



# The Effect of Virtual Human Rendering Style on User Perceptions of Visual Cues

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**Introduction:** Virtual humans have expanded the training opportunities available to healthcare learners. Particularly, virtual humans have allowed simulation to display visual cues that were not previously possible in other forms of healthcare training. However, the effect of virtual human fidelity on the perception of visual cues is unclear. Therefore, we explore the effect of virtual human rendering style on the perceptions of visual cues in a healthcare context.

**Methods:** To explore the effect of rendering style on visual cues, we created a virtual human interface that allows users to interact with virtual humans that feature different rendering styles. We performed a mixed design user study that had undergraduate healthcare students (n = 107) interact with a virtual patient. The interaction featured a patient experiencing an allergic reaction and required trainees to identify visual cues (patient symptoms). The rendering styles explored include a 3D modeled virtual human and an AI generated photorealistic virtual human. Visual cues were applied using a Snapchat Lens.

**Results:** When users are given a frame of reference (users could directly compare symptoms on both rendering styles), they rated the realism and severity of the photorealistic virtual human's symptoms significantly higher than the realism of the 3D virtual human's symptoms. However, we were unable to find significant differences in symptom realism and severity ratings when users were not given a frame of reference (users only interacted with one style of virtual humans). Additionally, we were unable to find significant differences in user interpersonal communication behaviors between the 3D and photorealistic rendering styles.

**Conclusion:** Our findings suggest 1) higher fidelity rendering styles may be preferred if the learning objectives of a simulation require observing subtle visual cues on virtual humans and 2) the realism of virtual human rendering style does not necessarily affect participants' interpersonal communication behaviors (time spent, questions asked).

**Keywords:** virtual human, rendering style, visual cue, augmented reality, photorealistic, conversational agent

## 1 INTRODUCTION

Virtual humans are an important aspect of virtual reality. Virtual humans are often utilized in virtual reality applications as either a user's avatar or as characters a user can interact with Fox et al. (2015). Virtual humans have been used in educational virtual environments to train the observational and critical thinking skills of target populations such as those in the military, construction, and healthcare fields (Cendan and Lok, 2012; Hays et al., 2012; White et al., 2015; Eiris et al., 2021). It is critical that when training these populations we provide training observations with levels of fidelity that create appropriate perceptions of realism (Watts et al., 2021). Otherwise, training may be ineffective or even counterproductive (Watts et al., 2021).

Visual cue identification is essential for many forms of training ranging from symptom identification to aviation (Pausch et al., 1992; Huber and Epp, 2021). Cues deliver information to observers by providing some form of verbal or written messaging, or by providing visual artifacts to observers (Xu and Liao, 2020). For example, Kotranza et al. used visual cues such as a sagging face and drifting eyes to help train users to identify cranial nerve symptoms (Kotranza et al., 2010). Observers apply critical thinking to interpret the information provided by cues (Xu and Liao, 2020). Cues can lead to observers applying heuristics that affect decision making (Sundar, 2008). Therefore, understanding how virtual human rendering style may affect user perceptions of visual cues on virtual humans is critical to training appropriate decision making in virtual human simulation (Sundar, 2008; Vilaro et al., 2020).

When exploring virtual human rendering styles, previous research has focused on how realism impacts user perception of virtual humans. This study explores how rendering style fidelity affects the perceived realism and severity of visual cues that will appear on a virtual human in a healthcare context. We also report how rendering style fidelity affects participant interpersonal communication behaviors such as the time spent interacting with a patient and the number of questions they ask. Our approach to examining the effect of virtual human rendering style on visual cues involves using allergic reaction symptoms as visual cues that learners must identify in healthcare training.

To continue building on this previous work, we address the following research questions:

- RQ 1) How does virtual human rendering style affect user perceptions of visual cues on a virtual human?
- RQ 2) How does virtual human rendering style affect interpersonal communication behaviors?

To answer these research questions, we created a virtual human interface that allows users to interact with virtual humans of different rendering styles. We performed a mixed design user study that had undergraduate healthcare students ( $n = 107$ ) interview a virtual patient. During the patient interview, the virtual patient developed an allergic reaction to the blood transfusion they were receiving. The rendering styles explored include a 3D modeled virtual human and a photorealistic virtual human.

Our findings suggest that higher fidelity rendering styles may be preferred if the learning objectives of a simulation require observing subtle visual cues on virtual humans. We also found that the realism of virtual human rendering style does not necessarily affect participants' interpersonal communication behaviors (time spent, questions asked). This work contributes to the field of virtual human design, by reflecting on the role of fidelity in simulations intended to train the identification of visual cue.

## 2 RELATED WORK

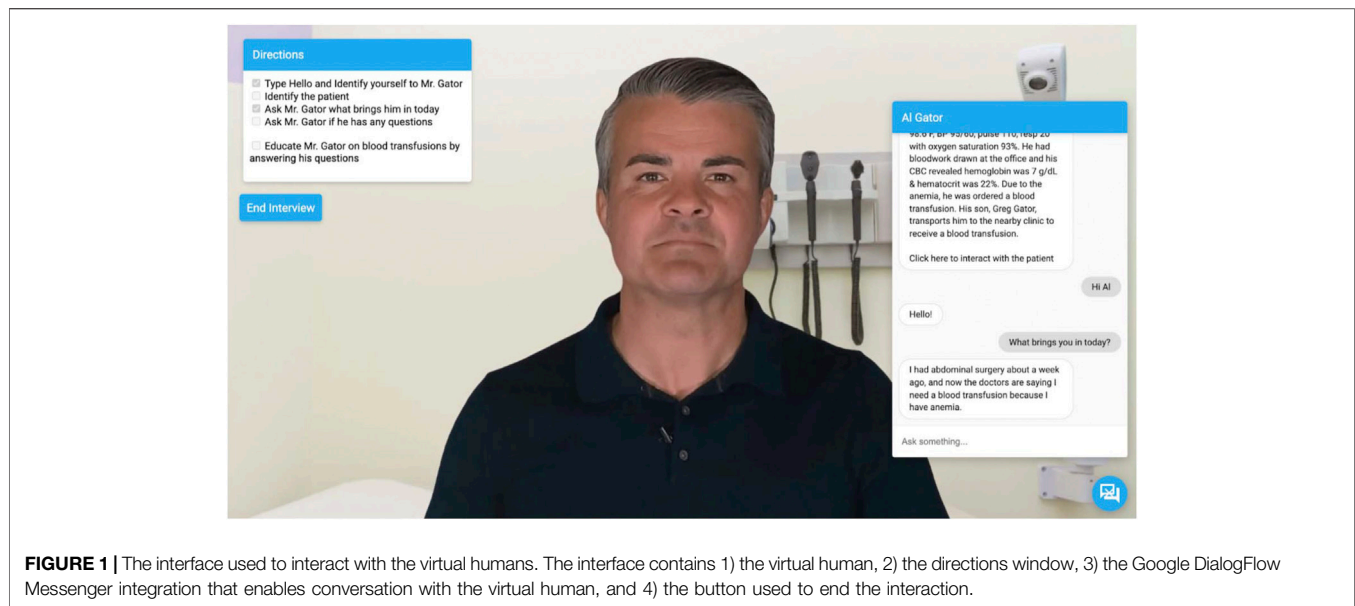
In this section, we discuss how previous advances in virtual human technology have expanded training possibilities, and previous findings on the impact of virtual human rendering style's on user perceptions of a virtual human.

### 2.1 Virtual Human's Expanding Cue Training Possibilities

Virtual humans offer training opportunities that were not previously possible for other forms of healthcare training. These new training opportunities include the depiction of visual cues (e.g., symptoms and other physiological changes) that real actors used for patient interviews (standardized patients) cannot display (Kotranza and Lok, 2008; Deladisma et al., 2009; Kotranza et al., 2009; Kotranza et al., 2010; Cordar et al., 2017; Daher et al., 2018; Daher et al., 2020).

The work of (Deladisma et al., 2009; Kotranza et al., 2010), Cordar et al. (2017), and (Daher et al., 2018; Daher et al., 2020), are examples of how virtual humans offer training opportunities that were not previously possible for other forms of healthcare training. Kotranza used virtual humans to display cranial nerve symptoms. Cranial nerve symptoms (e.g. sagging face, drifting eyes, etc.) are not symptoms that actors can perform in healthcare training interviews (Kotranza et al., 2010). Kotranza and Deladisma et al. used a virtual human, virtual reality, and a physical breast mannequin to allow medical students to practice interactive clinical breast examinations in a mixed reality setting (Kotranza and Lok, 2008; Deladisma et al., 2009). Prior to the use of virtual humans, healthcare learners did not have opportunities to practice handling breast complaints in an interactive training simulation. Cordar used virtual humans to provide team training opportunities using only virtual humans. Prior to this, team training would require the presence of multiple individuals to take place (Cordar et al., 2017). Daher et al. created the Physical-Virtual Patient Bed that uses a virtual human and a mannequin to provide interactive experiences that exhibit physical symptoms (e.g. changes to temperature, changes to skin appearance, etc.) that are not possible for actors to recreate in a healthcare training interview (Daher et al., 2018; Daher et al., 2020).

Unfortunately, these advantages have only been applicable to virtual humans and it is unclear how a virtual human's rendering style may affect the perception of visual cues that virtual humans display (Lok, 2006; Kotranza and Lok, 2008; Deladisma et al., 2009; Kotranza et al., 2009; Daher et al., 2018; Daher et al., 2020).



**FIGURE 1** | The interface used to interact with the virtual humans. The interface contains 1) the virtual human, 2) the directions window, 3) the Google DialogFlow Messenger integration that enables conversation with the virtual human, and 4) the button used to end the interaction.

By exploring the perceived realism and severity of visual cues on virtual humans of different rendering styles, we hope to continue to expand and improve the training possibilities that virtual humans provide.

## 2.2 Virtual Human Rendering Style Effects on User Perceptions

This study, which investigates how virtual human rendering style affects user perceptions of virtual human and virtual symptoms, is the first step towards understanding if these symptoms can be applied towards standardized patients. Currently, commercial virtual human healthcare training does not use photorealistic rendering styles (Kognito, 2022; Shadow Health, 2022). It is unclear how the rendering style of the virtual human affects user perceptions of realism and severity of physiological changes that occur in virtual humans during virtual human healthcare training. Previous works have explored how virtual human rendering style may affect user perceptions of a virtual human (McDonnell et al., 2012; Zibrek and McDonnell, 2014; Zell et al., 2015; Zibrek et al., 2019). However, these works often do not occur in applied settings. Instead, they use still images or short videos of virtual humans to determine if virtual human rendering style affects factors such as perceived agreeableness, friendliness, and trustworthiness (McDonnell et al., 2012; Zell et al., 2015).

For example, McDonnell et al. developed a virtual human with various rendering styles (McDonnell et al., 2012). McDonnell then had participants view still images and short videos of the differently rendered virtual humans. McDonnell found that cartoon style virtual humans were seen as more appealing and friendly than more realistic virtual humans. Using a similar methodology to McDonnell, Zell et al. found that the facial shape used in rendering styles affects perceptions of realism and expression intensity, that the materials used in rendering style affects the appeal of virtual humans, and that rendering style

realism may be a poor predictor of user ratings of appeal, eeriness, and attractiveness (Zell et al., 2015).

Unlike McDonnell and Zell, Volonte et al. used a more applied approach when exploring the effects of rendering style. Volonte et al. investigated the effect of virtual human fidelity on interpersonal communication behaviors in a healthcare context in two previous works (Volonte et al., 2016, 2019). In the first work, Volonte had participants interact with a virtual human created using either a realistic, cartoon, or sketch-like rendering style. Volonte was unable to find significant differences between conditions for either time spent interacting with the virtual patient or the number of questions asked (Volonte et al., 2016). In the second work, Volonte again had participants interact with a virtual human created using either a realistic, cartoon, or sketch-like rendering style. However, in this work Volonte also manipulated the rendering style of the environment separately from the virtual human as well. Volonte found that the number of questions asked was significantly higher for the higher fidelity rendering of the virtual human and higher fidelity rendering of the environment (Volonte et al., 2019)). Further work is needed to determine if virtual human rendering style affects aspects in more applied settings such as interpersonal communication and the appearance of virtual symptoms.

## 3 MATERIALS AND METHODS

### 3.1 Web Interface Design

We developed a web application that allows healthcare students to interact with virtual patients (See **Figure 1**). The web interface consisted of four components: the virtual human, a directions window that displays steps a user should follow during the patient interaction, a Google DialogFlow Messenger integration that enabled conversation with the virtual human, and a button that ends the interaction and returns the user to Qualtrics (see



**Figure 1**) (Qualtrics, 2020; Google, 2021). Previous work has used Unity WebGL to display virtual humans (Zalake et al., 2019), our work uses premade videos of virtual humans. When a response is received from Google DialogFlow, the web application queries a cloud storage service to load the virtual human video that corresponds with the response. Using videos rather than WebGL allowed us to create higher fidelity patients with different rendering styles (see **Section 3.3**).

### 3.2 Video Design

We created 123 videos for each virtual human rendering style both with and without symptoms displayed. These videos each contained phrases that the virtual human could use to respond, as well as an idle video. When a virtual human was asked a question, the video would change to the correct phrase video and then upon its completion, the video player would switch back to playing the idle video. In addition to these videos, we also created a pre-brief video and a set of intermission videos. The pre-brief video informed students of the scenario they were to participate in and explained how to use the interface to interact with the virtual human. The intermission videos had the users answer multiple choice questions regarding blood transfusions (questions not used in this work). This intermission was used to act as a time buffer to simulate symptom development over time.

### 3.3 Character Design

We created the virtual human with two different rendering styles: a 3D virtual human rendering style and a photorealistic rendering style, as shown in **Figure 2**. Users interacted with only one of the rendering styles during the study.

The AI generated photorealistic virtual human was created using Synthesia.io, a platform that uses AI driven systems to create videos with photorealistic virtual humans (Synthesia.io, 2021). The 3D virtual human was then created based on this photorealistic character.

To create the 3D virtual human condition, an image of the Synthesia character was used in a program called FaceBuilder (KeenTools, 2021). FaceBuilder is a Blender plug-in that generates 3D virtual human head objects and face textures based on uploaded images (Blender, Online Community, 2021). These generated heads were applied to bodies created using Adobe Fuse (Adobe, 2020). Outfits were chosen to best match the photorealistic characters outfits based on what was available in Adobe Fuse.

The voices were identical across rendering style conditions. Both virtual humans used the voice created using Synthesia's text-to-speech software. To increase user perceptions of plausibility (Hofer et al., 2020), the background used for the virtual environment resembles a clinical environment. It should be noted that because of the different methods used to generate these virtual humans, the head movement animations used while speaking did differ. However, we did not find significant differences in the rated realism of the virtual human movement (See **Section 4.3.2**).

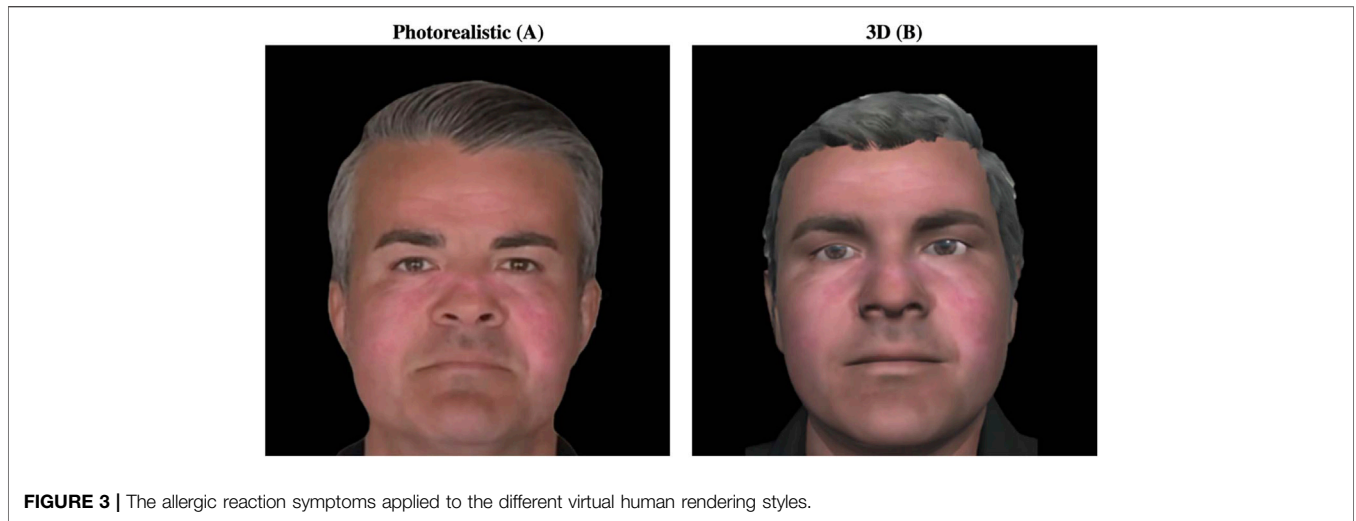
The virtual character designed represented a 50 year old white male. At this time, one race was chosen for participants to interact with. This is because allergic reaction may differ between individuals of different age, race, or gender (Brown, 2004; Robinson, 2007). Thus, one age, race, and gender was chosen to limit potential differences. However, we do recommend that future works explore if perception differences exist when manipulating age, race, and gender.

### 3.4 Symptom Design

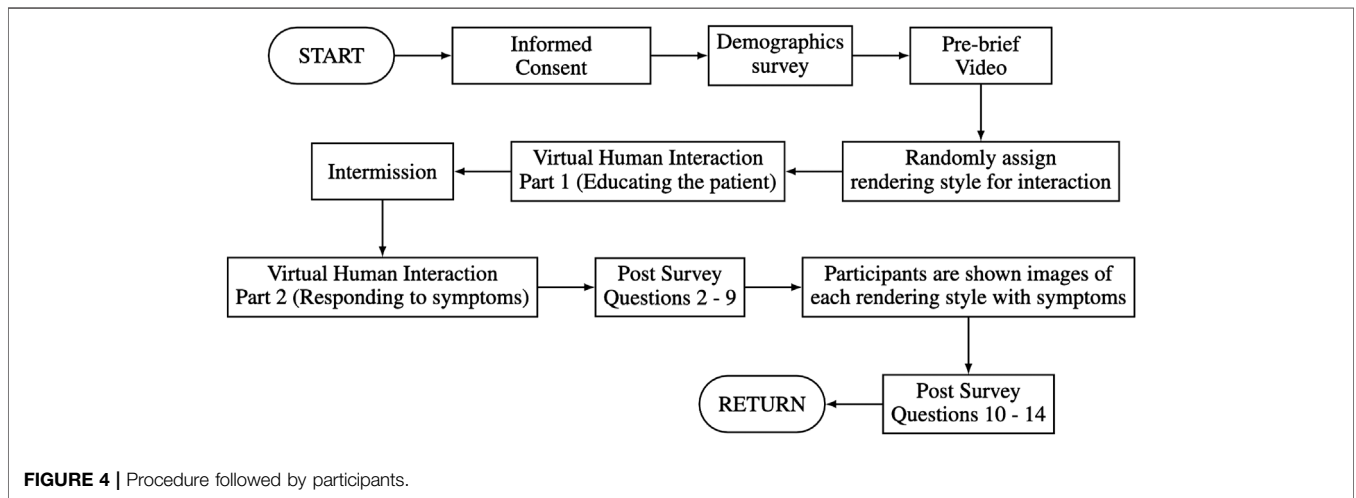
This study had healthcare students experience a virtual human having an allergic reaction to a blood transfusion. To apply this reaction to the virtual humans, an augmented reality filter was made using Lens Studio (Snap Inc, 2021). This filter was reviewed by nursing collaborators for accuracy. This filter was then applied to the videos of the photorealistic virtual human. As for the 3D character, a new face texture was created using the FaceBuilder software using images from the photorealistic virtual human with the filter applied. Then, we created the 3D character videos with the new face texture containing the symptoms (See **Figure 3**).

### 3.5 Conversation Design

The conversation users had with the virtual human was designed in collaboration with nursing educators. A case study that was used in previous semesters of the health assessment course was adapted for this interaction. The conversation was open-ended and allowed users to ask the patient any question at any time. However, the interface also provided participants directions that included typical nursing protocols they needed to complete to progress in the interview. This included having the participant introduce themselves to the patient, identify the patient, ask the patient why they are in the clinic, and then asking the patient if they have any questions. The patient was designed to ask questions regarding why they needed a blood transfusion and



**FIGURE 3** | The allergic reaction symptoms applied to the different virtual human rendering styles.



**FIGURE 4** | Procedure followed by participants.

the safety of receiving a blood transfusion. Participants are expected to be able to answer by providing the virtual human with the safety protocols used to keep blood secure for blood transfusions. Once, the patient begins to have a reaction to the blood transfusion, the participant must respond to the virtual human’s concerns and then provide the patient with a course of action that they will take (e.g. the participant says they will stop the transfusion, or the participant says they will provide medication). Once a course of action has been given, participants were free to ask about other symptoms the virtual human may be having or to end the interaction.

### 3.6 Study Design

Using a mixed design user study, we explored the effect of virtual human rendering style on user perceptions of visual cues. The user study had participants interact with a virtual patient. The interaction featured a patient experiencing an allergic reaction and required trainees to identify symptoms’ visual cues. In the following sections we will describe the participants, study procedure, and measures used.

### 3.7 Participants

Nursing students (n = 107) were recruited from a nursing course taught at the University of Florida. 79 students were between 18 and 24 years old, 20 were 25–34, six were 35–44, 1 was 45–54 years old, and 1 was 55–64 years old. Students self-reported genders were: 14 Male, 90 Female, and 3 chose not to identify. All students completed the interaction in a classroom setting. Students used their own laptops and headphones to complete the interaction.

### 3.8 Procedure

Participants completed the virtual human interaction as a part of an ungraded course lab exercise (See Figure 4 to view procedure). Participants were split into two groups that interacted with different rendering style conditions: 53 interacted with the photorealistic virtual human and 54 interacted with the 3D virtual human. The study was distributed via a link in the Canvas learning management system used by the course. The link led to a Qualtrics survey to begin the study (Qualtrics, 2020). Users began the study by completing the informed consent and a



**TABLE 1** | Questions asked in the survey.

Questions	Measure
1 Please drag the slider on the line to a point that best represents how much experience you have interacting with training simulations using virtual humans	No Experience - Extensive Experience
2, 3 Please drag the slider on the line to a point that best represents your confidence of managing a blood transfusion reaction?	No Confidence - Extensive Confidence
4 How would you rate the realism of the virtual human's rendering style (i.e. visual appearance)?	Not Very Realistic - Very Realistic
5 How would you rate the realism of the virtual human's movement?	Not Very Realistic - Very Realistic
6 What (if anything) did you find distracting about the virtual human?	Open Response
7 How would you rate the severity of the virtual human's symptoms?	Not Very Severe - Very Severe
8 How would you rate the visual realism of the virtual human's symptoms?	Not Very Realistic - Very Realistic
9 The virtual human's rendering style (i.e. visual appearance) affected my ability to identify the virtual human's symptoms?	Negatively affected my ability to identify symptoms - Positively affected my ability to identify symptoms
10 Following up on the previous question, please describe how the virtual human's rendering style (i.e. visual appearance) affected your ability to identify the virtual human's symptoms	Open Response
11 How would you rate the visual realism of the virtual human's symptoms in image A? (See <b>Figure 3</b> )	Not Very Realistic - Very Realistic
12 How would you rate the visual realism of the virtual human's symptoms in image B? (See <b>Figure 3</b> )	Not Very Realistic - Very Realistic
13 How would you rate the severity of the virtual human's symptoms in image A? (See <b>Figure 3</b> )	Not Very Severe - Very Severe
14 How would you rate the severity of the virtual human's symptoms in image B? (See <b>Figure 3</b> )	Not Very Severe - Very Severe
15 Following up on the previous questions, please describe how the virtual human's rendering style (i.e. visual appearance) affected your perception of the realism and severity of the virtual human's symptoms	Open Response

pre-survey. The users were then asked to watch a pre-brief video. The pre-brief video informed students of the scenario they were to participate in and explained how to use the interface to interact with the virtual human. Following the pre-brief video, the nursing students interacted with a virtual patient that is scheduled to receive a blood transfusion. The interaction is divided into two parts. In the first part, students were asked to educate the virtual patient by answering the patient's questions regarding their visit. In the second part, the virtual patient begins to exhibit symptoms and students must respond to the virtual human's adverse reaction to the blood transfusion. The two parts of the interaction are separated by the approximately 5 min intermission. Students interacted with the virtual human by typing their questions into a text box provided by the Google DialogFlow Messenger integration. Once the participants completed the interaction with the virtual human, they clicked on the "End Interview" button which returned them to the Qualtrics survey. The study concluded with a post survey (See **Section 3.9**).

### 3.9 Measures

The measures used in this study focus on users' past experience with virtual human simulations, user confidence, virtual human realism, virtual human symptom realism, and virtual human symptom severity. As previous work (Wang et al., 2019) described, we use visual analogue scales (VAS) (Flynn et al., 2004) to measure qualities of the user and the virtual human (See **Table 1**). All questions measured using VAS use ratio/scale data from 0–100 with one significant digit; open-ended questions are analyzed qualitatively.

#### 3.9.1 Pre-Survey

A pre-study demographics survey gathered data on user age, gender, past experience with virtual human simulations, and user confidence in managing a blood transfusion. Questions 1 and 2 were asked in the pre-survey in addition to demographics questions (See **Table 1**).

#### 3.9.2 Interaction Measures

During the interaction, we recorded the time a participant spent interacting with the virtual human and the participant's conversation transcript with the virtual human was recorded.

#### 3.9.3 Post-Survey

The post-study survey included measures regarding the participants' perceptions of the virtual human and its symptoms. The post-survey was divided into two parts. The first part of the post-survey focused on user perceptions directly after the interaction when they had only seen one virtual human rendering style. The second part of the post-survey focused on user perceptions when they could directly compare symptoms on both rendering styles. We refer to the first part of the post-survey as user perceptions with no frame of reference, and we refer to the second part of the post-survey as user perceptions with a frame of reference.

This method was used to investigate the effect of rendering style on the perception of visual cues because it was known that the participants had previous knowledge of virtual humans training simulations (based on previous curriculum). Based on previous work, we believed that participants might respond to the

initial survey (Part 1) based on their expectations and knowledge of past virtual human experiences, rather than on their true perceptions of the current virtual human Rademacher (2003). Therefore, we provided an opportunity for participants to directly compare virtual human rendering styles and provide feedback on how the rendering style affected their perceptions in part 2 of the post survey.

**Part 1:** Users were asked to respond to questions three to nine directly after interacting with the virtual human. This allowed us to gather user perceptions when they have no frame of reference outside of past experiences to compare virtual human rendering styles (See **Table 1**).

**Part 2:** After completing part 1 of the post-survey, users were provided two images side by side. One image depicted the virtual human experiencing symptoms in the rendering style they interacted with, and the other image depicted the virtual human experiencing symptoms in the rendering style they did not interact with (See **Figure 3**). Users were then asked to respond to questions 10–15 (See **Table 1**). By providing static images, we were able to gather user perceptions when they have a frame of reference to compare virtual human render styles. Static images were chosen over the use of videos to help the authors to control for differences in animation style of the rendering styles. By using static images, animations/movements that users experienced during the interaction could be assumed to be similar for both virtual humans.

## 4 RESULTS

### 4.1 Experience Interacting With Virtual Humans (Q1)

Participant average rated experience with training simulation experiences was 66.51/100 with a standard deviation of 20.09 (0 being no experience and 100 being extensive experience). This higher experience level is expected as virtual human training simulations were a part of the students' course curriculum. Additionally, for Question 1, we tested to see if there was a difference in experience ratings between groups. Normality and variance checks were conducted. The data distribution in both the conditions was normally distributed, and a Levene's test indicated equal variances ( $p = 0.079$ ). As expected, we could not find significant differences in experience levels between groups. Since we could not find differences between group experience levels, we continued with the rest of the data analysis.

### 4.2 User Confidence in Managing a Blood Transfusion Reaction (Q2,Q3)

For each rendering style, we used a Wilcoxon's signed-rank test to compare users' confidence in managing a blood transfusion reaction before and after the interaction. Confidence increased significantly for both the photorealistic condition (Mdn1 = 34.90, Mdn2 = 51.00,  $W = 118$ ,  $p < 0.001$ ) and the 3D condition (Mdn1 = 32.45, Mdn2 = 55.80,  $W = 105$ ,  $p < 0.001$ ). However, we used an independent sample t-test of

the differences (Post confidence - Pre Confidence) and we were unable to find a significant difference between the increases for each condition. This suggests that interacting with a more realistic virtual human will not necessarily increase user confidence in managing a blood transfusion reaction.

### 4.3 User Perceptions of Virtual Human Realism

In this section, the goal of this analysis was to understand if users perceived differences in virtual human realism when only one virtual human rendering style has been seen. It is important to explore whether there are differences when only seeing one virtual human because users may not have the frame of reference or virtual human experience to apply accurate ratings of realism.

#### 4.3.1 Virtual Human Appearance Realism (Q4)

For Question 3, variance and normality checks were conducted. A Levene's test indicated equal variances ( $p = 0.059$ ). The distribution of the data in the 3D condition was normally distributed. However, the data for the photorealistic condition was not normally distributed. Therefore, we used a Mann-Whitney U test to compare the two groups. The Mann-Whitney U test showed that there was a significant difference ( $U = 926.5$ ,  $p = 0.002$ ) between the photorealistic condition compared to 3D condition. The realism of the photorealistic rendering style was rated significantly higher than the realism of the 3D rendering style. The median appearance realism rating was 78.3 for the photorealistic group compared to 63.8 for those in the 3D condition suggesting that the appearance of the photorealistic virtual human is seen as more realistic by participants.

#### 4.3.2 Virtual Human Movement Realism (Q5)

For Question 4, variance and normality checks were conducted. A Levene's test indicated equal variances ( $p = 0.071$ ). The distribution of the data in both the conditions was normally distributed. Therefore, we used an independent sample T-test to compare the two groups. There was no significant effect for rendering style on the rated realism of the virtual human movement,  $t(105) = -1.17$ ,  $p = 0.241$ , despite the photorealistic condition ( $M = 61.39$ ,  $SD = 20.34$ ) attaining higher scores than the 3D condition ( $M = 56.93$ ,  $SD = 18.73$ ).

#### 4.3.3 Virtual Human Distractions (Q6)

83 students provided a response to Q6. 36 (3D = 20, Photorealistic = 16) stated nothing was distracting. 15 (3D = 4, Photorealistic = 11) noted the virtual human movement was distracting with the most mentioned feature being the looping of the movements (3D = 2, Photorealistic = 11). 11 (3D = 8, Photorealistic = 13) students noted the virtual human either ignored their questions or had strange responses. 6 (3D = 3, Photorealistic = 3) students noted that the loading delay in the virtual human responses was distracting. 6 (3D = 3, Photorealistic = 3) noted the virtual humans voice or tone

was distracting. 4 (3D = 2, Photorealistic = 2) students reported they saw glitchy/unusual visuals. Five students reported other miscellaneous responses.

#### 4.4 User Perceptions of Virtual Human Symptoms - No Frame of Reference

The goal of this analysis was to understand if users perceived differences in virtual symptom realism when only viewing one virtual human rendering style. Similar to the above analysis, it is important to explore whether there are differences when only seeing one virtual human rendering style because users may not have the frame of reference or virtual human experience to apply accurate ratings of realism. In this between subjects analysis our variable was 3D vs. AI-generated and the dependent measures were users' self-reported perceptions of symptom realism (See Questions six and 7).

##### 4.4.1 Virtual Symptom Severity (Q7)

For Question 7, variance and normality checks were conducted. A Levene's test indicated equal variances ( $p = 0.103$ ). The distribution of the data in both the conditions was normally distributed. Therefore, we used an independent sample T-test to compare the two groups. There was no significant effect for rendering style on the rated severity of the virtual human's symptoms,  $t(105) = 0.69$ ,  $p = 0.492$ , despite the photorealistic condition ( $M = 53.15$ ,  $SD = 20.73$ ) attaining lower scores than the 3D condition ( $M = 55.69$ ,  $SD = 17.13$ ).

##### 4.4.2 Virtual Symptom Realism (Q8)

For Question 8, variance and normality checks were conducted. A Levene's test indicated equal variances ( $p = 0.085$ ). The distribution of the data in both the conditions was normally distributed. Therefore, we used an independent sample T-test to compare the two groups. There was no significant effect for rendering style on the rated realism of the virtual human's symptoms,  $t(105) = 0.50$ ,  $p = 0.617$ , despite the photorealistic condition ( $M = 61.85$ ,  $SD = 20.22$ ) attaining lower scores than the 3D condition ( $M = 63.57$ ,  $SD = 15.15$ ).

##### 4.4.3 Rendering Style Effect On Symptom Identification (Q9, Q10)

For question 9, users were asked if the rendering style positively or negatively affected their ability to identify the virtual human's symptoms. Variance and normality checks were conducted. A Levene's test indicated equal variances ( $p = 0.112$ ). The distribution of the data in both the conditions was normally distributed. Therefore, we used an independent sample T-test to compare the two groups. There was no significant effect for rendering style on participants' abilities to identify the virtual human's symptoms,  $t(105) = -1.14$ ,  $p = 0.258$ , despite the photorealistic condition ( $M = 64.17$ ,  $SD = 21.17$ ) attaining higher scores than the 3D condition ( $M = 60.00$ ,  $SD = 16.49$ ).

82 students provided a follow-up response to this rating in Q10. Without having a frame of reference, many students seemed to struggle to answer how the rendering style affected their ability to identify the virtual human's symptoms. 39 students (3D = 24, Photorealistic = 15) responded with answers that simply

acknowledge that they could see the symptoms with no reference to rendering style and 8 (3D = 5, Photorealistic = 3) students stated they did not notice the symptoms. However, 13 (3D = 7, Photorealistic = 6) students stated the rendering style made no difference. Seven students in the photorealistic group noted that the realism helped them identify the symptoms at this point in the study. 15 (3D = 7, Photorealistic = 8) students provided miscellaneous comments.

#### 4.5 User Perceptions of Virtual Human Symptoms—With a Frame of Reference

To improve the depiction of virtual human symptoms in future simulations, users can directly compare the symptoms applied to different rendering styles. By allowing users to compare different rendering styles, we would be able to elicit user perceptions of depicted symptoms. This approach would allow us to understand which rendering style is better suited for virtual human medical simulations that use visual cues for depicting symptoms. Therefore, after completing the interaction and all other survey questions, users were asked to directly compare the symptoms of the two rendering styles.

##### 4.5.1 Virtual Symptom Realism (Q11, Q12)

In a within subjects comparison, the realism of the photorealistic virtual human's symptoms were rated significantly higher than the realism of the 3D virtual human's symptoms. A Wilcoxon's signed-rank test showed that the photorealistic condition was rated significantly higher ( $Mdn = 92.40$ ) compared to the 3D condition ( $Mdn = 35.10$ ),  $W = 5515.50$ ,  $p < 0.001$ , and has a large effect size (0.982).

##### 4.5.2 Virtual Symptom Severity (Q13, Q14)

In a within subjects test, the severity of the photorealistic virtual human's symptoms was rated significantly higher than the severity of the 3D virtual human's symptoms. A Wilcoxon's signed-rank test showed that the photorealistic condition was rated significantly higher ( $Mdn = 64.40$ ) compared to the 3D condition ( $Mdn = 51.30$ ),  $W = 4682.00$ ,  $p < 0.001$ , and has a large effect size (0.715).

##### 4.5.3 Virtual Human Rendering Style Effect Open Response (Q15)

66 students provided a follow-up response for Q15.33 of these students noted the rendering style affected their symptom identification. 26 students (3D = 13, Photorealistic = 13) responded with answers that stated the more realistic rendering style helped in identifying symptoms, 6 (3D = 1, Photorealistic = 5) students noted that less realistic rendering styles made it more difficult to identify symptoms, and 1 student in the photorealistic group stated it affected their identification but did not elaborate (See Table 2 for examples).

#### 4.6 Total Time Spent

The distribution of the data was normal but Levene's test indicated unequal variances ( $p < 0.05$ ). Therefore, we used a Mann-Whitney U test to compare the number of questions asked by the two groups. We were unable to find a significant difference between the number of questions asked to the 3D virtual human



**TABLE 2** | Example User Responses to question 15, “How the virtual human’s rendering style (i.e. visual appearance) affected your perception of the realism and severity of the virtual human’s symptoms.”**Example User Responses**

It was hard to tell what was a symptom and what was just the way the program is programmed  
 Seeing the symptoms on a “real” person makes it easier to tell if something is wrong, versus seeing the symptoms on a “cartoon.” In the cartoon, it is difficult to distinguish a real issue from a glitch. In the real person, the symptoms are clear  
 It’s hard to see what a human’s reaction will appear as on a virtual figure bc human skin responds variably  
 With image A (Photorealistic), it is easier to assess him like he is an actual patient. Image B (3D) feels more like a simulation  
 Patient A (photorealistic) looked more real so it was easier to pick up on his symptoms  
 I had the person in image B (3D), and I wasn’t sure how it would look in a real person. I think image A (photorealistic) would have been more helpful for figuring out what it would look like on a real person  
 It helped me realize the change from baseline  
 It is harder to notice symptoms when the image is less realistic  
 The less realistic the rendering, the more difficult it is to find symptoms on the patient  
 As stated before, human skin is variable and sometimes the virtual figure is too vague  
 It was easier to identify in the first image (photorealistic) that the patient’s skin was an abnormal color. It blends in more with the second image (3D)  
 The fact that the face was more realistic in image A (photorealistic), made the symptoms more realistic  
 In image B (3D), the patient’s face is animated which makes it more difficult to see the redness  
 I think the first image (photorealistic) had a more dramatic symptom appearance then the second image (3D) allowing for a quicker identification of what might be happening to the patient  
 The visual appearance of the person in image A (photorealistic) is more realistic than the person in image B (3D), which made it easier to see the severity of the symptoms

and the photorealistic virtual human. The Mann-Whitney U test showed that there was no significant difference ( $U = 1259.50$ ,  $p = 0.363$ ) between the photorealistic condition compared to 3D condition. The median time spent interacting with the virtual human was 359.5 s for 3D and 401.5 s for the photorealistic condition. The means were 404.35 s (3D) and 413.25 s (photorealistic). This suggests that increasing rendering style realism will not necessarily increase the amount of time users spend interacting with virtual humans.

## 4.7 Number of Questions Asked

The distribution of the data was not normally distributed and Levene’s test indicated unequal variances ( $p < 0.05$ ). Therefore, we used a Mann-Whitney U test to compare the number of questions asked by the two groups. We were unable to find a significant difference between the number of questions asked to the 3D virtual human and the photorealistic virtual human. The Mann-Whitney U test showed that there was no significant difference ( $U = 1409$ ,  $p = 0.977$ ) between the photorealistic condition compared to 3D condition. The median number of questions asked was 15 for both conditions and the means were 16.37 (3D) and 15.62 (photorealistic). This suggests that increasing rendering style realism will not necessarily increase the number of questions users ask to virtual humans.

## 5 DISCUSSION

### 5.1 RQ1—How Does Virtual Human Rendering Style Affect User Perceptions of Visual Cues on a Virtual Human?

When providing participants with a frame of reference, we found that the realism and severity of the photorealistic virtual human’s symptoms were rated significantly higher than the 3D virtual human’s symptoms. Additionally, several open-ended responses

suggest that the photorealistic rendering style allowed participants to assess the virtual human and its symptoms with lowered difficulty. The main reason participants cited for the lowered difficulty was that the visual cues used to display the symptoms on the virtual humans are more easily identified as intentional when shown on the photorealistic virtual humans than 3D virtual humans (See Table 2).

These results provide evidence that increasing the fidelity of a virtual human may aid participants in identifying symptoms in visual cue training. However, further research is necessary as these results could be domain specific. Previous work has found that medical illustrations, which opt for more cartoonistic style representations, have been found to aid in understanding while limiting the introduction of distracting details (Houts et al., 2006; Krasnoryadtseva et al., 2020). Therefore, increasing fidelity may not be the only option for improving visual cue identification. Ring et al. stated that the optimal rendering style used for virtual humans varies based on task domain and user characteristics, indicating it may also be helpful to consider lowering the fidelity of a virtual human to be more similar to medical illustrations Ring et al. (2014). Using a medical illustration rendering style may allow educators to highlight relevant visual cues when initially teaching about them, and once the information is well-learned, then using a scaffolded approach, cues could be made more realistically subtle using the higher fidelity virtual humans used in this work. We suggest future work explores how the effects of placing filters differ when used on more traditional medical illustrations or manikins, as compared to real humans or photorealistic virtual humans.

Additionally, we do not wish to ignore that we could not find significant differences in rated realism or severity when participants rated visual realism and severity of the virtual human symptoms without a frame of reference. It is paramount to train users with realistic training opportunities and this may include being able to display subtle visual changes (redness, slight yellowing of the eyes, etc.) (Watts et al., 2021).

However, trainees interacting in simulations will follow a fiction contract (Nanji et al., 2013). A fiction contract is an agreement between the trainee and those conducting the simulation regarding how the trainee should interact (Dieckmann et al., 2007). In the case of virtual humans with symptoms, a compelling fiction contract will lead trainees to see symptoms regardless of whether the symptoms are the most realistic or not. Therefore, comparisons where only 1 condition is shown to each group may not be the best option for understanding differences in user visual cue perception in simulation. Thus, we suggest, future works involving the perceptions of visual cues in simulation should be performed using within subjects designs to provide users with more context of how a visual cue would be depicted in the real world.

## 5.2 RQ 2) How Does Virtual Human Rendering Style Affect Interpersonal Communication Behaviors?

We found that without a frame of reference, participants rated the realism of the photorealistic rendering style significantly higher than the realism of the 3D rendering style. However, we were unable to find significant differences between the 3D rendering style and the photorealistic rendering style for the number of questions asked to the virtual human or the time spent with the virtual human. Additionally, there was no difference in the increase in participant confidence in managing a blood transfusion between the two conditions.

Overall, we believe that continuing to increase fidelity to photorealistic levels will not increase interpersonal communication behaviors such as time spent interacting or the number of questions asked. When comparing our work to that of Volonte et al. (See **Section 2.2**), our low fidelity character is comparable to the high fidelity character used in both works (Volonte et al., 2016; Volonte et al., 2019). If comparing our findings to Volonte in 2016, our work would provide further evidence that the realism of virtual human rendering style does not necessarily affect participants' interpersonal communication behaviors such as time spent interacting and the number of questions asked. However, if compared to (Volonte, 2019) work, our work may indicate that increasing fidelity may lead to diminishing return over time or that there is a ceiling effect on the correlation between increasing rendering style and increasing the number of questions asked. Unfortunately, these scenarios are not directly comparable as they involve different scenarios, participant demographics, and levels of virtual human fidelity. Nonetheless, our findings in combination with previous works highlight an opportunity for future work to further explore the effect of rendering style on interpersonal communication behaviors.

## 6 CONCLUSION

To prevent ineffective or counterproductive visual cue training, previous research in simulation-based medical education has recommended that simulation designers should provide training observations with levels of fidelity that create appropriate perceptions of realism (Watts et al., 2021). Thus,

this work explored the effect of virtual human rendering style on the perceptions of visual cues (patient symptoms) in a healthcare context.

In summary, we present our conclusions below in reference to the questions we raised in **Section 1**:

- RQ 1) How does virtual human rendering style affect user perceptions of visual cues on a virtual human?

Our results provide evidence that, when provided with a frame of reference, users view symptoms as more realistic and severe on photorealistic virtual humans compared to 3D virtual humans. From these findings, we suggest that simulation designers opt to use higher fidelity virtual human rendering styles when they are required to apply subtle visual cues to virtual humans. Based on user feedback, we believe this will help users to recognize subtle visual cues as intentionally occurring in a simulation.

- RQ 2) How does virtual human rendering style affect interpersonal communication behaviors?

Interpersonal communication behaviors (time spent interacting, number of questions asked) were not significantly different between rendering style conditions. Based on previous research in a similar context, there may be multiple reasons for this finding (see **Section 5.2**). Future work will be required to understand the effect of rendering style on interpersonal communication behaviors.

## 6.1 Implications for Virtual Reality Community

Ring et al. stated that the optimal rendering style used for virtual humans varies based on task domain and user characteristics Ring et al. (2014). This work highlights that the benefits provided by increased rendering style fidelity can be domain and task specific. In the task of identifying visual cues, this work shows that higher fidelity can provide users with noticeable benefits. However, this work also indicates that in the task of interacting with the patient, the users do not seem to change their behavior much in this domain. These findings may apply to virtual reality applications in the same domain, but researchers should consider how in virtual reality the virtual environment rendering style may also affect user interactions Volonte et al. (2020). Overall, this work encourages VR community members to research the optimal fidelity needed for specific tasks and domains. By doing so, the VR community may be able to better understand which fidelity levels should be used in new scenarios.

## 7 LIMITATIONS AND FUTURE WORK

As previously mentioned, there are a few limitations to this work. First, the animation styles were not able to be controlled to be the same due to the different methods used to generate the virtual humans. We do not believe this affected user perceptions of symptoms as we were unable to find significant differences in virtual human movement realism. However, this finding could

have been due to users basing their expectations on knowledge from past virtual human experiences such as previous course simulation exercises or other outside activities (see **Section 4.1**). Second, we only investigated two rendering styles. It is possible that other rendering styles not meant to simulate real life (e.g. cartoon style) may affect interpersonal communication behaviors and the perception of symptoms differently. Therefore, we suggest future work should further explore the effect of different rendering styles on these aspects. Third, students used their own laptops to complete the interaction. Differences in screen size, resolution, or brightness may have affected users' ability to identify the virtual patient's visual cues. This approach is more "in the wild." Since these variations occurred for both groups, we do not see this impacting our results. However, the variation should be noted, and future work may benefit by investigating the differences in perceptions using a more controlled screen environment. Fourth, the semi-guided approach may have affected the number of questions users asked. Users that strictly followed the interview directions may have prevented rendering style effects on the conversation from arising. Future work focusing on conversational effects of rendering style may wish to explore this area using an unguided approach. Finally, we did not explore how perceptions of virtual symptoms may change due to differences in virtual human race or gender. This was done because allergic reactions may differ between individuals of different age, race, or gender (Brown, 2004; Robinson, 2007). Thus, we limited the scope for this work. However, we do recommend that future works explore if perception differences exist when manipulating age, race, and gender.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Florida Internal Review Board (IRB). The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

JS conducted the user study, carried out the data analysis, and wrote the manuscript in consultation with all others. AS was the instructor for the courses in which virtual patient interviews were integrated. All authors contributed to the study design, virtual human design, visual cue design, and conceptualization of the paper.

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## SUPPLEMENTARY MATERIAL

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