Asymmetric Virtual Environments: Exploring the Effects of Avatar Colors on Performance

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Abstract

Due to the virtual nature of Virtual Environments (VE), there is an affordance to change game and avatar features asymmetrically, where the features that are rendered for one participant can be different from those rendered for other participants while still sharing the same virtual world. We are calling these kinds of VEs Asymmetric Virtual Environments (AVE). In this paper we present work on a platform for studying online interactions using an AVE. We do so through a preliminary study that explores the effects of avatar colors on individual and group performance when solving a scavenger hunt in a 3D virtual environment followed by a location identification task in a 2D virtual environment. While the results of this preliminary study are not conclusive, our data seem to indicate that players' avatar colors can indeed influence online performance.

1 Introduction

A virtual environment (VE) is a communication system in which multiple interactants share the same digital context (*e.g.*, a 3D world) while possibly occupying different physical locations (Bailenson et al. 2005). While in the great majority of virtual environments the representation of the "world" that is rendered to every interactant is congruent, this does not have to always be the case. The virtual nature of VEs allow for differences in what each participant experiences individually (*e.g.*, different sounds, colors, avatars or scenery), which affects individual and group dynamics (Bailenson 2006; Bailenson and Beall 2006; Bailenson et al. 2004; 2005; 2008; Yee and Bailenson 2007).

When people interact with each other in traditional face-to-face settings a great amount of communication happens implicitly. Facial expressions, tone of voice, and body language in general, together with how a person looks and what they wear, provide information that affects how we perceive each other (Harris and Nelson 2008). All of this information comes together when building a preliminary impression of the other person, which shapes our expectations before and during the social interaction. When the context of human interaction is switched to a virtual environment none of this information is readily available or is synthetic (*i.e.*, generated by algorithms as animations, and therefore not an accurate portrayal of the real-world).

Usually, the only immediate information available in VEs comes from a person's on-line name and possibly a visual representation of the person – an avatar (Deuchar and Nodder 2003). Since the amount of available information about other people is greatly reduced in VEs, the elements of information that are available become much more influential in the way people are perceived. Further, due to the virtual nature of these, there is an affordance to change appearances and interactions asymmetrically, where one participant is presented with a different set of social cues that others see. It is these *Asymmetric Virtual Environments* (AVE) that we are interested in studying.

In particular, this paper describes a study exploring the effects of avatar colors on individual and group performance when completing tasks in virtual environments.

2 Related Work

It is known that humans react to certain stimuli by triggering an instinctive and automatic response (Cialdini 1985). However, it cannot be assumed that people will react to virtual stimuli in the same way that they would react in real settings. It is therefore important to explore the effects of these stimuli in virtual environments and determine to what extent they apply. A viable approach to exploring these effects is identifying the stimuli that trigger an automatic response in humans in the first place.

2.1 Effects of Colors on Behavior, Perception, and Performance

Colors have been known to affect our perception and behavior. For example, the color red has been shown to have physiological effects on people who perceive it, such as increased respiratory rate and blood pressure (Gerard 1958). More recent research showed that these effects of red had a negative impact on consumer reactions, while the color blue had the most positive responses (Bellizzi and Hite 1992).

Colors can also affect how we perceive others. Vrij showed that suspects during a crime judgment were perceived as being more aggressive or offensive when wearing black clothes (Vrij 1997). This work also found that suspects were found more guilty when their clothes were black. Similar work also found that people wearing black clothes were perceived as being more masculine and less reliable (Vrij and Akehurst 1997).

Thorough a series of experiments encompassing various different tasks, Elliot *et al.* explored the effects of the color red on performance (Elliot et al. 2007). They discovered that when compared to green and gray, the color red impaired participants' performance. More recently, Lichtenfeld *et al.* showed through a set of four experiments that the color green had a positive effect in creative performance (Lichtenfeld et al. 2012) using a validated creativity assessment task.

2.2 Avatars

It has been shown that our avatars affect how we are perceived in VEs. Merola *et al.* showed that avatar colors had an effect on social identity (Merola, Peña, and Hancock 2006). Specifically, participants were asked to discipline an alleged offender where users given avatars in a black robe expressed a higher desire to commit antisocial behaviors than users given avatars in a white robe. Similar work by Peña *et al.* showed that the colors of our avatars also affect how we perceive ourselves (Peña, Hancock, and Merola 2009). Avatars wearing dark clothes had a priming effect for negative attitudes and tended to show more aggressive behavior than those wearing light-colored clothes. However, this work also showed that the type of clothes was also an important factor by comparing white-cloaked avatars in a Ku Klux Klan (KKK) outfit and in a doctor's coat. They found that people with the KKK avatars showed more aggressive behavior despite having the same color.

Work by Zanbaka *et al.* showed that avatar realism had an effect on how persuasive a message delivered by these would be (Zanbaka, Goolkasian, and Hodges 2006). They also found that people were more easily persuaded by avatars of the opposite gender. Researchers have also explored the effects of avatars on performance. For example, avatar realism has been shown to affect our performance on tasks that require precision (Linebarger and Kessler 2002). The importance of avatar realism has also motivated others in the creation of more expressive avatars (Thiebaux et al. 2008).

Despite the extensive exploration of avatar effects on behavior, perception, and performance, to the best of our knowledge, there has not been extensive work exploring how avatar colors affect performance.

2.3 Transformed Social Interactions

A Transformed Social Interaction (TSI) occurs when a computer-mediated social interaction is strategically altered or filtered (Bailenson et al. 2005). Every user perceives their own digital rendering of each other, and these renderings need not be congruent. TSI is a special case of our proposed AVE where, as opposed to AVEs, only the social interaction is asymmetric.

Previous work on transformed social interaction has demonstrated quite resoundingly that changing one's representation has large implications on others in terms of social influence (Bailenson 2006; Bailenson and Beall 2006; Bailenson et al. 2004; 2005; 2008; Yee and Bailenson 2007).

The Proteus Effect TSI was used in a series of experiments by Yee *et al.* (Yee and Bailenson 2007), which showed that changes in a person's avatar affect her behavior in VEs. One of the experiments found that the attractiveness of avatar faces affected the amount of information that people embodied in these avatars were willing to disclose about themselves to other people, as well as the amount of interpersonal distance they had with other avatars. Another experiment found differences in the negotiation behavior or people based on the height of their avatars in relation to others. They named this phenomenon the *Proteus Effect*.

2.4 Other

Other related research has shown that people are better at performing tasks that involve object manipulation in real settings as opposed to virtual environments (Lok et al. 2003). Additional work related to the applicability of social phenomena to virtual environments can be found in a survey by Sivunen and Hakonen (Sivunen and Hakonen 2011).

3 Asymmetric Virtual Environments

One of the contributions of this paper is the introduction of the concept of an Asymmetric Virtual Environment. Earlier in this paper we explained that AVEs take advantage of the virtual nature of VEs by exploiting its affordances for asymmetric rendering of content.

The affordances for asymmetric rendering of content of VEs are well known and have been exploited in the past, as is the case with Transformed Social Interaction. However, we propose that in addition to dynamically filtering or altering elements of a social interaction, such as avatar attributes and body language as is done in TSI, and AVE is able to also customize in real-time elements of the environment itself so that each individual may experience a personalized, yet shared, virtual reality. Therefore, a Transformed Social Interaction will be a special case of an Asymmetric Virtual Environment.

AVEs have applications for research as well as for naturalistic VEs. When used for research, they can increase measurement and internal validity by reducing spurious causes for effects and biases, providing a better control of experimental conditions. On the practical side, AVEs can be used to enhance player experiences by customizing feedback and representation for an individual or a set of players. For example, AVEs could enable an enjoyable multiplayer experience when interactants have a widely different skill level by making it seem as if other players have a comparable skillset to yours.

3.1 AVE Implementation

We created a research platform from the ground up that takes advantage of the affordance of VEs for asymmetric content. Our implementation of an AVE uses a Unity3D-based 3-D component supporting both first-person and third-person perspectives, and a web-based 2-D component.

The Unity3D component is divided into an game server and a game client. The client is capable of running on a desktop computer, a Web browser, or mobile devices. Asymmetry in the Unity3D component is handled by an authoritative server that instructs each client what type of content to render. Game clients use the Unity3D Master Server to discover and connect to our game server.

The Web component consists of an application server that renders HTML content and processes requests. In addition to handling asymmetric rendering, it provides a framework for conducting studies, such as participant sign-up, consent form, surveys, and access control. This application server is also in charge of handling chat communication among participants. Figure 1 shows a high-level diagram of how the different components of this platform are related.

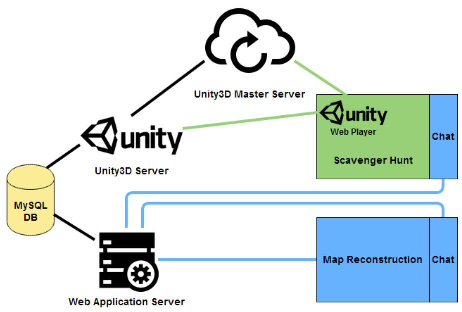

Figure 1: High-level architecture diagram

Both the Unity3D and the Web components have access to the same MySQL database where studies and conditions can be configured and collected data is stored. Our implementation supports asymmetry on both components. However, the study presented in this paper only makes use of asymmetric colors of avatars.

4 Preliminary Study

We asked participants to work in groups of at most 4 to solve two tasks: a *scavenger hunt* in a 3-D VE followed by a 2-D item placement task, which we are calling a *map reconstruction task*. During the scavenger hunt, participants were required to find 10 items (shown in Figure 2) scattered throughout the world. On the map reconstruction task they were presented a 2-D representation of the scavenger hunt world and had to place icons of the items from a palette into the position on the map where they believe they were originally located during the scavenger hunt.

Figure 2: Icons of items to be found

Every participant was given an avatar modeled after Ken Perlin's "Polly's World" character (Perlin). We opted for gender-neutral avatars to avoid introducing biases. Figure 3 shows what these avatars looked like.

Specifically, in this study we set out to test the following hypotheses.

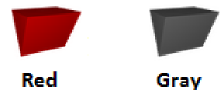

Figure 3: Avatar models in red and gray

- **Hypothesis 1** (*H1*): In a multi-player setting where a player perceives him or herself as having a red-colored avatar, while others perceive it as gray, he or she will perform significantly better than the other players.
- **Hypothesis 2** (*H2*): In a multi-player setting where a player perceives him or herself as having a gray-colored avatar, while others perceive it as red, he or she will not perform significantly better than other players.
- **Hypothesis 3** (*H3*): In a multi-player setting, groups where at least one player perceives him or herself as having a red-colored avatar, or is perceived by others as having a red-colored avatar, will perform significantly better than groups where every player is perceived as having a gray-colored avatar.

Performance will be defined in terms of time required to complete given tasks, number of items found during a scavenger hunt task, and accuracy on a location identification task. These metrics will be more precisely defined in Section 4.3 below.

4.1 Experimental Procedure

The target population was people at or over 18 years of age with access to a personal computer; desktop or laptop with an Internet connection. Recruiting information was distributed through NC State's Computer Science mailing lists, through social media and gaming-related online forums, and through flyers posted in Engineering Building II at NC State's Centennial Campus. Additionally, a few Computer Science courses at NC State offered extra-credit to their students as incentive to participate in this experiment.

The sessions were conducted exclusively online on participant's computers through the supported Web browser of their choice on either Windows or MacOS X. Interested individuals were required to visit a website and sign up for one of the available dates and times. They would then visit this website at the date and time they chose, where they would be presented with an informed consent form. They were initially asked to fill in a survey containing questions about demographics, such as age and gender. This survey additionally provided questions to test participants for different types of color blindness. Participants were randomly assigned an avatar color and name (*e.g.*, P1 – P4) according to the condition they were playing in. A detailed description of the experimental conditions will be provided in Section 4.2.

Participants were then presented a page with instructions on the scavenger hunt task which included a picture of how their avatar would look to them, their avatar's name, and pictures of the 10 items they were tasked to find. This page also contained instructions on how to control their avatar, pick up items, and use a chat to communicate with other players. In some conditions, the following page would display a leaderboard corresponding to the scavenger hunt component.

The next page would load the 3-D game inside the Unity Web Player next to a chat area. While participants waited for the game to start, they had the opportunity to use the chat functionality to communicate with each other. The game screen would display the avatar names of all the players as they reached this stage. The page displayed activity status and sounds that indicated that the game would start soon. Once all available participants reached this page, the researchers would start the game and participants could move freely in the environment by using their computer's mouse to choose a direction and the keys "W", "A", "S", "D" on their keyboards to move in that direction. For this study, this task used a third-person perspective to give participants the opportunity to see their avatars as they interacted with the game environment. The game also supported jumping by pressing the "space" key. Participants could pick up items by placing their avatars over an item and pressing "E" on their keyboard.

The game screen showed icons for all the items to be found. When a participant picked up an item, the game would display a message to all participants indicating the name of the player and the name of the item that was found, and the icon corresponding to the item that was just found would disappear from the list of missing items. They were given 45 uninterrupted minutes to find all the items. If no items were found for a period of 7 minutes, the game would display a hint randomly selected from a set of valid hints about the location of one of the missing items to all players simultaneously. This task ended when every item was found or when the 45 minutes elapsed, after which the game would display a countdown of 5 seconds before moving on to the next phase.

The following page would display a second set of instructions; this time for the map reconstruction task. In some conditions, the next page would display a second leaderboard corresponding to the map reconstruction component. Participants were asked to place all the items over a 2D representation of the 3D world as close to the position they were originally found as they could. For this purpose, an icon for every item was displayed on one side of the page and was made draggable using the computer's mouse. This page also contained a chat area, but messages sent during the scavenger hunt component were not displayed. All the items could be moved by all participants. Every time an item was moved, a small label was displayed over it containing the name of the participant that last moved it. This task would end after all the participants agreed on the placement of all the items by selecting a checkbox at the bottom of the page. Once each participant had checked to agree on placement, the task would be considered complete.

4.2 Experimental Conditions

The experiment used a full factorial design with two factors, as shown in Table 1. We will refer to the first factor as the *type*, and to the second one as the *appearance*.

In all conditions, unless otherwise noted, every participant saw her avatar as gray and was seen as having a gray avatar by other participants. In the *Red to others* conditions, the avatar of one randomly chosen participant was seen as red by every other participant, but was seen as gray to herself. In the *Red to self* conditions, one randomly chosen participant saw herself as red while everyone else saw her as gray. Participant names were always randomly assigned.

Type	**Appearance**
Without leaderboard (*L*-)	All gray
	Red to others
	Red to self
With leaderboard (*L*+)	All gray
	Red to others
	Red to self

Table 1: Full factorial experimental conditions

The difference between the *L*+ and *L*- types was a randomly generated leaderboard shown to every participant on a screen before each task started. These leaderboards were presented to participants as being from a previous real session, and their purpose was to prime for competitiveness. The *L*- conditions simply skipped displaying these and went straight from the task instructions to the task itself.

4.3 Evaluation Metrics

To evaluate our hypotheses we defined metrics for performance on each of the two tasks for individual or group level. Here we will describe them in detail.

Group Metrics To evaluate group performance during the scavenger hunt we are measuring the total duration of this task in seconds. This time is measured from the moment the game is started until all 10 items are found or 45 minutes elapse, whichever happens first. Similarly, we are measuring the duration of the map reconstruction task as a metric for performance for this task. On this task, time is measured from the moment a participant first places an item on the map until the last item placement is made. Additionally, on the map reconstruction task we are also considering the proximity of the final collective placement of all the items on the map with respect to their original location in the 3-D world calculated as the linear distance of the projection of both points on the XZ plane (*i.e.*, the map floor). Given that the 3-D world is laid out as a 1000 by 1000 unit square, the maximum possible distance would be the diagonal: $1000\sqrt{2} = 1414.21$ units.

Individual Metrics As a metric of performance of an individual during the scavenger hunt we are considering the number of items found by each participant. During the map reconstruction task, we are considering the total number of times a participant moved any item, as well as the average proximity of all of the participant's item placements with respect to the original location of each item in the 3-D world calculated as the linear distance of the projection of both points on the XZ plane (*i.e.*, the map floor).

5 Results and Significance

To evaluate the significance of the differences in our measurements for performance and social interaction we conducted a series of two-way ANOVAs. In this section we present these results.

5.1 Sampling and Condition Assignment

A total of 56 people registered to participate of which only 23 ultimately completed the study. These 23 were divided into 8 groups, of which 4 were assigned to the *L-* type and the other 4 to the *L+* type. Each type had one group on the *All gray* condition, two groups on the *Red to others* condition, and one group on the *Red to self* condition. Participants were between the ages of 18 and 48 where 87% of them were male and 13% female. Figure 4 contains a breakdown of gender and participation by experimental conditions.

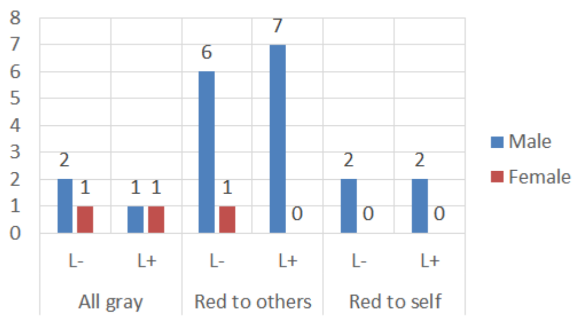

Figure 4: Gender distribution across conditions

The *red to others* conditions had two sessions each, while the rest had one session. Even though most sessions had four participants scheduled, many of them didn't show up to participate. The available time slots had to match the researchers' schedules, making it difficult to accommodate a large number of slots. These scheduling issues caused an unbalanced distribution of participants across conditions.

5.2 Group Performance

Scavenger Hunt Duration The average duration of the scavenger hunt task was 1727.63 seconds (28.63 minutes) overall, where the average on the *L-* type was 1485.75 seconds and on the *L+* type 1969.5 seconds. The interaction between the type and appearance on the duration of this task was not significant ($p = 0.414$).

Map Reconstruction Duration The average duration of the map reconstruction task was 76.929 seconds overall, where the average on the *L-* type was 93.427 seconds and on the *L+* type 54.848 seconds. The interaction between the type and appearance on the duration of this task was not significant ($p = 0.508$).

Proximity of Items The average distance of the final placement of all the items with respect to their original location in the 3-D world was 199.37 units, where the average on the *L-* type was 228.72 units and on the *L+* type 170.02. The interaction between the type and appearance on the distance of all the items was not significant ($p = 0.558$).

We also looked at the distances of every item individually with respect to their original location in the 3-D world. The interaction between the type and appearance on the distance of each individual item was not significant with the notable exception of the chest ($p = 0.030$).

5.3 Individual Performance

Number of Items Found The average number of items found during the scavenger hunt task by players that saw themselves as having a red avatar is 4.5 out of 10, while the average found by players that saw themselves as having a gray avatar is 3.33. The interaction between the type and appearance on the number of items found during this task was not significant ($p = 0.666$).

The average number of items found during the scavenger hunt task by players who were perceived by others as having a red avatar is 3 out of 10, while the average found by players who were perceived by others as having a gray avatar is 3.53. The interaction between the type and appearance on the number of items found during this task was statistically significant ($p = 0.016$).

Number of Times Items were Moved The average number of times that an item was moved during the map reconstruction task by players that saw themselves as having a red avatar is 9, while the average moved by players that saw themselves as having a gray avatar is 6.29. The interaction between the type and appearance on the number of items moved during this task was not significant ($p = 0.553$).

The average number of times that an item was moved during the map reconstruction task by players who were perceived by others as having a red avatar is 4.75, while the average moved by players that were perceived by others as having a gray avatar is 6.89. The interaction between the type and appearance on the number of items moved during this task was not significant ($p = 0.302$).

Proximity of Items The average proximity of all the items placed on the map with respect to the original location in the 3D world by players who saw themselves as having a red avatar is 429.70, while the average distance achieved by players that saw themselves as having a gray avatar is 495.87. The interaction between the type and appearance on the distance of the items to their original location during this task was not significant ($p = 0.079$).

We also looked at the distances of every item individually with respect to their original location in the 3-D world. The interaction between the type and appearance on the distance of each individual item was not significant with the notable exceptions of the bottle ($p = 0.019$) and the cone ($p = 0.038$).

The average proximity of all the item's placed on the map with respect to the original location in the 3D world by players who were seen by others as having a red avatar is 514.82, while the average distance achieved by players who were perceived by others as having a gray avatar is 483.91. The interaction between the type and appearance on the distance of the items to their original location during this task was slightly statistically significant ($p = 0.049$).

We also looked at the distances of every item individually with respect to their original location in the 3-D world. The interaction between the type and appearance on the distance of some of the individual items was statistically significant, such as the bottle ($p = 0.001$), the chest ($p = 0.003$), and the lamp ($p = 0.011$).

6 Discussion

Based on the results obtained through statistical analysis, even though we were able to establish a few statistically significant relationships between our variables, the fact that statistical significance is not consistent prevents us from making generalizable claims. Therefore, we can only interpret results as they apply to our participants and no conclusions about how these variables are related can be made, or about how these results apply to a wider population. Having said that, our results show some interesting trends.

When looking at performance as a group, the only significant result that we found was the difference in the distances of the chest with respect to its original location in the 3-D world. What we see is that when everyone perceives themselves and others as gray, players in the *L*- types place the chest closer to its original location than players on the *L*+ types. However, when a person in the group is perceived as red, either by themselves or by others, groups in the *L*+ types outperform groups in the *L*- type. The results obtained when on the *L*+ types align with hypothesis *H3*, but the results obtained when on the *L*- types appear to contradict it. The same trend is observed in the distance average for all items. This seems to indicate that having a red avatar in a group alters how people perform based on whether they believe they should compete or collaborate. A possible reason for the chest being the only item with statistically significant associations is this item's location near the center of the map, and its proximity to distinctive landmarks such as palm trees, sandy shores, and the river.

Regarding a player's performance based on how she perceives the color of her avatar, we found that, in general, players that see themselves as red performed better on both the scavenger hunt and map reconstruction tasks in terms of number of items found, number of items placed, and average distance of item placement. The only exception to this is that all players performed approximately the same on *L*- types when placing items on the map reconstruction task as close to the items' original location as possible. While in general these results were not statistically significant, the trend aligns with our hypothesis *H1*. The two significant results we found in this area come for the placements of the bottle and the cone during the map reconstruction task. Players who saw themselves as red placed the bottle closer than others in *L*+ types, but placed it farther in *L*-. Conversely, people who saw themselves as red placed the cone closer in *L*- than in *L*+ types than people who saw themselves as gray. Interestingly, people who saw themselves as red found and placed more items on the *L*- types than on the *L*+, but their average distance of placement was smaller on *L*+ than on *L*- types. This seems to indicate that the effects that colors will have on people will increase or decrease performance based on the nature of the task.

Players primed to be competitive (*L*+ types) who were perceived by others as having a gray avatar outperformed players that were perceived as red by others. This was consistent across the two tasks in terms of number of items found, number of items placed, and average distance of items placed. These results align with our hypothesis *H2*, and for the number of items found and average distance of items placed, the differences are statistically significant. While on *L*- types the trend is reversed, the differences are small with the exception of the number of items found.

7 Conclusions and Future Work

While we cannot make any conclusive statements about the effects of avatar colors on behavior, our results are encouraging. The fact that some of our results showed statistically significant relationships seems to indicate that avatar colors can indeed affect performance. Furthermore, this study demonstrated the use of Asymmetric Virtual Environments as a viable platform for isolating experimental conditions for research purposes, and by showing a working implementation, opened the doors for further applications of AVEs in other domains.

Despite the fact that some of our results show statistically significant relationships between our variables, we don't consider these results to be externally valid for two reasons. First of all, a sample of 23 participants and 8 groups are not sufficient to statistically represent our target population given our full factorial experimental design of 6 conditions. Additionally, our sample may suffer from biases introduced by the fact that extra-credit was offered as incentive to participate in at least one undergraduate Computer Science course at NC State where the gender distribution inclines towards males. Not being able to establish external validity prevents us from making any claims that are generalizable to our population.

On the other hand, the use of an Asymmetric Virtual Environment in this study helped us increase the internal validity by better isolating our variables from spurious factors. For example, on conditions where a player saw her avatar as red while others saw it as gray, the use of an AVE eliminates behavioral confirmation as a possible explanation for differences in behavior due to avatar colors.

While conducting this study, we recorded a few anecdotal observations of players' behaviors. A notable one was that players tended to visit areas with distinctive land features such as mountains, trees, and rivers more often than other areas. Future work could investigate this further and take advantage of this by dynamically, and possibly asymmetrically, generating and placing land features in locations of interest. Another observation is that the effects of colors on how well a person performs depends on the nature of the task. This means that the same color can be both detrimental and beneficial to performance, given the right task.

Further work could explore the effects of other online user representation features such as player names, different colors, avatar gender, language, and body gestures. Once the effects of these features on how we perceive others and the reaction this perception causes on people can be reliably established, an interesting possibility is the creation of computational models of influence that would take advantage of these cognitive biases to shape people's choices and actions in VEs.

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