Toward Understanding the Effects of Virtual Character Appearance on Avoidance Movement Behavior

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Abstract

This virtual reality study was conducted to assess the impact of the appearance of virtual characters on the avoidance movement behavior of participants. Five experimental conditions were examined. Under each condition, one of the five different virtual characters (classified as mannequin, human, cartoon, robot, and zombie) was studied. Each participant had to experience only one condition and was asked to perform the collision avoidance tasks two times. During the walking task, the motion of participants was recorded. After finishing the collision avoidance segment of the study, a questionnaire that examined different concepts (emotional reactivity, emotional contagion, attentional allocation, behavioral independence, perceived skill, presence, immersion, virtual character realism, and virtual character unpleasantness) was distributed to the participants. Based on the collected measurements (avoidance movement behavior and self-reported ratings), we tried to understand the effects of the appearance of a virtual character on the avoidance movement behavior, and its possible correlation to subjective ratings. The results obtained from this study indicated that the appearance of the virtual characters did affect the avoidance movement behavior and also some of the examined concepts. Additionally, participant avoidance movement behavior correlates with some subjective ratings.

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

1 Introduction

When exploring how a virtual character impacts a human's reaction, the most common concern is that of the appearance of the virtual character [38]. The understanding of the uncanny valley effect [37], which expresses a negative response from the user who is observing a human-like virtual character, is an ongoing investigation and the most common problem is the variety of stimuli used to represent different appearances of the virtual character. Although there are many studies on how people navigate in a group of virtual characters [28, 29, 41], we are missing information on how individuals interact with a single character that its appearance can be considered as pleasant, neutral, or aversive. Thus, in this paper, we approached this problem by using a variety of virtual characters, while keeping the realism of appearance and motion constant. Understanding how participants' reactions and perceptions are affected when interacting with virtual characters with different appearances could help developers to more precisely develop the parts of the virtual reality experiences that include human-character interaction. Thus, both the engagement and the immersion of participants could increase, while also achieving the necessary emotional and perceptual effects.

This study investigates whether the appearance of a virtual character can affect user movement behavior and how these potential movement changes could be associated with participants' self-reported ratings. Specifically, participants were asked to perform avoidance maneuvers from a starting to a finishing point, having the virtual character placed in the middle of the two points. Each participant had to experience only one of the conditions of the experiment. Specifically, each participant was asked to perform the collision avoidance maneuver by assuming the character of either only a mannequin, human, cartoon, robot, or zombie (see Figure 1). Hence, this study has a between-group design.

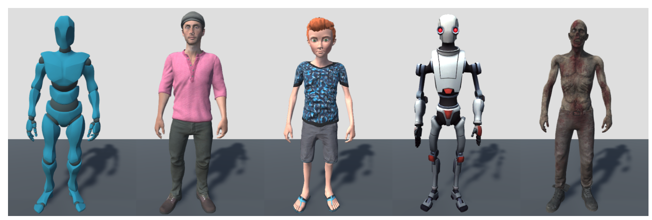

Figure 1: The different characters that were used in this study which participants were asked to avoid. From left to right: mannequin character (MC), human character (HC), cartoon character (CC), robot character (RC), and zombie character (ZC).

Since we are aware that virtual characters can be used to understand how participants perceive a character's appearance [19, 20], and since human motion can be used to assess interactions within virtual environments [39] and virtual characters [40, 44, 51], we assume that it might be feasible to extract a fair amount of useful information pertaining to the association between avoidance behavior and the appearance of a virtual character by examining how participants react and maneuver themselves when encountering mixed types of virtual characters. Two goals set for this study. The first goal was to investigate whether the appearance of a virtual character could affect a participant's movement behavior and perceptions during a collision avoidance task. The second goal was to investigate whether there are correlations between the avoidance movement measurements and the self-reported ratings of participants. These goals are embodied in the following research questions:

- **RQ1:** Are there differences in the avoidance movement behavior of participants across the five experimental conditions?
- **RQ2:** Are there emotional and perceptual changes across the five experimental conditions?
- **RQ3:** How do characters with neutral and pleasant appearances compare with aversive virtual characters?
- **RQ4:** Does the measured data from the participants' avoidance movement behavior correlate with the participants' self-reported ratings?

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Related works are presented in Section 2. The methodology and implementation details are given in Section 3. The results are presented in Section 4 and discussed in Section 5. Finally, conclusions, limitations, and potential future work are addressed in Section 6.

2 Related Work

A number of studies have investigated virtual character appearance from different perspectives. Specifically, Bailenson et al. [4] tried to link appearance with realism and proximity. It was found that behavior and appearance implications in virtual characters can be quite complex. The study of McDonnell et al. [35] investigated the render style and found that even without changing the geometry (3D mesh) of the virtual character, appeal ratings were affected regardless of the perceived realism. Zibrek et al. [64] examined whether rendering style and personality traits had the most significant impact on the appeal of virtual characters or not. The results indicated that the rendering style (realistic rendering) is in fact the most important factor. Zell et al. [62] went a step further and investigated how shape (3D mesh) and appearance (material) factors can affect character realism. The study concluded that a character's degree of appeal is mainly based on materials and a character's degree of realism is mainly based on shape.

A study conducted by Zibrek et al. [65] found that there is a correlation between the appearance of virtual characters and the personality assigned to them. It was found that a less attractive virtual character would be assigned with fewer desirable traits compared to a more attractive one. However, it should be noted that the mentioned study explored only two styles and was not conducted in virtual reality. To further understand the effects of rendering realism, Zibrek et al. [63] compared the effect of render style in virtual reality. Results from this study indicated that realism was related to appeal but did not impact the proximity. Kätsyri et al. [26] investigated virtual face models by exploring degrees of human-likeness and affinity. They found that less realistic faces were perceived by participants as more pleasant. Finally, Bruneau et al. [10] assessed virtual character appearance implications by investigating participant navigational choices when asked to perform a locomotion task with a joystick instead of actual physical involvement, as our participants had to do in our study. They found that both crowd appearance and crowd motion affected the chosen paths that participants followed.

Bönsch et al. [8] studied collaborative collision avoidance tasks and found that participants were anticipating collaborative collision avoidance when interacting with a virtual character; however, participants were also willing to independently change their paths within the virtual environments. Sanz et al. [51] studied avoidance behavior in natural walking scenarios by comparing real and virtual static obstacles as well as human-like and inanimate objects. Participants performed different locomotive behaviors when encountering real and virtual obstacles as well as anthropomorphic and inanimate objects. Silva et al. [54] compared the collision avoidance behaviors between participants and virtual characters and found that participants implemented different avoidance strategies while walking and circumventing virtual human characters when compared to non-human obstacles in a virtual environment.

In evaluating social interaction between humans and virtual characters, proxemics [17, 18, 51] and interpersonal distance [3, 13, 23] have been used quite efficiently. Among other, research on interpersonal distance, equilibrium theory [2] and/or personal space (the immediate space surrounding a person) has shown two things. First, proxemics can potentially generate objective insights in the social presence as perceived by the human user [2]. Second, the characters' appearance in terms of how their body shape is [22], how they gaze [2, 40], and how they express emotions [53], have indeed an effect on the behavior of participants.

Furthermore, a number of different techniques have been proposed by kinesiology and virtual reality researchers to analyze and understand the avoidance behavior and human locomotion. Some of the criteria used include completion time, distance traveled [11, 12], number of collisions [33], precision of the followed path [48], shape of the trajectory [1], distance metrics between trajectories [9, 15, 57], distance error [24], and empirical observations of trajectory visualizations [61]. A set of various metrics was proposed by Fink et al. [15] that includes the followed path's mean radius of curvature, the distance between the origin and the target given by a straight line, and the distance between the path and the obstacles participants were instructed to avoid. Whitton et al. [60] conducted a trajectory-based principal component analysis to compare virtual reality locomotion interfaces. Various other methods that incorporated components of the gait cycle such as stride length, stride velocity, as well as step width and its variability, have also been used to understand and compare walking motion [21, 57]. Finally, Cirio et al. [11] used trajectographical criteria that take into account shape, performance and kinematic features. Then, they used trajectographical criteria to compare human motion performed in virtual and real environments. This present study considered three avoidance movement behavior features (length of the trajectory, clearance distance, and walking speed) in order to analyze and to further understand participant avoidance behavior as these features can provide a great deal of significant information regarding the spatiotemporal movement of participants as they avoid a virtual character.

Previous research on interpersonal distance [7, 46] has also examined the association of avoidance behavior with subjective reactions and perceptions in regards to (social) presence. However, unlike Kätsyri et al. [26] who argued that subjective affinity should be measured rather than objective factors, this paper investigates whether subjective ratings correlate with objective measurements so that we can further understand how humans perceive and react to virtual character's appearance. To the best of our knowledge, no research has been conducted that captures and analyzes movement behavior data in order to investigate the effects of virtual character appearance on participant behavior during a collision avoidance task. Thus, our study extends the general understanding of avoidance behavior when interacting with virtual characters. In short, we think that valuable insight from this study could lead significant input for virtual reality developers when implementing applications involving virtual characters. Moreover, a connection of avoidance movement behavior measurements with self-reported participant ratings could generate new methods for assessing human interaction with virtual characters.

3 Materials and Methods

This section presents the methodology and implementation details of this study.

3.1 Participants

Participants were recruited in various ways; e-mails were sent to undergraduate and graduate students, posters were placed on various notice boards on campus, and in-class announcements were made. In total, 60 students participated in this study on a voluntary basis; no compensation was given for participating. All participants provided informed consent form in accordance with the Institutional Review Board of Purdue University. The study group consisted of 44 male students ($M = 22.36$, $SD = 3.47$), and 16 female students ($M = 23.25$, $SD = 2.93$). Participants were assigned to each group randomly. We also made sure we kept a roughly equal ratio of female participants in each groups, that is, the human character (HC) group consisted of four female participants while each of the rest of the groups consisted of three females. Only 11 participants had prior virtual reality experience. Moreover, none of the participants reported nausea or cybersickness and no students reported motor implications or musculoskeletal disorders that might have affected their movement behavior.

3.2 Experimental Conditions

Each participant experienced only one of the five conditions according to our between-group design (12 participants per group). In each condition the examined virtual character (see Figure 1) was placed in the middle of the virtual environment (see Figure 3). We used a mannequin character (MC), a regular human character (HC), a cartoon character (CC), a robot character (RC), and a zombie character (ZC). All characters had similar height and shoulder width in order to standardize the experimental conditions across the participant groups. Moreover, the characters were not scripted to look at the participants (`LookAt` functionality) for two reasons. First, we realized that such a parameter might not work for all conditions as expected since the mannequin character did not have eyes. Second, we decided to avoid implementing such a parameter because research has shown [2, 40] that the gaze of the virtual character might have had an additional effect on the avoidance movement behavior of our participants. Moreover, we did not change the height of the characters according to the height of the participants. We considered this a key aspect that would help us standardize the experimental conditions. Apart from the virtual character, all other aspects of the virtual environment were identical.

3.3 Measurements and Ratings

Both objective measurements (avoidance movement behavior data) and subjective ratings (questionnaire responses) were collected to investigate possible changes on the participants' reactions and perceptions during the experiment. The following sub-sections describe the measurements and ratings in detail.

3.3.1 Avoidance Movement Data

A motion capture system was used to record the avoidance movement behavior of participants under the assigned experimental conditions. It is feasible to extract a number of different measurements based on the recordings [11, 15, 57]. We computed three features of avoidance movement: the length of the trajectory, the clearance distance, and the walking speed of the participants. The extracted trajectories from the full-body motion of the participants were filtered in hundred equidistant points as in [39, 40], and therefore the measurements were based on those filtered points. These measurements provided spatiotemporal information about the participants' movement behavior. The avoidance movement measurements were as follow:

- **Length:** The length of the extracted root trajectory between the starting and ending point (goal position), measured in meters.
- **Clearance:** The shortest distance between the participant and the virtual character during the avoidance task, measured in meters.
- **Speed:** The average speed of the participants' walking motion from the start to the goal position, measured in meters/second.

3.3.2 Questionnaire

We developed a questionnaire to capture various reactions and perceptions from the participants. The questionnaire included fifteen items that explored the following concepts: emotional reactivity, emotional contagion, attentional allocation, behavioral independence, perceived skill, presence, immersion, virtual character realism, and virtual character unpleasantness. Four emotional reactivity (Q1-Q4) questions were adopted by Mousas et al. [38], two emotional contagion (Q5-Q6), one attentional allocation (Q7), and two behavioral independence (Q8-Q9) questions were adopted by Biocca et al. [6], one perceived skill (Q10) question was adopted by Tcha-Tokey et al. [58], two presence (Q11-Q12) questions were adopted by Slater et al. [55], and one immersion (Q13) question was adopted by Jennett et al. [25]. Some of the questions were adjusted to fit the purpose of this experiment. The questions regarding the realism (Q14) and unpleasantness (Q15) of the virtual character were developed by the researchers of this paper. The questionnaire was given to participants in a paper-based format and was distributed after the end of the collision avoidance segment (after the second trial) of the study. Finally, participants were allowed to include comments or concerns about the study. The questionnaire used in this study is shown in Table 1.

3.4 Real and Virtual Environment

The site used by the research team was the motion capture studio of a university department. The studio was 8 meters long and 8 meters wide, with a ceiling height of 4 meters. These dimensions were used to design the virtual environment. Besides a computer desk and chairs, no obstacles were in the real space; this made the studio appropriate for this experimental study. A virtual replica of the motion capture studio was designed in 3ds Max and then imported into the Unity game engine to represent the real space. We created a virtual replica of the real space as a prior studies had shown that imaginary virtual environments affect the movement behavior and arousal [39] of participants.

3.5 Equipment and Virtual Reality Application

The application that was used for this study was developed in the Unity game engine (version 2019.1.4). An MSI VR One backpack computer (Intel Core i7, NVIDIA GeForce GTX1070, 16GB RAM) was used for running the application, the HTC Vive Pro head-mounted display was used for projecting the virtual reality content, and an Xsens motion capture system was used for capturing the motion of participants. In regard to the backpack's rather substantial weight at 3.3 kg., all participants reported that it bore no impact on neither their sense of comfort nor on their ease of walking. Figure 2 shows a participant wearing the equipment while performing the collision avoidance task.

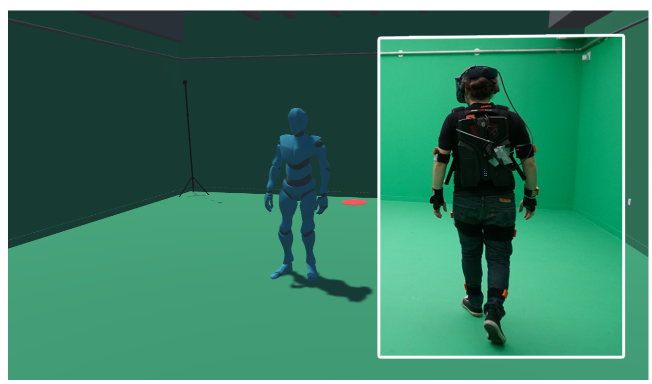

Figure 2: A participant wearing all the equipment used for this study while performing the collision avoidance task during the mannequin character condition.

A single scene was developed in Unity, as shown in Figure 3, which included the designed virtual environment replica. Blue and red marks on the ground were used to indicate the start (blue mark) and goal (red mark) positions to the participants. Invisible cylindrical colliders with a .50 meter radius were placed at the center of the start and goal marks to detect when the participant exited the start and entered the goal positions respectively. A collider was used to start and stop the recording respectively when the participant left the start position and entered the goal position, as well as to initiate the saving of the recording when the participant entered the start position after performing the collision avoidance task. The experimenter, who was looking at the Inspector window in Unity, was

Table 1: The questionnaire that was developed and used for the purpose of this study.

Label	Question	Anchors of the Scale
Q1	Would you feel uneasy if this virtual character communicated with you?	1 indicates not at all, 7 indicates totally.
Q2	Would you feel uneasy if this virtual character tried to approach you?	1 indicates not at all, 7 indicates totally.
Q3	Does the appearance of the character make you feel uncomfortable?	1 indicates not at all, 7 indicates totally.
Q4	Do you feel that the appearance of the character made you unready to interact with him?	1 indicates not at all, 7 indicates totally.
Q5	I was influenced by the character's appearance.	1 indicates not at all, 7 indicates totally.
Q6	The character's appearance did affect my mood.	1 indicates not at all, 7 indicates totally.
Q7	I paid close attention to the character.	1 indicates not at all, 7 indicates totally.
Q8	My behavior was in direct response to the character's appearance.	1 indicates not at all, 7 indicates totally.
Q9	My avoidance behavior was in direct response to the character's appearance.	1 indicates not at all, 7 indicates totally.
Q10	I felt confident moving around the virtual environment.	1 indicates not at all, 7 indicates totally.
Q11	Please rate your sense of being in the virtual environment.	1 indicates not at all, 7 indicates totally.
Q12	To what extent were there times during the experience when the virtual environment was reality for you?	1 indicates being in the real world, 7 indicates being in the virtual environment.
Q13	I was so immersed in the virtual environment; it seemed real.	1 indicates not at all, 7 indicates totally.
Q14	How realistic was the virtual character?	1 indicates not at all, 7 indicates totally.
Q15	How unpleasant was the virtual character?	1 indicates not at all, 7 indicates totally.

responsible for monitoring and controlling this process, if necessary. As previously mentioned, the virtual character that participants were asked to avoid was put at a midway point. Participants were shown a black screen in between trials of the collision avoidance task. Additionally, the character was aligned with the goal position mark facing the participant. This process was controlled and inspected by the experimenter using a button in the Inspector window of the Unity.

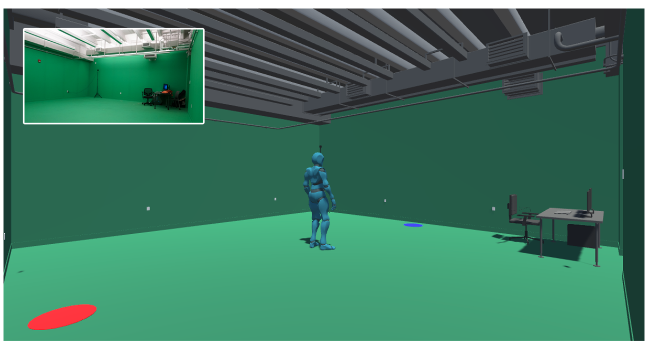

Figure 3: The main scene developed for our virtual reality experiment during the mannequin character condition.

The robot character was downloaded from Unity Asset Store and the other four characters shown in Figure 1 were downloaded from Adobe's Mixamo. We used the Unity Mechanim animation engine to assign a neutral idle motion to the virtual characters. A neutral idle motion was selected because we did not want to influence the reactions of participants by assigning an exaggerated motion to the avoidance character, since it has been found that body motion with high amplitude assigned to a virtual character affects the emotional reactivity of participants [38], and this reaction might have affected negatively the avoidance behavior of participants. The motion data assigned to the virtual characters was downloaded from the Unity Asset Store. A previously conducted study has shown that self-avatars affect the avoidance movement behavior of participants [40]. Therefore, we decided to avoid representing participants with a self-avatar in order to capture a general collision avoidance reaction that was not influenced by the appearance of the avatar of the participant. We also decided that the humanoid characters that participants were asked to avoid should be male (or male-like for the humanoid mannequin and the robot). If we had additional virtual characters of the opposite gender the total duration of the experiment would have increased, and we were therefore concerned that the experiment might have bored the participants and cause loss of motivation. The influence of character gender on avoidance behavior will be addressed in future research.

A 7-meter distance was set between the start and goal positions and the virtual character was placed in the midpoint at 3.5 meters to give participants enough space to maneuver. It should be noted that a previous study [40] has shown that such a distance is enough to allow participants to move smoothly without sudden maneuvers. Finally, in the virtual environment, the virtual character was oriented in such a way that it was always facing toward the starting point (see Figure 3.

3.6 Procedure

The participants came to the motion capture studio where the experimental study took place. After the experimenter briefly informed participants about the project, participants were asked to sign the provided consent form and to complete the demographics questionnaire. The experimenter helped the participants to attach the motion capture system and then the calibration process begun. Then, the experimenter assisted the participants with the backpack computer and the head-mounted display. Once everything was set, participants were asked to take a short walk, first in the real room and then in the virtual environment, to ensure they were able to move comfortably when wearing all the required equipment. The virtual environment was the virtual replica of the motion capture studio; there was no virtual character in the virtual environment at this stage. Participants were then informed that there was a one-to-one matching size ratio between the real and virtual environment, which meant that a wall in the virtual environment corresponded to a wall in the real environment.

After participants were familiarized with the virtual reality equipment, the experimenter turned on the indicators and participants were asked to move toward the start position (blue indicator) and to face the red indicator, which was the goal position. Once participants landed on the start indicator a black screen would appear. During this initial black screen mode participants were informed that once the application began there would be a virtual character midway between the start and goal position.

Participants were informed that the virtual character's position would not be altered or updated. Once arrived at the goal position, participants were instructed to move back toward their initial marked position (blue indicator) for the next trial. Participants were further instructed the screen would turn black, once they had reached the goal position. At that point the application would restart but this time the virtual character would not be present. The experimenter informed the participants that they had enough space to avoid the virtual character—so that participants feel safe in the virtual environment—and that they were allowed to avoid the virtual character by moving either right or left, as they preferred. As an additional precaution, participants were informed that in the event that they approached within 50 centimeters of any of the walls a warning sound (a "beep") would play to alert them, so they could stop moving and avoid hitting the walls. However, none of the participants moved close enough to trigger the warning. Participants were told that they could have breaks between the trials of the condition if needed and that they had full permission to leave at any time without any consequences.

A visual countdown graphical icon was implemented to inform participants when the system was ready for them to begin walking. Participants were also told about the structure of the experiment. Specifically, they were told that the experimenter would inform them when the collision avoidance segment (collision avoidance part of the study) of the study was concluded, and that after this segment was completed, they would be asked to move to the second segment of our experiment (collection of self-reported data) and complete a questionnaire that would be handed to them. The virtual reality condition (character appearance) to which each participant would be exposed was not mentioned. Participants only saw the appearance of the character only once the experiment had begun. Participants were also told that they would be asked to avoid the virtual character and reach the target position and that this process would be performed two times as in Berton et al. [5]. It is worth noting that the total duration of the whole procedure, including the calibration process of the motion capture system, lasted on average 30 minutes.

4 Results

A one-way analysis of variance (ANOVA) was used to analyze the obtained data, using the five experimental conditions as independent variables, and the avoidance movement behavior measurements and the answers from the questionnaire as dependent variables. The individual differences were assessed using a post-hoc Bonferroni corrected estimates if the ANOVA was statistically significant. A $p < .05$ value was judged as statistically significant. The avoidance movement behavior and the self-reported data were screened for correlations using the Pearson product-moment correlation coefficient.

The normality assumption of the objective measurements and subjective ratings were evaluated graphically using Q-Q plots of the residuals. Q-Q plots indicated that the obtained data fulfilled the normality assumption. Moreover, the homogeneity of participants was tested by using their age and the height as the dependent variables and the five experimental conditions as independent variables. One-way ANOVAs revealed no statistical significant results for the age [$F(4,55) = .389$, $p = .816$, $\eta_p^2 = .284$] and the height [$F(4,55) = 1.049$, $p = .390$, $\eta_p^2 = .231$].

The obtained data was screened for gender differences. Despite the fact that past research literature has shown gender can affect behavior [65], we did not detect any gender-based effects across the five experimental conditions; most likely due to the small sample of female participants per group. Additionally, the collected data was screened to identify whether our participants changed their trajectory length, clearance, and speed when avoiding the virtual character from the other side. No statistical significant results were found most likely because only the 5.5% of captured trajectories were on the other side.

We also screened our data to identify whether there were trajectory length, clearance, and speed significant differences between the participants' first trial and the subsequent one. No statistical differences were observed. A possible explanation for this finding could be the participants' knowledge of the virtual character's position in the virtual environment acquired during the first trial.

4.1 Movement Behavior

We compared the effect of virtual character appearance on participant movement behavior using three avoidance movement behavior measurements (length, clearance, and speed) across the five experimental conditions (MC, HC, CC, RC, and ZH). The average avoidance-movement trajectories of all participants during each condition are shown in Figure 4. Finally, descriptive statistics for the movement measurements are provided in Table 2.

Table 2: Descriptive statistics of each avoidance movement behavior measurement across the five experimental conditions, and patterns of differences. MC: Mannequin Character, HC: Human Character, CC: Cartoon Character, RC: Robot Character, and ZC: Zombie Character.

Condition	*M*	*SD*	*Min*	*Max*	Pattern of Differences
			Length		
MC	8.53	.58	7.30	9.67	(MC=HC)<ZC
HC	8.47	.55	7.89	9.49	
CC	8.72	.68	7.85	9.74	
RC	8.75	.81	7.93	9.96	
ZC	9.41	.63	7.69	10.08	
			Clearance		
MC	.65	.09	.52	.79	(MC=HC=CC=RC)<ZC
HC	.62	.10	.46	.81	
CC	.68	.08	.55	.82	
RC	.72	.11	.53	.85	
ZC	.94	.07	.79	1.06	
			Speed		
MC	1.26	.19	.96	1.64	(MC=HC=CC)<ZC
HC	1.33	.16	1.08	1.59	
CC	1.31	.29	.83	1.72	
RC	1.54	.30	.91	2.07	
ZC	1.73	.30	1.11	2.11	

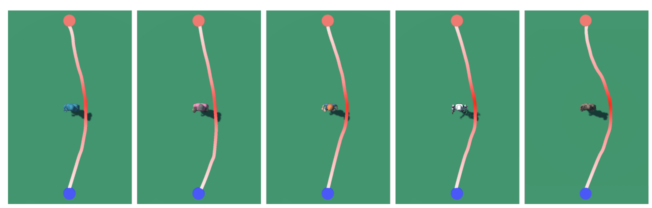

Figure 4: Visualization of the average avoidance-movement trajectories of all participants for all examined conditions. The gradient color denotes the distance between the participants and the virtual character. Red denotes the closest and white the furthest. From left to right: mannequin, human, cartoon, robot, and zombie characters.

The **lengths** of the participants' trajectories were judged to be significantly affected by the appearance of the virtual character across the five experimental conditions [$F(4,55) = 1.693$, $p < .01$, $\eta_p^2 = .702$]. Pairwise comparisons indicated that the mean score for the ZC condition was significantly higher than that for the MC condition ($p < .05$) and the HC condition ($p < .01$).

We identified a statistical significant effect on the participants' **clearance** across the five experimental conditions [$F(4,55) = 28.359$, $p < .001$, $\eta_p^2 = .473$]. Pairwise comparisons indicated that the mean score for the ZC condition was significantly higher than that for the MC condition ($p < .001$), the HC condition ($p < .001$), the CC condition ($p < .001$), and the RC condition ($p < .001$).

Finally, we also found a statistical significant effect on the participants' **speed** across the five experimental conditions [$F(4,55) = 6.860$, $p < .001$, $\eta_p^2 = .395$]. Pairwise comparisons indicated that the mean score for the ZC condition was significantly higher than that for the MC condition ($p < .001$), HC condition ($p < .01$), and CC condition ($p < .01$).

4.2 Self-Reported Ratings

The effect of virtual character appearance on the participants' self-reported ratings across the five experimental conditions (MC, HC, CC, RC, and ZH) was also explored. Descriptive statistics are provided in Table 3.

We found non-significant effects at the $p < .05$ level regarding **attentional allocation** [$F(4,55) = .681$, $p = .608$, $\eta_p^2 = .259$], **behavioral independence** [$F(4,55) = .415$, $p = .797$, $\eta_p^2 = .169$], **perceived skill** [$F(4,55) = .443$, $p = .777$, $\eta_p^2 = .224$], and **immersion** [$F(4,55) = .907$, $p = .466$, $\eta_p^2 = .190$]. However, analyzing the self-reported ratings for **emotional reactivity**, we identified a statistical significant effect of virtual character appearance across the five conditions [$F(4,55) = 5.673$, $p < .001$, $\eta_p^2 = .421$]. Pairwise comparisons indicated that the mean score for the ZC condition was significantly higher than that for the MC condition ($p < .05$), the HC condition ($p < .001$), the CC condition ($p < .005$), and the RC condition ($p < .05$).

The obtained self-reported ratings for **emotional contagion** revealed a statistical significant effect of virtual character appearance across the five conditions [$F(4,55) = 5.787$, $p < .001$, $\eta_p^2 = .368$]. Pairwise comparisons indicated that the mean score for the MC condition was significantly lower than that for the HC condition ($p < .05$), and the ZC condition ($p < .001$).

Regarding **presence** the results indicated a statistical significant effect of virtual character appearance across the five conditions [$F(4,55) = 4.854$, $p < .002$, $\eta_p^2 = .422$]. Pairwise comparisons indicated that the mean score for the ZC condition was significantly higher than that for the MC condition ($p < .01$), the HC condition ($p < .05$), the CC condition ($p < .005$), and the RC condition ($p < .05$).

The **virtual character realism** was also evaluated by the participants. The results indicated a statistical significant effect of virtual character appearance across the five conditions [$F(4,55) = 12.652$, $p < .001$, $\eta_p^2 = .227$]. Pairwise comparisons indicated that the mean score for the MC condition was significantly lower than that for the HC condition ($p < .001$), the CC condition ($p < .001$), the RC condition ($p < .05$), and the ZC condition ($p < .005$). Additionally, the mean score of RC condition was statistically significant lower that the HC condition ($p < .05$).

Finally, the results regarding **virtual character unpleasantness** indicated a statistical significant effect of virtual characters' appearance across the five conditions [$F(4,55) = 9.801$, $p < .001$, $\eta_p^2 = .480$]. Pairwise comparisons indicated that the mean score for the ZC condition was significantly higher than that for the MC condition ($p < .001$), the HC condition ($p < .001$), the CC condition ($p < .001$), and the RC condition ($p < .001$).

4.3 Correlations

We conducted a correlation analysis to understand whether the avoidance movement behavior measurements of participants were correlated with the subjective self-reported ratings. In total, we examined 27 combinations between avoidance movement behavior measurements and the participants' emotional reactions and perceptions (three avoidance movement behavior measurements and nine components from the questionnaire) using a bivariate Pearson correlation. A summary of bivariate Pearson correlation coefficients for all examined avoidance movement behavior data and self-reported subjective ratings are given in Table 4.

We found a weak positive correlation between the **emotional reactivity** and the **length** of the trajectory [$r = .309$, $n = 60$, $p = .016$], a moderate positive linear correlation between the **emotional reactivity** and the **clearance** [$r = .516$, $n = 60$, $p = .001$], and a weak positive correlation between the **emotional reactivity** and the **speed** of the participants [$r = .326$, $n = 60$, $p = .011$]. We also found a moderate positive linear correlation between the **emotional contagion** scores and the **speed** of the participants [$r = .365$, $n = 60$, $p = .004$], and a weak positive linear correlation between the **emotional contagion** and the **clearance** [$r = .320$, $n = 60$, $p = .013$]. Finally, we found a weak positive linear correlation between

Table 3: Descriptive statistics for each variable obtained from the subjective ratings across the five experimental conditions, and patterns of differences. MC: Mannequin Character, HC: Human Character, CC: Cartoon Character, RC: Robot Character, and ZC: Zombie Character.

Condition	*M*	*SD*	*Min*	*Max*	Pattern of Differences
Emotional Reactivity					
MC	3.75	1.01	2.25	5.00	(MC=HC=CC=RC)<ZC
HC	3.29	.92	1.25	4.75	
CC	3.43	.73	2.25	4.50	
RC	3.77	.99	2.00	5.00	
ZC	4.89	.88	3.50	6.00	
Emotional Contagion					
MC	3.39	1.46	1.00	5.25	MC<(HC=ZC)
HC	4.52	.66	3.25	5.50	
CC	4.29	.68	3.50	5.50	
RC	4.20	.72	3.50	5.75	
ZC	5.18	.84	4.00	6.25	
Attentional Allocation					
MC	4.08	1.56	2.00	6.00	MC=HC=CC=RC=ZC
HC	3.58	1.50	2.00	6.00	
CC	4.16	1.33	2.00	6.00	
RC	3.75	1.71	2.00	5.00	
ZC	3.33	1.07	2.00	6.00	
Behavioral Interdependence					
MC	4.67	.91	3.00	6.00	MC=HC=CC=RC=ZC
HC	4.37	1.22	2.50	6.00	
CC	4.16	.96	2.50	5.50	
RC	4.37	.97	3.00	6.00	
ZC	4.54	.99	2.50	6.00	
Perceived Skill					
MC	5.16	1.33	3.00	7.00	MC=HC=CC=RC=ZC
HC	4.66	1.66	2.00	7.00	
CC	4.50	1.44	3.00	7.00	
RC	5.08	1.31	2.00	7.00	
ZC	4.83	1.46	3.00	7.00	
Presence					
MC	4.12	1.20	2.50	6.00	(MC=HC=CC=RC)<ZC
HC	4.25	.94	3.00	5.50	
CC	4.04	1.17	2.00	6.00	
RC	4.16	.91	3.00	5.50	
ZC	5.62	.95	3.50	7.00	
Immersion					
MC	4.50	1.62	2.00	7.00	MC=HC=CC=RC=ZC
HC	5.00	1.59	2.00	7.00	
CC	4.25	1.76	2.00	7.00	
RC	4.16	1.46	3.00	6.00	
ZC	5.08	1.16	2.00	7.00	
Virtual Character Realism					
MC	2.25	1.21	1.00	4.00	(MC=HC=CC=RC)<ZC
HC	5.50	1.62	3.00	7.00	
CC	5.08	.66	4.00	6.00	
RC	3.83	1.19	2.00	6.00	
ZC	4.16	1.26	3.00	7.00	
Virtual Character Unpleasantness					
MC	3.16	1.80	1.00	6.00	(MC=HC=CC=RC)<ZC
HC	2.58	1.08	1.00	4.00	
CC	2.41	1.16	1.00	4.00	
RC	3.16	1.64	3.00	6.00	
ZC	5.66	1.43	1.00	7.00	

Table 4: Summary of bivariate Pearson correlation coefficients for all examined objective measurements (avoidance movement behavior data) and subjective ratings (questionnaire).

	Length	Clearance	Speed
Emotional Reactivity	.31*	.52**	.33*
Emotional Contagion	.26	.32*	.37**
Attentional Allocation	−.12	−.16	−.11
Behavioral Interdependence	.10	−.04	−.09
Perceived Skill	.09	.07	−.05
Presence	.24	.22	.18
Immersion	.02	.11	.03
Virtual Character Realism	.04	−.03	.02
Virtual Character Unpleasantness	.32*	.49**	.19

*Correlation is significant at the .05 level (2-tailed).
**Correlation is significant at the .01 level (2-tailed).

the **virtual character unpleasantness** scores and the **length** of the trajectory [$r = .319$, $n = 60$, $p = .013$], and a moderate positive linear correlation between the **virtual character unpleasantness** and the **clearance** [$r = .493$, $n = 60$, $p = .001$].

5 Discussion

Five experimental conditions were developed that examined a different virtual character (mannequin, human, cartoon, robot, and zombie) in order to investigate the effects of character appearance on the users' collision avoidance behavior. Specifically, two goals were set. First, we assessed the avoidance behavior of participants based on the appearance of a virtual character using avoidance movement behavior measurements and self-reported rating. Second, we explored whether there was a correlation between the avoidance movement measurements, and the self-reported ratings of the participants.

The obtained results from the avoidance movement behavior measurements **(RQ1)** indicated that the length of the trajectory was greater when participants were asked to avoid a zombie virtual character when compared with a human character or a neutral character such as the mannequin character. We also found that the clearance distance during the zombie character condition was greater when compared to any other virtual character. We could say that, based on the average clearance distance, and the proxemics [17, 18, 51] and interpersonal distance [3, 13, 23] models, our participants approached the virtual character within its personal space (between .46-1.22 meters), which we think indicates they experienced a certain degree of intimacy with all virtual characters. Moreover, based on the trajectory information (see Figure 4), it can be clearly understood that the closest distance between the participants and the virtual character was observed when our participants were either positioned side-by-side (MC, HC, and CC) or behind the virtual character (RC and ZC). This finding is in agreement with Bailenson et al. [3] who indicated that participants usually keep a greater distance (connoting safety) from virtual characters when approaching them from the front. Our results indicated that the speed of participants during the zombie virtual character condition was greater when compared with the mannequin character, human character, and cartoon character scenarios. Additionally, **(RQ3)** the speed of the participants during the collision avoidance with the robot character was in-between the speeds recorded for the zombie character (aversive stimulus) and the rest of the characters (neutral and pleasant stimuli).

Based on this statistical significant differences the length, clearance, and speed of participants were greater in the zombie character condition. Overall, the avoidance movement behavior measurements indicated distinct differences **(RQ3)** between the zombie virtual characters condition on one side, and the mannequin, human and cartoon character conditions on the other side. Moreover, we found that the robot character is placed somewhere between these two groups of characters (neutral and pleasant stimuli versus aversive stimulus). In other words, the results indicate that the participants regulate their avoidance movement behavior differently when interacting with an aversive virtual character when compared with regular, pleasant, and neutral virtual characters.

The ANOVA analyses indicated that the appearance of the zombie virtual character had an effect on the length of the trajectory, the clearance, and the speed of the participants. The avoidance movement behavior measurements indicated that the zombie character triggered stronger avoidance reactions by causing the participants to exhibit greater trajectory length, greater clearance distance, and higher walking speed when compared to their reaction to the other four virtual characters. The findings of the current study are quite promising and encouraging because they indicate that virtual character appearance does indeed affect avoidance movement behavior. The five conditions of the experiment were classified in three categories: those characters that had a low effect (mannequin, human, and cartoon characters), a medium effect (robot character), and a high effect (zombie character). The low and high effect categories of characters had a higher impact on the length, the clearance, and the speed measurements of the participants than the robot character.

The self-reported ratings **(RQ2)** showed that there were emotional and perceptual changes and were mainly found in the group that interacted with a zombie virtual character. Specifically, the emotional reactivity, presence, and the virtual character unpleasantness scores were higher when facing the zombie character than any other examined virtual character. We also found that the emotional contagion scores for a virtual mannequin (neutral) character were lower when compared with the human character and zombie character. Finally, we found that the virtual character realism scores were lower for the virtual mannequin character than all the other examined virtual characters, and the virtual character realism score for the robot character was lower than the human character.

Although we found statistically significant differences in emotional reactivity, emotion contagion, presence, virtual character realism, and virtual character unpleasantness; no such differences were found in the attentional allocation, behavioral interdependence, perceived skill, and immersion of participants. Attentional allocation was not related to the appearance of the virtual character, and according to the results, participants reported similar attention scores for all virtual characters, regardless of their appearance. Although previous studies have identified differences in attentional allocation [36, 53], we think that those results are attributed mainly to the fact that participants were only able to see the face of the virtual characters, and not the whole body. It should be noted that the five different virtual characters that were used in this study did not all share identical facial expressions. For example, MC and RC have almost no facial expressions, HC and CC have similar facial expressions with each other, and ZC has completely different facial expressions from all the rest. Facial expressions of virtual characters could be important, as previous work has shown that they could easily affect emotional bias and proximity levels between participants and virtual characters [7, 26]. Finding a perfectly "neutral" expression is challenging, but it is worth noting the potential effect expressions may have on the obtained data. On the basis of non-significant results, we can say that facial expressions do not affect participants' attentional allocation.

The results obtained for behavioral independence were partially anticipated since all participants indicated that their behavior was in direct response to the exposed virtual character. The results with respect to perceived skill were also anticipated since the virtual environment (the virtual replica of the motion capture studio) was the same across all groups. Similarly, the results with respect to immersion were also anticipated, since all of the participants locomotive movements were transferred within the virtual environment in the same way, similar immersion ratings were obtained. Our findings confirm those from Slater et al. [56] study, which found that in case there is correspondence between the participants' proprioceptive feedback and the information generated on the displays, such correspondence enhances the immersive experience.

The self-reported ratings indicated distinct differences **(RQ3)** between the zombie virtual character (aversive stimulus) and the rest of the virtual characters that were used in this study. The emotional reactivity, emotional contagion, and virtual character unpleasantness scores indicated that the appearance of the virtual characters was perceived by the participants of this study in the way they were expected to be perceived. More specifically, the zombie character elicited more negative reactions than the neutral and more pleasant characters. Another interesting result is the enhanced level of presence that participants had when interacting with an aversive virtual character (zombie character). This result suggests that even if the environment is unchanged, changing the exposed character condition was sufficient to change the participants' presence. This finding is in agreement with a previously conducted research that indicated that the feeling of presence increases in emotional environments [49]. Overall, based on statistically significant differences, it can be said that the appearance of characters, which can be characterized as neutral or pleasant (mannequin, human, and cartoon character), has less effect on the participants' emotional and perceptual reactions compared to an aversive virtual character even if the participants' rating of the perceived realism of such characters contradicts this.

The results from the ANOVAs suggest that the appearance of the virtual character impacted the participants' ratings. The zombie character was able to change the participants' emotional reactions. The realism of the robot character was ranked between the mannequin and the human characters, but even that realism was insufficient to affect the participants' emotional state or the unpleasantness level scores that the character received. The self-reported ratings suggest that the zombie character (aversive stimulus) generated more intense reactions than the other four virtual characters, and these findings indicate that a virtual character's appearance affects participants' reactions and perceptions. In addition, it is noted that even if participants rated the appearance of the zombie character as less realistic compared to human and cartoon characters, the participants' reactions and perceptions were more intense when facing that character. It should be noted that previously conducted studies found that when participants were asked to interact with virtual characters, the interaction between humans and virtual characters had been considered to be highly realistic in terms of subjective, objective, and physiological measurements [45, 47] even if the participants were aware that the interaction was taking place with virtual characters and not real humans [16].

The second goal of our study was to investigate whether there was a possible correlation between the avoidance movement behavior measurements and the subjective ratings obtained from the participants through the questionnaire. The results have indicated that perception and reaction levels indeed correlate with measurements related to avoidance movement behavior **(RQ4)** and that the appearance of virtual characters can in fact affect human movement behavior. It should be noted that, while avoidance movement behavior data may be associated with changes on the participants' reactions and perceptions, such behavior can also be highly affected by the task and the environment in which participants interact [51, 54]. Since correlations were found between avoidance movement behavior measurements and self-reported ratings, it is probable that avoidance movement behavior measurements, such as length of trajectory, clearance, and speed, could function as indicators of self-reported emotional and perceptual changes. Even though the current study has found some evidence, such correlations demands further investigation in order to determine whether a collision avoidance task between participants and static virtual characters can be used as a method for predicting and identifying participants' reactions and perceptions.

6 Conclusions, Limitations, and Future Work

In this study, we investigated the impact of virtual character appearance on participant avoidance movement behavior, emotional reaction and perception when asked to avoid a variety of virtual characters. Despite the fact that our results indicated a number of different effects that had already been anticipated, we still benefited from confirming them empirically. Related work has indeed demonstrated the impact of the appearance of virtual characters on the participants' emotional reactions [38,53,59] and perceptions [43,50,52]. However, our results indicate that there is evidence that emotional reactivity, emotional contagion, and virtual character unpleasantness ratings can be inferred from the avoidance movement behavior of participants during locomotive tasks since significant differences were found between the examined conditions. This is also consistent with the positive correlations that were found between the objective measurements and subjective ratings. To the best of our knowledge this is a rather novel finding.

There are four limitations to the results obtained from the current study. First, although no statistically significant differences were found with respect to the attentional allocation, it is highly hypothesized that the use of a head-mounted display with embedded eye-tracking functionality [30] should provide useful insights into the distribution and duration of gaze fixations, which would help us understand how participants pay attention to different virtual characters. Second, although no correlation was found between the self-reported behavioral independence rating and any of the avoidance movement behavior measurement of the participants, it is unclear whether or to what extent the behavior of participants was in direct response to the characters' appearance. This missing correlation should be thoroughly explored to be able to provide this missing link. Third, as mentioned earlier, no gender-based differences were found. It can be said that the limited number of female participants might have limited the generalizability of the results, since, according to past literature [38] the emotional reactivity levels of female participants to virtual characters is in fact higher when compared to males. Fourth, we also know that, based on interpersonal space and social virtual reality research, demographics such as right- or left-handedness, cultural background, and game preferences can be a factor that influences a participant's degree of social interaction and type of behavior when interacting with virtual characters [14, 34, 38]. However, we consciously chose not to collect such data since our main focus was to investigate the effects of virtual character appearance on participant avoidance movement behavior, and not its correlation with participants' background characteristics or personality traits. To conclude, despite the number of limitations we have set forward, we would like to point out that these do not invalidate our findings of the effects of virtual character appearance on participant avoidance movement behavior.

Apart from the aforementioned limitations that need further exploration, we would like to expand our work to different domains by analyzing human movement behavior in other virtual environments. Additionally, we would like to study the avoidance behavior between participants and characters with different personalities as well as with pleasant and unpleasant characters of both males and females. We are also planning to investigate the effects of tactile feedback [31, 32] during collision avoidance tasks with virtual characters to further understand movement changes in virtual environments. Finally, future work can focus on human movement behavior when interacting with multiple characters, such as when the participants are placed in a virtual crowd [3, 27, 29, 41, 42].

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