where participants have no other example of a character to compare it to; previous knowledge and experience with characters, since most participants indicated that they do not have much experience with virtual characters. In addition, our changes to the character's appearance did not include alterations to the shape (geometry) of the character, while it was previously found that shape is the main predictor of realism [41]. The

removal of texture and normal maps, as well as material functions might not have been enough to create an obviously less realistic style to our realistic one.

While the same animation was used for all styles, the movement was perceived more realistic on a sketch character. This result is similar to the result reported by Chaminade et al. [9], where the biological motion of characters, rendered in different level of detail, was easier to recognize when their appearance was less detailed. Perhaps due to the simplicity of our sketch character, the movement appeared more natural as well. Another possibility is that the higher quality rendering raises the bar of expectations for facial animation fidelity. We also did not expect any differences in the perceived behavioral realism between emotional scenarios, however, the sad character had a more believable behavior. This could be due to the particularities of the scripted story or the actor's performance.

Some effects of participant's gender were found as well, where females felt more concern and fear for the character, but also less excitement than male participants. As females are generally more empathetic than males [19], this could explain their higher reported concern. We were not able to determine why they also felt less excited and liked the realistic character less than males, even though they found it equally visually appealing as males.

We also found a confirmation for previous findings, that realism is not necessarily unappealing for the design of virtual characters [8, 25], and is particularly appealing in virtual reality [42, 43]. This finding shows that higher render quality could be more fascinating and motivating to explore, an outcome worth considering when deciding which render quality of the virtual reality experience to use.

9 LIMITATIONS AND FUTURE WORK

The use of only one stereotypical game-industry female model could be the reason for the reported gender differences in responses in our study, in particular that female participants liked the realistic character less than males. Interesting to note is that previous work by Zibrek et al. [43] showed no such gender effects with a casually-dressed male model. Future work should investigate a more variances in appearance of both male and female models.

Another limitation of our study was that the current state-of-the-art technology in VR is not advanced enough to create a near-perfect illusion of a real place or a character which would be mistaken for an actual person. Specifically, the render quality was limited by the HMD display resolution and there were limitations in the number of blendshapes for facial animation of our character, which is the current industry standard for an AAA-game character design. Additionally, since we did not have access to the actor, whose scans were used to build the virtual model, we could not make a comparison with a real human. Because of this, we cannot evaluate our result that photorealistic character's intentions were interpreted differently to what we expected, while reactions to the stylized characters were more appropriate (higher concern for sad, etc.). Without comparing to a real human portraying the same scenario, it is not possible to determine which reactions were more 'correct'. Advances in rendering, animation, volumetric capture, and augmented reality will allow for these comparisons in the future. The effect of photorealism found in our study should therefore be understood in the context of the technological limitations, as preliminary results which give an indication of how realism could affect future communication with avatars or agents in VR.

As the experiment took place in an environment that was difficult to fully control, it is possible that participants got distracted during the experiment, or were interrupted. However, we are still confident that collecting results from a relatively high number of participants, coming from various demographic backgrounds, is an indication of a sufficient generalizability of our results from the sample to the population. We also made sure to include indirect measures of assessment (proximity comfort) as subjective responses are known to be less reliable [40].

For future work, under a more controlled lab environment, we believe that additional behavioral responses could provide more insights into the observed effects.

Previous work has shown that a mismatch of realism in the voice of the character and its appearance produced an uncanny valley effect [26]. Therefore, it would be interesting to evaluate the character's voice in future studies to determine the effect, particularly of synthesized voices which are commonly used for virtual assistants. Also, we would like to include a virtual self-representation of the user in the interactive scene with the character and evaluate the effect of realism as well, since studies have shown realistic self-representation increases social presence and one's own body ownership [5, 18, 20, 23].

10 CONCLUSION

We conclude that photorealism is an important factor in interactive emotional scenarios. Our main findings are: photorealism changes the perceived interpretation of the character's intent; it also increases the feeling of being present in an actual space and is considered more visually appealing. Support was found for the use of stylized characters as well, since animation is perceived to be more realistic on a less detailed character, and emotional responses are more likely to match the intended emotions of the interactive scenario. Our results have important implications for the design of interactive expressive virtual characters.

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