The effect of operating a virtual doppleganger in a 3D simulation

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Figure 1: *We present a system whereby a human subject can be quickly captured and animated as a 3D avatar. We present a study where we ask subjects to operate either their own avatar or someone else's avatar in a simulation and gauge performance.*

Abstract

Recent advances in scanning technology have enabled the widespread capture of 3D character models based on human subjects. Intuition suggests that, with these new capabilities to create avatars that look like their users, every player should have his or her own avatar to play video games or simulations. We explicitly test the impact of having one's own avatar (vs. a yoked control avatar) in a simulation (i.e., maze running task with mines). We test the impact of avatar identity on both subjective (e.g., feeling connected and engaged, liking avatar's appearance, feeling upset when avatar's injured, enjoying the game) and behavioral variables (e.g., time to complete task, speed, number of mines triggered, riskiness of maze path chosen). Results indicate that having an avatar that looks like the user improves their subjective experience, but there is no significant effect on how users perform in the simulation.

Keywords: avatar,gesture,3D,animation,simulation,scanning

Concepts: •**Computing methodologies** → **Perception;**

1 Introduction

Recent advances in scanning technology have enabled the rapid creation of 3D characters from human subjects using image, video and depth sensing cameras. One use of such technology is to represent the user in a simulation, i.e as an avatar. Indeed, with these new advances in scanning technology, simulations could be developed where users are first scanned so they have their own "personal" avatar that looks like them. It is thought important for the user to be able to recognize his or her avatar in the simulation. As an example, a military training simulation might require a user to run practice drills with virtual squad members that look like the real squad members. Alternatively, a training simulation might require the presence of coworkers to be part of the 3D training environment. Indeed, for the military or industry to undertake the costs to integrate such scanning technology into simulations, having an avatar that photorealistically resembles one's own physical appearance should be shown to improve performance in these simulations.

There is a growing body of research related to the psychological effects of having an avatar that looks like the user (a virtual "doppelganger") in a simulation [Aymerich-Franch and Bailenson 2014; Bailenson 2012; Fox and Bailenson 2009; Fox and Bailenson 2010; Fox et al. 2009; Hershfield et al. 2011; Lee et al. 2010]. Specifically, research has demonstrated that observing one's own avatar over time (i.e., in time lapse) can help users to change their behavior. For example, individuals who saw their own avatar change levels of physical fitness were more engaged in healthier physical behaviors, including physical exercise and eating habits than those who saw an avatar that was not their own [Fox and Bailenson 2009; Fox et al. 2009]. Likewise, individuals who saw their own avatar age were more willing to engage in prudent financial behavior [Hershfield et al. 2011]. Applications have also been developed to overcome public speaking anxiety by seeing one's own avatar give a speech [Aymerich-Franch and Bailenson 2014].

Building off this literature, the current work considers whether operating an avatar that is built to look like the user will affect motivation and performance in a simulation. Prior work has considered the effects of the "naturalness" of the character (i.e., more dynamic movement vs. static character navigated through a simulation). Results have been mixed; for example, researchers have found that users were most satisfied with their own performance using the least natural character (i.e., one that moves around the environment in a static pose) [Normoyle and Jörg 2014]. Recent research with embodiment of avatars has looked at differences between embodied robot, cartoon-like humans, stick figures in 1st person perspectives in virtual reality [Lugrin et al. 2015b] or 3rd person perspectives [Lugrin et al. 2015a] for fitness applications. However, our study uses photorealistic avatars from a 3rd person perspective where the user has full view of their avatar, including the avatar's face. Additionally, this work has not considered the

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effect of characters that are "more natural" to the user in terms of its likeness to the user. Some video game systems allow users to personalize characters by adjusting their physical attributes. For example, Nintendo offers "Mii" characters. Although these "Mii" characters are of relatively low fidelity, users can customize their avatar to create a likeness of themselves. The common perception is that this makes the game more enjoyable for users and increases engagement. In such a simulation context, prior work has considered whether people respond differently to an avatar that depicts an idealized version of themselves (compared to a more accurate one). Users who created a "Mii" character reflecting what they would ideally look like reported the simulation felt more interactive than those who created a "Mii" character that mirrored their actual physical appearance [Jin 2009]. However, it has not tested the effect of having one's own avatar in such a simulation compared to having someone else's avatar. We test that possibility here.

Prior correlational research supports the prediction that participants will enjoy operating an avatar more if it looks like them (vs. someone else). Indeed, players report greater enjoyment of video games to the extent that they identify with the character being operated [Christoph et al. 2009; Hefner et al. 2007; Trepte et al. 2010]. In addition to motivation and enjoyment, we also consider the impact of using a doppelganger on performance. While the effect on performance has been unstudied, prior work suggests that having an avatar who looks more like the user can affect behavior. For example, users who played a violent video game using a character that mirrored their actual physical appearance were significantly more aggressive than those who played the same violent video game with a generic avatar [Hollingdale and Greitemeyer 2013].

If there is a significant effect of operating one's own avatar on performance in a simulation, this could have important implications for certain applications. For example, more high fidelity military applications have been envisioned where photorealistic characters are used in simulations. For example, multiple players may need to identify their own avatar as well as other virtual squad members in order to run drills in a virtual environment. Additional benefits might possibly be that users in such simulations act more realistically with an avatar that looks like them rather than a generic character. Users might take more care for their avatar not to get injured or killed in the simulation to the extent that they identify it with their person. To achieve this in a high fidelity application, modern scanning technology that allows for rapid creation of 3D characters from human subjects could be used. While this is becoming more affordable, expenses would still accumulate if it was used on a wide scale across the armed forces.

Therefore, we conduct research to establish the effects that using one's own avatar has on user engagement, liking, and enjoyment as well as behavior in the virtual environment, especially performance and the care that is taken to prevent the avatar from harm. In this paper, we compare two groups of users on all of these variables; specifically, we compare users who have been assigned to play with an avatar that was scanned from them (experimental condition) to those who have been assigned an avatar built from the previous participant of the same gender (yoked control condition).

2 Related Work

Creating a virtual character from a particular subject is not a trivial task and usually requires extensive work from a 3D artist to model, rig, and animate the virtual character. The first step of avatar creation requires reconstruction of a 3D model from either a set of images or depth range scans. With the availability of low-cost 3D cameras (Kinect and Primesense), many inexpensive solutions for 3D human shape acquisition have been proposed. The work by [Tong et al. 2012] employs three Kinect devices and a turntable. Multiple shots are taken and all frames are registered using the Embedded Deformation Model [Sumner et al. 2007]. The work done in [Zeng et al. 2013] utilizes two Kinect sensors in front of the self-turning subject. The subject stops at several key poses and the captured frame is used to update the online model. More recently, solutions which utilize only a single 3D sensor have been proposed, and this allows for home-based scanning and applications. The work in [Wang et al. 2012] asks the subject to turn in front of a fixed 3D sensor and 4 key poses are uniformly sampled to perform shape reconstruction. To improve the resolution, KinectAvatar [Cui et al. 2012] considers color constraints among consecutive frames for super-resolution. More recently, the work in [Li et al. 2013] asks the subject to come closer and obtains a super-resolution scan at each of 8 key poses. The second step is to create an animated virtual character from the scanned 3D human model. A 3D model needs to be rigged with a skeleton hierarchy and appropriate skinning weights. Traditionally, this process needs to be done manually and is time consuming even for an experienced animator. An automatic skinning method is proposed in [Baran and Popović 2007] to reduce the manual efforts of rigging a 3D model. The method produces reasonable results but requires a connected and watertight mesh to work. The method proposed by [Bharaj et al. 2012] complements the previous work by automatically skinning a multi-component mesh. It works by detecting the boundaries between disconnected components to find potential joints. Such a method is suitable for rigging the mechanical characters that consists of many components. Other rigging algorithms can include manual annotation to identify important structures such as wrists, knees and neck [Mix 2013].

In the last few years, video-based methods have enabled the capture and reconstruction of human motions as a sequence of 3D models [Starck and Hilton 2007]. Such methods, which are capable of reproducing surface and appearance details over time, have been used to synthesize animations by the combination of a set of mesh sequences [Casas et al. 2014]. This results in a novel motion that preserves both the captured appearance and actor style, without the need of a rigging step. However, current approaches only demonstrate successful results for basic locomotion motions such as walk, jog and jump. The complexity of the movements needed in this work would still require the video-based 3D models to be rigged.

3 System Design

We used the method proposed in [Feng et al. 2015] to obtain an articulated 3D character from human subjects. Participants then navigated a maze with mines in a virtual environment using a WASD keyboard; they were randomly assigned to complete the maze in either the experimental condition (own avatar) or a yoked control condition. We first describe the method used to scan the participants, and then describe the experiment (in Section 4).

We utilized the Occipital Structure Sensor to obtain the 3D avatar scan from the test subject. It is a depth sensor attached on the Apple iPad to allow portable 3D scanning. The process requires the subject to stand still in an A-pose while being captured. During capture, the scanning operator will hold the scanner and walk around the participant to obtain 3D scans from all directions. The resulting scans are then aligned and merged through both rigid and non-rigid alignments to register all scans. The final static geometry is then produced via Poisson mesh reconstruction. The texture information is also inferred from scans of different views via Poisson texture blending. The body scanning capture and reconstruction takes approximately 8 to 10 minutes. Examples of the results of such scans can be seen in Figure 2. The scanned character model also requires proper rigging structure in order to move in the virtual environment (in this case, a maze). The method automatically builds and adapts a skeleton to the 3D scanned character. The auto-rigging method is based on the one proposed in [Feng et al. 2015] by utilizing a 3D human model database to generate a morphable model to automatically fit a 3D human scan. Once the morphable model is constructed, we can transfer the location of skeletal bones, as well as the skinning deformation information onto the scan. The quality of the skinning and bone location is of similar quality to that of the original rigging, which can be performed once by a professional 3D rigger. This is in contrast to previous automatic rigging methods [Shapiro et al. 2014; Feng et al. 2014; Baran and Popović 2007] that rely only on geometry to determine the skeletal location. Once the skinned avatar is created, the user can navigate the avatar in the virtual space (i.e., maze). For the current study (described below), participants were also asked to record 4 utterances for pain reactions (e.g. ”Ow!”, ”Ouch!”). The steps for the preparation of the character are detailed in Table 1.

Order	Description	Time (min)
1	Subject stands in A-pose and is scanned	3
2	Subject records verbal responses (”ow”,”ouch”)	4
3	Scan is automatically processed into 3d model	10
4	Model is automatically rigged	2

Table 1: *Subject capture and 3D character creation process.*

4 Evaluation

One hundred and six participants (65 males, 41 females) completed a study in which they were randomly assigned to complete the maze with an avatar that looked like them or another participant. Participants were recruited off of CraigsList and volunteered to participate in the study in exchange for monetary compensation of $25. Their performance was further motivated by lottery entries for a cash prize. Specifically, before beginning the maze task, participants were instructed to navigate a maze as fast as possible while avoiding hitting the mines and the walls, and they would receive entries into a lottery based on their ability to do so. They were then shown the avatar which they were going to navigate the maze with (Figure 3).

For participants in the experimental condition, they were shown the avatar that was just created from their scan in front of the maze they were going to run. For participants in the yoked control condition, they were shown the avatar that was created from the scan from the last gender-matched participant in front of the maze they were going to run. Additionally, they were allowed to hear the pain reactions of that avatar. Specifically, in the experimental condition, these were their own recordings, whereas in the yoked control condition, they were the recordings of the last gender-matched participant. The cover story suggested that the scanning procedure and the maze running task were unrelated, so that participants in the yoked control condition could have an ostensible explanation for using another avatar. This deception was revealed upon debriefing, and no participants expressed concern about being deceived. Once participants viewed the avatar they were going to use to navigate the maze, they were oriented to navigating the avatar around walls and obstacles in the maze virtual environment. Navigation was controlled through a WASD keyboard configuration (a gaming standard similar to the arrow keys). Participants controlled their assigned avatar in a third-person view. Running into an obstacle (e.g. a wall or spiked trap) stopped avatar movement and triggered a sound effect of the avatar expressing pain (see Figure 4).

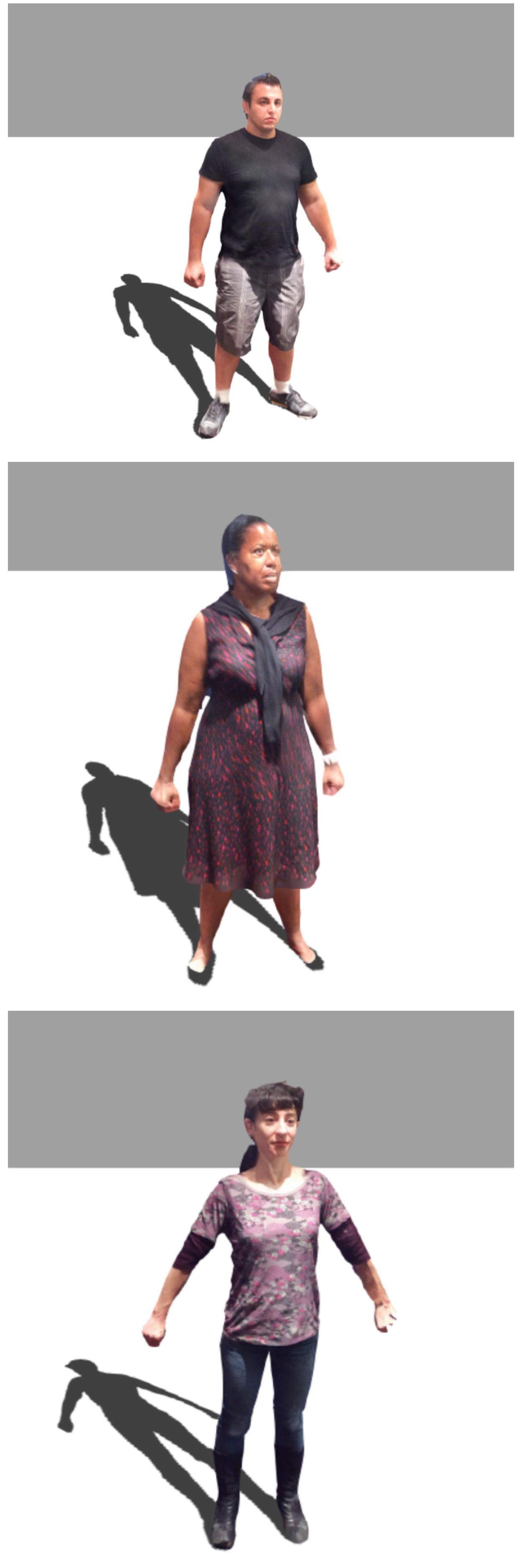

Figure 2: *Example scan results of subjects.*

Figure 3: *Presentation of avatar to the user before the maze task begins. Note that the subject is initially given a frontal view of the doppleganger.*

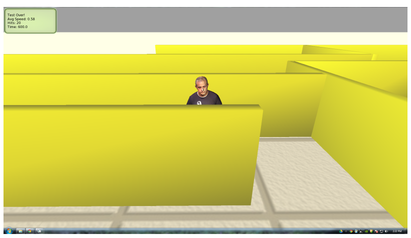

Figure 4: *Screen capture from a session where a user is navigating his own avatar through the maze.*

Participants were given 15 minutes to complete the maze. Sixteen participants failed to complete the maze in the time given, and were therefore excluded from analyses below.

Upon completion of the maze, participants were asked to answer 16 questions about their experience. All items were answered using a 5 point scale ranging from Strongly Disagree (1) to Strongly Agree (5). Participants were asked to complete a manipulation check (1 item) and indicate how realistic the avatar looked (4 items), as well as to report on: the extent to which they were feeling connected and engaged (4 items), how much they liked the avatars appearance (3 items), the extent to which they were feeling upset when the avatar was injured (3 items), and how much they enjoying the game (1 item). Example items are provided below in Table 2.

A number of measures were extracted from the game play during this maze running simulation. First, we measured the total time it took participants to complete the maze in seconds (up to 900 seconds, which corresponded to the 15 minute time limit). We measured the distance they navigated to complete the maze in (virtual) meters, and, thus, also their average speed across the maze in meters per second. We measured the number of times they collided with the maze wall or mines. Additionally, in the areas of the maze where participants had the choice between riskier and safer paths, we calculated the percent of the path that was taken that was risky. Specifically, as seen in Figure 5 below, participants could choose shorter distance paths with more mines (1 and 4) or longer distance paths with fewer mines (0 and 2, as well as 3 and 5, respectively). We computed the proportion of steps taken, time spent in the risky zones using the formula: (0.5 * (N steps taken time spent in 1 / N steps taken time spent in 0, 1, 2)) + (0.5 * (N steps taken time spent in 4 / N steps taken time spent in 3, 4, 5)). All paths taken by the subjects can be seen in Figure 6.

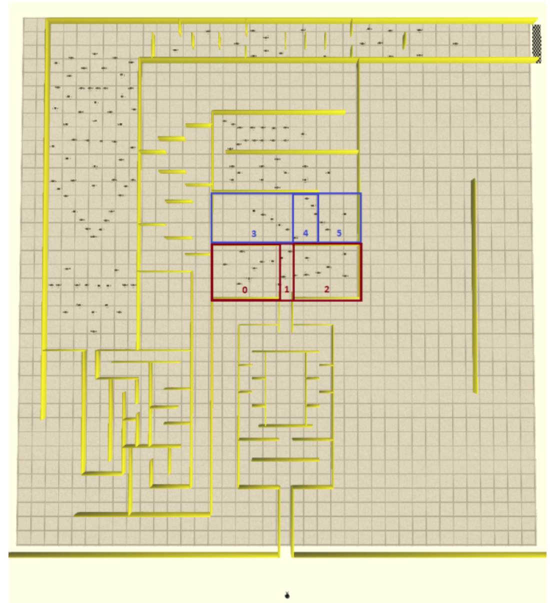

Figure 5: *Specifically, as seen in Figure 6 below, when choosing between which of the red zones (0, 1, 2) to traverse, participants could choose the shorter distance path with more mines (zone 1) or longer distance paths with fewer mines (zones 0 or 2) Likewise, when choosing how to navigate through the blue zones (3, 4, 5), they could choose the shorter distance path with more mines (zone 4) or longer distance paths with fewer mines (zones 3 or 5). Accordingly, we computed the proportion of time spent in the risky zones using the formula:*

$$t_{risky} = (0.5 * (n_1/n_{012}) + (0.5 * (n_4/n_{345}))$$

where n_1 is the time spent in zone1, n_{012} is the time spent in zones 0, 1 or 2, n_4 is the time spent in zone 4, and n_{345} is the time spent in zones 3, 4 or 5.

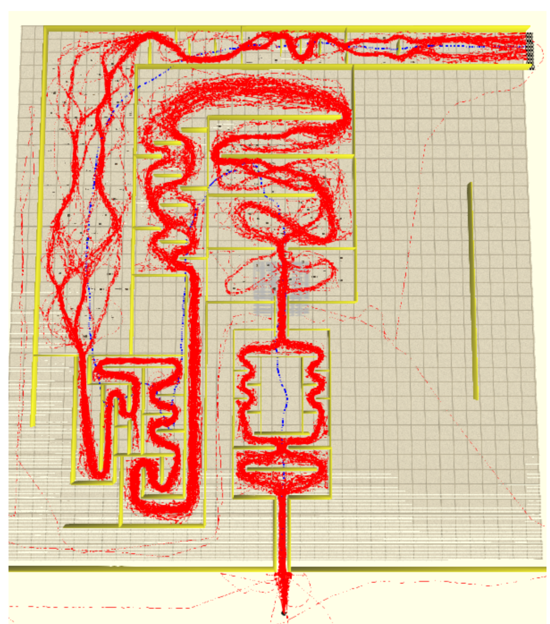

Figure 6: *Paths taken by the subjects through the maze.*

	Scale	Number	Items
i	Manipulation check	1	The avatar resembled my personal appearance.
ii	Realism of the avatar	4	The avatar looked physically realistic. The sounds from the avatar seemed realistic. The avatar physically behaved in a realistic way (body movement). I felt comfortable controlling my avatar.
iii	Connected and engaged	4	I was invested in the task and personally cared about my performance. I perceived a relationship with my avatar. The avatar's appearance increased my interest in the task. I am proud of my avatar's performance.
iv	Liked the apperance	3	The avatar was attractive. I felt comfortable with my avatar's appearance. I am proud of my avatar's performance.
v	Feel upset when injured	3	I cared when the avatar expressed pain. I did not enjoy seeing my avatar get hurt. I felt responsible for my avatar.
vi	Enjoyed the game	1	The game was enjoyable.

Table 2: *Subjective Measures*

5 Results

Analyses are reported for the 90 participants who completed the maze within the given (15 minute) time limit. We first present the results for the subjective measures, and then turn to the behavioral (gameplay) measures. For both subjective and behavioral measures, ANOVA was conducted to test the effect of condition (experimental vs yoked control), gender (male vs female), and their interaction. Given that men and women differ in height, the height of the participants avatar (in virtual meters) was controlled for to rule out confounds due to height differences.

First, we wanted to ensure that participants found that the avatar looked more like them in the experimental condition than in yoked control; indeed, this manipulation check showed that our manipulation was successful (M = 4.39, SE = 0.16 vs M = 2.37, SE = 0.15; $F(1,85) = 85.69$; $p < .001$). However, this did not affect the extent to which the avatar seemed realistic (M = 4.06, SE = 0.10 vs M = 3.98, SE = 0.10; $F(1,85) = 0.36$, $p = .55$), so differences in perceived realism cannot account for any effects on subjective experiences. Furthermore, for both the manipulation check and realism, there were no effects of or interactions with gender ($Fs < 1.45$, $ps > .23$).

We analyzed the subjective experiences of: feeling connected and engaged, liking the appearance of the avatar, feeling upset when the avatar was injured, and enjoying the game. First, as can be seen in Figure 7, participants who navigated the maze with their own avatar reported feeling more connected and engaged than those in the yoked control condition ($F(1,85) = 14.90$, $p < .001$). There was no effect of or interaction with gender ($Fs < 0.21$, $ps > .64$).

Furthermore, as can be seen in Figure 8, participants who navigated the maze with their own avatar also reported liking the appearance of their avatar more than those in the yoked control condition ($F(1,85) = 12.89$, $p = .001$).

There was also a trend for women to like the appearance of the avatar less than men (M = 3.39, SE = 0.15 vs. M = 3.74, SE = 0.11; $F(1,85) = 2.90$, $p = .09$); however, this effect of gender did not depend on condition ($F(1,85) = 1.01$, $p = .32$). Apparently women liked the appearance of the avatar less -whether it was their avatar or someone elses- compared to how much men liked the appearance of the avatar.

Concerning either feeling upset or enjoyment, however, there were no main effects. Specifically, there was no effect of condition or gender on feeling upset when the avatar was injured by running into a mine or wall ($Fs < 1.27$, $ps > .26$) or on enjoyment of the game ($Fs < 0.30$, $ps > .58$). There was also no interaction of condition and gender for feeling upset when the avatar was injured ($F(1,85) = 0.04$, $p = .84$). However, there was a significant interaction between condition and gender for enjoyment of the game ($F(1,85) = 3.81$, $p = .05$). As can be seen in Figure 9, men who were assigned their own avatar tended to enjoy navigating the maze more than men who used someone elses avatar ($p = .12$), whereas women who used another player's avatar tended to enjoy the game more compared to those women who were assigned to use their own avatar ($p = .21$).

In contrast to these effects on subjective experience of the users, there were no significant effects of experimental condition (own avatar vs. yoked control) on time to complete the maze, distance travelled in the maze, average speed, number of mines or walls hit, or percent of risky paths chosen ($Fs < 0.93$, $ps > .34$). Only one effect of gender approached significance; women were marginally slower (M = 1.44 meters/second, SE = 0.08) than men (M = 1.65 meters/second, SE = 0.06; $F(1,85) = 3.55$, $p = .06$); because avatar height was controlled for, this marginal effect is not due to gender difference in height. Furthermore, all other effects of gender were not significant ($Fs < 1.90$, $ps > .17$), and it did not interact with condition ($Fs < 1.22$, $ps > .27$).

6 Discussion

From previous speculation, users piloting their own avatars (vs. someone elses) would be expected to show more engagement, liking and enjoyment, as well as better performance and care to prevent injury to their avatar. While the current work suggests that users do feel more engaged and connected and also liked their avatar more, the remaining possibilities were not supported. Only men enjoyed playing the game more with their own avatar than someone elses; women actually showed the opposite effect. Moreover, there were no significant effects of any kind on any behavioral factor. Users with their own avatars did not show differences in time to complete the maze, distance traveled, or speed. They also were no more careful with their avatar on any metric we considered collisions with mines, collisions with walls, and ratio of riskier paths (shorter but with more mines) over safer paths.

Across all these measures, a clear pattern emerged: users were more motivated and engaged when they had access to their own avatars, but performance and the care that is taken to prevent the avatar from

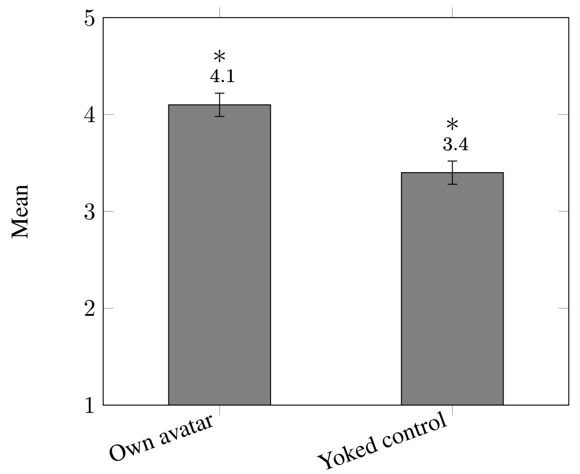

Figure 7: *Effect of condition on feeling connected and engaged.*

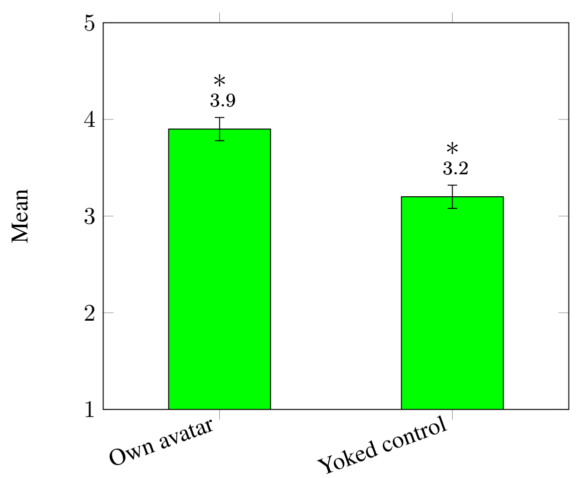

Figure 8: *Effect of condition on liking the avatar's appearance.*

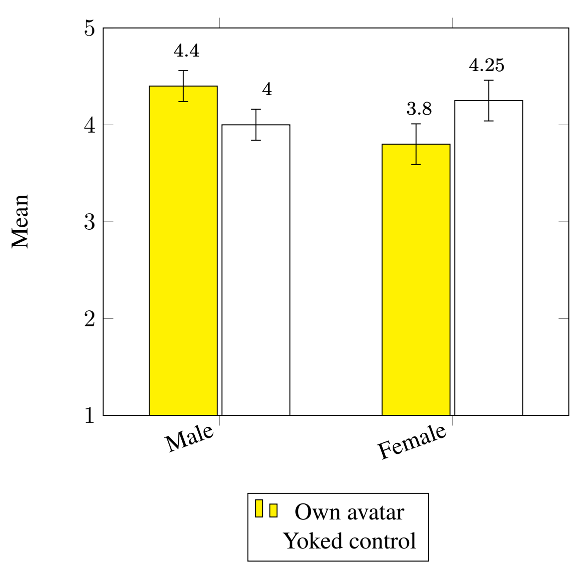

Figure 9: *Interaction of condition and gender on enjoyment.*

harm were unaffected. There are a number of reasons that this may be the case. First, concerning the latter null effect, it is possible that the crude control method of the avatar prevented users from feeling sufficient responsibility for potential harm that occurred to the character. This seems somewhat unlikely, however, because on average participants reported concern for the avatar above the scale midpoint (M = 3.79). Likewise, while the effort described above focused on modeling the avatar to be realistic, less care was taken to create an engaging background for the task or to ensure the quality of the motion (e.g., when changing directions, appearance of shadow) or ensure that users saw the avatar's face consistently across the game. These factors together could possibly have hindered our ability to find effects of avatar appearance (own vs someone else's); however, because the current study did find effects on some subjective measures, this explanation for the null results holds less weight. More generally though, avatar appearance (own vs someone elses) may truly have no relevance to how users play the game. Evidence from self-reported subjective experience supports this possibility, as participants in the experimental condition reported no greater concern over the avatar being injured than those in the control condition.

However, it is possible that there is an effect on user performance or behavior, but we failed to find it due to chance. Although we had a sufficient sample size to detect a moderate effect, we could have still failed to detect such an effect due to chance. To the extent that the effect is smaller, we would have had a greater chance of failure to detect the effect. Estimates of effect size based on the current data show that, if there is an effect, it is most likely quite small (d 0.1 to 0.2). The practical significance of such a small effect would be limited. Even if such an effect does exist, it may not be large enough to warrant the expense of scanning users on a large scale just to reap benefits on performance and behavior. Rather our results suggest that the significant win that would come from scanning avatars from users would be on motivation and engagement with the simulation.

It is also possible that other tasks would show a larger, and thus perhaps statistically significant, effect of piloting ones own avatar. For example, in contrast to such training exercises, simulations that are more social in nature may show a significant effect of avatar appearance (own vs someone elses). Individuals being asked to negotiate or exchange goods may act more trustworthy if their avatar looks like them. Indeed, having a different body (and thereby being unrecognizable) may afford users a sense of anonymity, which has been shown to reduce concern of being judged for socially undesirable behaviors [Lucas et al. 2014]. Freed from such social pressures when using someone else's avatar, users may be more willing to violate social norms by acting in dishonest or untrustworthy ways during negotiations or other exchanges. To facilitate such subsequent research, additional future work could capture a few key facial expressions as a part of the capture procedure. Further research should address this possibility, as well as explore whether other types of virtual tasks show differences based on avatar appearance (own vs. someone else's).

Along these lines, future studies should also consider if effects of using ones own avatar are found in multi-player situations. For example, an evaluation could be built to resemble a military training simulation where users run practice drills with virtual squad members that look like the real squad members. Although there was no effect in a single player simulation, one might be found when two or more players pilot their own avatars in the same virtual environment simultaneously.

Research should also further investigate gender differences in this realm. In spite of stereotypes regarding gender and gaming, women only exhibited one marginally significant difference in gameplay: their average speed was marginally lower than men. However, they did show some differences in subjective experience. Women's enjoyment did not seem to benefit from using their own avatar like it did for their male counterparts. In fact, women who piloted their own actually reported less enjoyment than those who used someone else's. Similar effects have been found in other studies such as [Aymerich-Franch and Bailenson 2014], where women responded more poorly to public speaking training that involved seeing their own doppelganger give a speech than men. We, and others, may have found such an effect because female users feel more self-conscious about their bodies; such concerns may detract from their experience using their own avatar. Indeed, anecdotal evidence for this possibility presented itself when several female participants reported being dismayed at the appearance of their own avatar, expressing a desire to look more attractive when scanned. While this anecdotal evidence supports self-consciousness as an explanation, another possibility for this result could be that physical features that were more important to females were not reproduced as well. This may be especially the case for features such as the hair or the eyelashes etc. which are more prominent in females than males. In the current work, the finding that women tended to like the appearance of the avatar less than men may speak to this point, but admittedly this trend was not qualified by appearance condition (own vs. someone else's).

However, these results do indicate that both male and female users experience greater engagement and connection as well as liking while piloting their own avatar compared to someone else's. Accordingly, modern scanning technology that allows for rapid creation of 3D characters from human subjects could be used to increase engagement and motivation in training simulations. Users may not perform or behave differently in the simulation, but increased engagement and/or motivation from piloting their own avatars could encourage them to train more and, thereby, possibly improve learning.

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