Effects of Rendering Styles of a Virtual Character on Avoidance Movement Behavior

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Abstract

Avoidance movements between humans performing locomotive tasks and virtual characters represent typical interactions in immersive virtual environments. When performing these avoidance maneuvers, decisions are based on several factors, including self-presence and the perception of other virtual individuals. However, the impact of visual information on collision-free interactions is not yet fully understood. In this study, we aim to manipulate how the appearance of virtual characters is represented using five different rendering styles (realistic, toon, creepy, scary, and robot) to understand how alternate appearances could potentially affect the avoidance movement behavior of participants. To gather avoidance behavior data, 24 healthy participants performed a two-trial locomotive task toward a target in a virtual environment. Our results indicated that eerie rendering styles affected trajectory length, duration, speed, minimum distance, and side-by-side distance measurements. Additionally, most participants maintained a minimum distance behind the virtual characters and avoided them by keeping to their left side in all examined conditions. We posit that the presented findings contribute toward a fuller understanding of the effects of the appearance of virtual characters on avoidance movement behavior in room-scale virtual environments.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality

1 Introduction

On the one hand, many ordinary situations require humans to regulate their movement behavior relative to another co-located virtual character in the same virtual environment. A typical example is when humans walk in a public space, such as on a sidewalk in a virtual metropolitan city or inside a shopping mall. In such cases, due to their co-location with other virtual individuals, virtual reality (VR) users should plan and regulate their interpersonal interactions to avoid potential collisions. Previously, researchers have studied the movement of VR users when different locomotion interfaces (including natural walking) have been used in room- and non-room-scale interactions [24] and different immersive setups [4]. Moreover, researchers have also examined the movement behavior of VR users, mainly focusing on following behavior [32], coordination [16], collision avoidance [13], or meeting and reaching [14].

On the other hand, VR users can choose a virtual character that can be edited/modified (in most cases) in immersive environments. Therefore, this results in interactions with virtual characters that have different appearances and levels of realism. From previous studies, we know that the rendering style of virtual characters can affect interactions and communication with VR users [3, 22, 26]. Thus, we posit that such appearance variations could also affect how VR users decide to act in virtual environments. For example, avoidance behavior could be affected simply because the other virtual character's appearance was considered eerie. We suggest that an eerie appearance could have significant outcomes in VR applications (including virtual social environments, training, and games), where the accurate performance of locomotive tasks is essential.

The initial inspirations for this project came from Zibrek et al. [41], who explored whether the style of rendering affected the appeal of virtual characters, and Mousas et al. [26], who studies collision avoidance with virtual characters. We also considered that humans could recognize the likelihood of an impending collision and then estimate the timing such that it could be avoided [8]. Moreover, we realized that their subjective perception of realism changed how they behaved in room-scale environments [24]. We thought that this perception and action constituted a dynamic coupling between humans and virtual characters, which could help us understand how people plan and execute their avoidance behavior in an immersive virtual environment. Thus, this paper focuses on collision avoidance between a human performing a locomotive task (toward a goal position) and a standing virtual character whose appearance varies according to the examined rendering styles. Accordingly, this would provide a greater understanding of how such appearance variations could affect how the study participants plan and execute their avoidance movements in a room-scale VR setup.

Figure 1: The five different rendering styles (realistic, toon, creepy, scary, and robot appearances) of the virtual character we examined in this paper.

We compared how differences in the appearance of virtual characters could affect the behavior of other VR users. To achieve this, the character model was represented using different rendering styles (realistic, toon, creepy, scary, and robot), which are linked to varying levels of affinity, empathy, realism, and presence [41] (see Figure 1). Based on our study design and the collected data (both movement data and self-reported ratings), the aim was to answer the following research questions:

- **RQ1:** How does the rendering style of a virtual character affect participants' avoidance movements and decisions?
- **RQ2:** To what extent do the different rendering styles affect participants' sense of presence and their perceived realism of, affinity with, and empathy for the virtual character?

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- **RQ3:** How do demographic factors correlate with avoidance movement behavior, and how does this behavior correlate with participants' attitudes towards the virtual character?

2 Related Work

Understanding interactions in virtual environments through analyzing human locomotion has been studied by various researchers. For example, researchers have explored behavioral patterns [18] including walking side-by-side [30] or face-to-face [10] with a virtual character, walking in crowds and groups [15–17, 27, 28], collision avoidance [13, 24], gazing during collision avoidance tasks [4, 19], and fear conditioning avoidance [9, 31]. With regard to avoidance behavior, previous researchers have examined the information that walkers must absorb and consider during a collision avoidance task [8], how walkers alter their movements [29] or circumvent [38], the safety margin's effect on path planning [33], and the way humans walk in passive [12] and dynamic environments [39].

Previous studies have also successfully utilized proxemics [12, 34] and interpersonal distance [2, 10] between humans and virtual characters to analyze social interactions, revealing two main findings. First, using proxemics, we can retrieve objective information related to the social presence of humans in a VR environment [1]. Second, the appearance and expression of a virtual character [14, 25, 26] could be a factor that affects human behavior.

Several research projects have examined the appearance of virtual characters from various angles. Bourgaize et al. [5] found that the size and orientation of a virtual character can have a significant effect on the medial-lateral clearance. Bailenson et al. [3] attempted to connect appearance realism with proximity, finding that such a relationship is complicated. McDonnell et al. [20] explored different rendering styles and found that appeal ratings were altered without affecting the virtual character's geometry, regardless of apparent realism. Zibrek et al. [41] studied whether the rendering style or personality of virtual characters were essential components in affecting their attractiveness. Their results indicated that appearance (realistic rendering) is the most critical aspect. Zell et al. [40] investigated the effects of character realism by examining the impact of a virtual character's shape (3D geometry) and appearance (material). Their study revealed that a character's appeal is primarily based on the materials, while their realism is based mainly on the shape. Finally, Mousas et al. [22] explored how humans react emotionally to virtual characters in an immersive setting. They discovered that the unpleasant appearance of virtual avatars and their excessive movement affected the participants' emotional reactivity.

3 Materials and Methods

3.1 Participants

We performed an *a priori* power analysis using G*Power v. 3.10 to explore the sample size of our study [6]. Our calculations were based on 95% power, a medium effect size of .35 [11], one group with five repeated measures, a nonsphericity correction of $\varepsilon = .60$, and $\alpha = .05$. The analysis resulted in a recommended sample size of 24 participants who were recruited from undergraduate and graduate students at a Midwest U.S. university through e-mails. The participant demographics were as follows: $18-31$ years old ($M = 21.95$, $SD = 3.56$); $160-198$ cm height ($M = 175.41$, $SD = 9.22$); and $51-110$ kg weight ($M = 77.33$, $SD = 14.574$). No compensation was awarded for participation. Of the sample, 16 were male (age: $M = 20.69$, $SD = 2.08$), six were female (age: $M = 25.50$, $SD = 4.50$), and two identified as non-binary/other gender (age: $M = 21.50$, $SD = 4.34$). In addition, 18 participants reported being right-handed, two as left-hanged, and two as ambidextrous.

3.2 Experimental Conditions

We used a white male virtual character as our baseline, and five different rendering styles were developed to change the character's appearance. Our decision to use the five different rendering styles was based on prior work [41] that examined virtual characters' effects or realistic appearances. We decided to include two appealing rendering styles (realistic and toon) and three eerie (creepy, scary, and robot). The reason for using eerie rendering styles was to induce extreme reactions (if possible), especially when compared to participants' reactions to the realistic and toon styles. More importantly, we assumed that the eerie style would affect the avoidance movement behavior of participants. Specifically, our conditions were as follows:

- **Realistic:** This virtual character could be considered the most realistic. The material assigned to this virtual character included a bump map and subsurface scattering for skin, refraction for eyes, and transparency for hair.
- **Toon:** The appearance of the toon character was considered less realistic and was rendered with a Cel shading postprocess.
- **Creepy:** We included this style to induce discomfort. It involved enlarging the eyes of the virtual character while adding color to the surrounding area of the eyes. We perceived that such a rendering style would induce an uncanny effect (see Seyama et al. [35] and Tinwell et al. [37]).
- **Scary:** The representation of this virtual character was considered less realistic and unappealing. We enhanced the diffuse map for the skin and the eyes by adding an unusual color (green for the skin and red for the eyes) to create this style, resulting in a "scary" virtual character.
- **Robot:** This rendering style was also considered less realistic and appealing. We added an unnatural color (grey for skin) and changed the glossiness of the material to imply a metallic finish. These changes resulted in a "robot" virtual character.

3.3 Measurements and Ratings

First, we collected movement measurements to understand how the participants planned and executed their avoidance movements when encountering characters with different rendering styles. We then examined the self-reported ratings to understand the participants' perceptions of the virtual characters and the virtual environment during the experiment.

3.3.1 Movement Measurements

For this project, the following measurements were collected:

- **Duration:** The total time a participant spent traveling from the start to the goal spot in the virtual environment (measured in seconds).
- **Trajectory length:** The length of the captured trajectory between the start and goal spot (measured in meters).
- **Speed:** The average speed of the participant's movement when walking in a virtual environment (measured in meters/second).
- **Minimum distance:** The minimum distance between the global positions of participants and virtual characters (i.e., how closely the participant approached the virtual character during the avoidance maneuver). This was measured in meters.
- **Side-by-side distance:** The distance between the participant's and virtual character's root position when they were side-by-side (measured in meters).
- **Side of minimum distance (front or behind):** We extracted information to understand whether the minimum distance between the participant's and virtual character's root position was when the participant was in front of or behind the virtual character (measured in meters).

- **Avoidance side (right or left):** We counted how many times participants avoided the virtual character by keeping to their right or left sides.

We used the raw captured data to extract the necessary information, although it should be noted that the first five measurements were primarily used to help us understand how participants executed their locomotive behavior during avoidance tasks. The other two measurements were used to inform how participants planned and decided to perform avoidance tasks. Therefore, additional information about participants' decisions on avoidance behavior was extracted (e.g., changes to minimum distance and avoidance side between the two trials), which is presented in Section 4. Our participants performed two trials per experimental condition, similar to that of Berton et al. [4]. Thus, the mentioned measurements were captured twice, which is common in human movement analysis research [4, 16, 24]. For the first five measurements, we computed and used the average of the two trials in our statistical analysis.

3.3.2 Self-Reported Ratings

Since our study conditions (rendering styles) had many similarities to the study conducted by Zibrek et al. [41], we adopted their questionnaire. In turn, this was based on measures previously used by McDonnell et al. [20] on uncanny valley questions (Affinity and Realism groups). We also included the Slater-Usoh-Steed (SUS) questionnaire on presence [36]. All questions were answered using a 5-point Likert scale.

3.4 Study Site, Equipment, and VR Application

Our study was conducted in the motion capture lab (width: 8 m; depth: 8 m; height: 4 m) of our department. An imaginary virtual environment could potentially impact both the movement behavior and the arousal levels [23] of participants. Accordingly, based on the measurements, we employed a professional designer to create a virtual replica, which was subsequently used in our application to immerse the participants in a virtual world. The 3D replica was designed in Autodesk's 3ds Max. Figure 2 illustrates our lab space and the virtual replica used for our study. It should be noted that the motion capture lab was almost empty of objects, containing only a desk (on which the computer was running the application), two desk chairs, and two tripods at the diagonal corners of the lab, which were used to hold the HTC VIVE base stations.

Figure 2: The motion capture lab (left), where we conducted our experiment, the 3D replica (middle), and a bird-eye view of the main scene of our application with a virtual character standing between the start and goal spot (right).

We developed our VR application using the Unity game engine (version 2019.1.4). Blue and red spots on the floor indicated the participants' start (blue spot) and goal (red spot) positions. We set the distance between the start and goal spots at 7 m. According to previously published work [25], 7 m provides enough space for participants to perform smooth avoidance maneuvers. The research team instructed the participants to avoid a virtual character placed between the start and goal spots (3.5 m from the start and goal positions). The virtual character was aligned based on the start and goal positions and faced the participant automatically once a new trial was loaded. The recording of participant movements was handled automatically by our application. The researcher responsible for conducting the experiment and collecting the data monitored this process.

3.5 Procedure

Once participants arrived in the motion capture lab, the research team provided them with a consent form, which had been reviewed and approved by the Institutional Review Board (IRB) of our university. Upon agreement, the participants were instructed to complete the form. Then, an online short demographic questionnaire was provided using the Qualtrics survey tool. The experimenter helped participants wear the backpack computer and the HMD and assisted in attaching the HTC VIVE tracker to their chest. Then, the research team asked the participants to perform a short walk in the replica virtual environment to ensure they were comfortable and to become aware of the one-to-one size matching between the real environment and the virtual replica. At this point, there was no virtual character in the virtual environment. After the participants became familiar with the VR equipment, the researcher turned on the start and goal spots. Then, the experimenter instructed the participants to head toward the start position (blue spot) and face the goal position (red spot). Then, a black screen initiated the trial, and participants were informed that a virtual character would appear in the virtual environment once the new scene was loaded, after which they performed the avoidance task.

The research team informed the participants that the virtual character would not update its global position. Additionally, as soon as the participants arrived at the target position, they were asked to head toward the start position for the subsequent trial. Between trials, the participants did not remove the HMD—they were still immersed in the virtual replica (although no virtual character was present). Once they reached the start spot and faced the goal spot, the research team turned the screen black again. Although the participants were partially aware, the research team told them that they had sufficient clearance to avoid the virtual character. Consequently, the participants felt safe in the virtual environment. The research team also told the participants to avoid collisions with the virtual character by performing right or left avoidance maneuvers. Participants were informed that they would have breaks between the conditions (every two trials) to complete the questionnaire. In addition, they could have additional time between conditions to relax if required, and they were informed that they could terminate the experiment at any time without any negative consequences.

No indication was provided to the participants on when to start moving toward the goal position. At the beginning of the experiment, they were informed that they could move to the target position at any time after the scene with the virtual character was loaded. The research team was responsible for informing the participants about the progress of the experimental study. The participants were not aware of the rendering style of the virtual character and only saw its appearance once the first trial of each experimental condition was loaded. After the participants performed the second trial for a given condition, they were asked to remove the HMD and answer the developed questionnaire in a computer-based format on Qualtrics. The participants were informed that the research team would answer any questions after completing the study. Overall, the duration of the experiment did not exceed 40 min.

4 Results

We used a one-way repeated measures analysis of variance (RM-ANOVA) to statistically analyze the collected data. The five rendering styles served as independent variables, and we used avoidance movement behavior measurements and self-reported ratings as dependent variables. Additionally, we used post-hoc Bonferroni corrected estimates to assess the statistically significant ($p < .05$) results, and the reported correlations were performed using the Parson bivariate correlation test. Before analyzing our data, we screened for normality using Q-Q plots of the residuals and with the Shapiro-Wilk tests at the 5% level, which both indicated that the obtained data fulfilled the normality criteria. We provide descriptive statistics in the supplementary materials file.

4.1 Avoidance Movement Behavior

The rendering style significantly affected the **duration** of the walking task [$\Lambda = .326$, $F(4,20) = 10.324$, $p = .0001$, $\eta_p^2 = .674$]. The post hoc pairwise comparison indicated that participant avoidance movements in the toon rendering style lasted significantly more than for creepy ($p = .001$), scary ($p = .001$), and robot ($p = .001$).

We found a statistically significant impact on participant **trajectory length** across the five rendering styles [$\Lambda = .500$, $F(4,20) = 4.997$, $p = .006$, $\eta_p^2 = .500$]. Post-hoc pairwise comparisons indicated that participant trajectory length in the scary style was significantly longer than realistic ($p = .006$) and toon ($p = .004$). Moreover, our results also revealed that the participants followed significantly longer paths in the robot rendering style compared to realistic ($p = .026$) and toon ($p = .016$).

The **speed** measurement also revealed significant results across the examined rendering styles [$\Lambda = .232$, $F(4,20) = 16.524$, $p = .006$, $\eta_p^2 = .768$]. The post hoc pairwise comparison revealed that the speed in the toon condition was significantly lower than for the realistic ($p = .041$), creepy ($p = .040$), scary ($p = .001$), and robot ($p = .013$) rendering styles. Moreover, our analysis also revealed that in the realistic rendering style, the speed of our participants was significantly lower for creepy ($p = .001$), scary ($p = .001$), and robot ($p = .001$).

The **minimum distance** measurement also provided statistically significant results across the five rendering styles [$\Lambda = .633$, $F(4,20) = 2.896$, $p = .048$, $\eta_p^2 = .367$]. Here, the post hoc comparison indicated that the minimum distance that the participants maintained with the virtual character in the scary rendering style was longer compared to realistic ($p = .032$) and toon ($p = .029$).

The **side-by-side distance** measurement was also statistically significant across the five rendering styles [$\Lambda = .595$, $F(4,20) = 3.380$, $p = .029$, $\eta_p^2 = .403$]. The post-hoc comparison indicated that when the participants and virtual characters were side-by-side, the distance in the scary rendering style was greater compared to realistic ($p = .037$) and toon ($p = .034$).

4.2 Avoidance Decisions

We also collected data to investigate participants' decisions pertaining to avoidance movements. First, we collected data to examine whether the minimum distance between participants and characters was in front of or behind the virtual character. From the figure, it can be seen that the minimum distance between the participant and the virtual character was behind for most of the participants in both trials. Specifically, for the first trial, we counted the following minimum distances to being behind the virtual character: realistic ($n = 21$), toon ($n = 11$), creepy ($n = 16$), scary ($n = 16$), and robot ($n = 13$). By comparison, the second trial elicited the following results: realistic ($n = 17$), toon ($n = 18$), creepy ($n = 16$), scary ($n = 14$), and robot ($n = 16$).

We also explored whether participant minimum distances were the same (either behind/behind or in-font/in-front) in both trials. By looking at the collected data from both trials, we determined that our participants followed a similar avoidance minimum distance pattern in three of the conditions (realistic, toon, and scary). Here, we counted the following: realistic ($n = 15$), toon ($n = 15$), and scary ($n = 16$). For the creepy virtual character, the results were balanced, with 12 participants maintaining a similar minimum distance between the two trials and 12 changing their minimum distance. Unexpectedly, we found the opposite result for the robot appearance. Specifically, nine participants decided to have their minimum distance on the same side in both trials, while the remaining 15 participants changed the side of the minimum distance when performing the avoidance maneuver.

We also collected data to explore which side the participants used to avoid the five different virtual characters. We found that most of our participants decided to keep the virtual character on their left side when avoiding it during their first trial, with the following results: realistic ($n = 13$), toon ($n = 14$), creepy ($n = 16$), scary ($n = 18$), and robot ($n = 17$). Participants in the second trial changed their avoidance decision slightly (although still to the left): realistic ($n = 16$), toon ($n = 18$), creepy ($n = 13$), scary ($n = 12$), and robot ($n = 15$). However, it is worth noting that there was a balance between avoiding on the left and right sides in the scary virtual character condition. Additionally, we found that most participants avoided the virtual character from the same side in both trials: realistic ($n = 17$), toon ($n = 18$), creepy ($n = 15$), scary ($n = 14$), and robot ($n = 17$).

Finally, we investigated the avoidance movement behavior of our participants according to the proxemics model [21]. In this study, the following proxemic distances were used to delineate how far our participants avoided the five virtual characters used in this study: intimate: $15 - 46$ cm; personal: $46 - 122$ cm; social: $122 - 370$ cm; and public: $370 - 760$ cm. We found that all minimum and side-by-side distances were within the social space ($122 - 370$ cm) of the proxemics model for all rendering styles.

4.3 Self-Reported Ratings

The self-reported ratings for **empathy** revealed a statistically significant effect of rendering style across the five conditions [$\Lambda = .345$, $F(4,20) = 9.476$, $p = .0001$, $\eta_p^2 = .655$]. Moreover, post-hoc pairwise comparisons indicated that the mean score for realistic was significantly greater than for creepy ($p = .008$), scary ($p = .002$), and robot ($p = .028$). We also discovered that the toon condition was rated significantly higher than scary ($p = .035$).

We found a statistically significant **realism** effect of rendering style across the five experimental conditions [$\Lambda = .530$, $F(4,20) = 4.434$, $p = .001$, $\eta_p^2 = .470$]. In addition, post hoc pairwise comparisons indicated that the mean score for scary was rated significantly lower than realistic ($p = .007$) and toon ($p = .031$).

The participants also evaluated the **affinity** of the rendering styles. The results suggested a statistically significant effect of rendering style across the five conditions [$\Lambda = .323$, $F(4,20) = 10.480$, $p = .0001$, $\eta_p^2 = .677$]. Post-hoc pairwise comparisons indicated that the mean score for realistic was rated higher than scary ($p = .0001$) and robot ($p = .002$). Moreover, toon was rated higher than both scary ($p = .0001$) and robot ($p = .003$), and creepy was rated higher than scary ($p = .009$). Finally, we did not find any statistically significant results at the $p < .05$ level regarding the presence variable [$\Lambda = 1.025$, $F(4,20) = .830$, $p = .418$, $\eta_p^2 = .170$] across the five different rendering styles.

4.4 Correlations

We explored whether there were any statistically significant correlations between the movement data and the self-reported ratings. We also explored whether factors such as handedness, height, and weight correlated with participants' decisions about avoidance movement. We only found a weak negative correlation between the **side-by-side distance** and **affinity** measurements [$r = .200$, $n = 120$, $p = .029$].

We also explored whether the **handedness**, **weight**, **height**, and **age** of participants could be correlated with any of the collected avoidance movement data (**duration**, **trajectory length**, **speed**, **minimum distance**, **side-by-side distance**, **side of minimum distance**, and **avoidance side**). Here, we only found a moderate negative correlation between the **minimum distance** and **weight** for the scary rendering style [$r = .459$, $n = 24$, $p = .024$].

5 Discussion

The most interesting result was that the appearance of a virtual character affected the movement behavior of participants during the examined locomotive task (**RQ1**). The most distinguishing results were revealed for the scary virtual character, which we placed on one end of the avoidance behavior spectrum of our participants. When the participants were exposed to such rendering style, they regulated their avoidance movement behavior to move faster, follow a longer path, and maintain greater minimum and side-by-side distances from that virtual character. At the other end of the avoidance behavior spectrum, we placed the realistic and toon rendering styles. Even though there was no similar pattern in the speed measurements, we observed that the duration, length of the captured trajectories, minimum distance, and side-by-side distance in both the realistic and toon rendering styles were not significantly different. Thus, our participants decided to regulate their avoidance movements somewhat similarly for both virtual characters. The duration in robot and creepy styles was significantly differentiated from toon and realistic and was closer to scary. However, such a pattern was not visible in trajectory length, minimum distance, or side-by-side distance. Given the mean values of all measurements, we posit that the robot and creepy styles should be placed in the middle of the avoidance behavior spectrum, although erring toward the "scary end."

As mentioned previously, according to the proxemics model, the participants approached virtual characters within their social spaces ($122-370$ cm) and more specifically inside the close phase of social spaces ($122-210$ cm). We suggest that such results could indicate that our participants experienced a similar degree of intimacy with all virtual characters, disagreeing with the norm of the uncanny valley effect [35, 37]. However, it should also be considered that the range of proxemics could be too wide to capture potential differences in avoidance movement tasks. Our results confirmed that the minimum distance between participants and standing virtual characters was behind for most of the examined rendering styles, which was followed in both trials (with the exception of creepy and robot). It should be noted that this finding aligns with previously published work that indicated humans usually maintain a greater distance (signifying safety) from virtual characters when approaching them from the front [2]. It is also worth noting that in both trials (and almost all examined rendering styles), most participants decided to keep the virtual character on their left side when performing avoidance tasks. This constitutes an interesting result, which indicates participants' tendencies toward executing such tasks. To the best of our knowledge, this is a relatively novel finding with respect to avoidance movements in virtual environments, and such fiding proves that real-world avoidance decisions [7] are similar to VR avoidance decisions.

Our findings on avoidance movement are quite interesting and encourage further exploration since they suggest that the rendering style of a virtual character affects the avoidance movement behavior of participants without apparently affecting their decisions. This assumption materialized since no evidence was found to indicate that the appearance of a virtual character was a factor that affected participant decisions to avoid characters from the left or right side or to maintain smaller distances in front or behind. These results reveal new paths that can be followed to gain a deeper understanding of how humans plan and execute avoidance movements based on the appearance of virtual characters.

Regarding our results on the self-reported ratings (**RQ2**), we found that different rendering styles caused the participants to change their perceptions of the virtual characters. Interestingly, toon was rated with lower empathy compared to realistic, robot was rated more realistic than scary, and the affinity level of robot was between scary and creepy. Although no significant results were found in the abovementioned comparisons between rendering styles, such small differences provide us with a sense of the complexity of understanding human perceptions when small manipulations between character appearances are examined [41]. While we suppose that the collected self-reported data is more complex, it still follows a certain logic: realistic (more pleasant) rendering styles induce empathy for the virtual character, whereas unappealing (less pleasant) styles prevent empathy toward the virtual character.

For the last research question (**RQ3**), we wanted to explore whether demographic factors correlated with avoidance movement behavior data and whether the movement measurements correlated with self-reported ratings. The results indicated that despite a single moderate negative correlation between **minimum distance** and **weight** for the scary rendering style and a weak negative correlation between **affinity** and **side-by-side distance**, no other significant correlation was found. Accordingly, we considered these correlations somewhat random instead of regular. We also suggest that the missing statistically significant correlations and their implications should be considered in future studies. However, we should mention that our study results contradict a previously published work [26], in which more significant correlations between avoidance movement measurements and self-reported ratings were found. This could be because a completely different questionnaire was used to collect self-reported ratings. As mentioned in the study conducted by Zibrek et al. [41] (the source of our questionnaire), it was too complex to capture precise participant responses toward the virtual character since the responses to such a questionnaire also depend on the behavior assigned to the virtual character. Accordingly, we were not able to identify any significant correlations.

6 Limitations

First, the virtual character model used for our study was a white male with a height of 175 cm, which was close to the average height of our participants. We used the same base model across conditions for two reasons: 1) we wanted to standardize the experimental conditions, and 2) we realized that the study duration would have increased, which could have been boring to our participants, causing them to lose motivation. To ensure broader generalizability of the findings, variations in height, shoulder width, gender, and ethnicity should be considered and explored in subsequent studies.

Second, we did not ask our participants to walk toward the goal position immediately after loading the experimental condition. Instead, we instructed them to start the walking task once they felt comfortable and ready. However, the time participants spent observing the virtual characters was relatively short. Specifically, the average time per virtual character was: 1.57 s for realistic, 1.41 s for toon, 1.51 s for creepy, 1.65 s for scary, and 1.70 s for robot. In addition, the character was 3.5 m away from the participants, which might have affected the way the participants observed subtle features (such as in the creepy rendering style). As a result, some more subtle features may not have been noted. While only a single participant commented on this potential issue, we still think it should be mentioned.

7 Conclusions

In this study, we examined the effect of virtual characters with realistic appearances on avoidance movement behavior. Various interesting results were obtained on how participants regulated their avoidance movements and decided to perform the given tasks and how they perceptually evaluated each of the examined rendering styles. Although prior work has demonstrated the effect of the appearance of virtual characters on participant responses, our paper extends this by demonstrating how such appearance alterations could affect avoidance behavior. Furthermore, we suggest that VR developers should consider our findings during the development process of room-scale VR environments that contain virtual characters.

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