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The Effects of Avatars on Presence in Virtual Environments for Persons with Mobility Impairments

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Abstract

The main question we ask is: How do avatars affect presence specifically for Persons with Mobility Impairments (PMIs)? For example, PMIs' deficits in the proprioceptive sense could affect their body perception in immersive virtual reality, which could impact presence. To investigate this we replicated the classic virtual pit experiment and included a responsive full body avatar (or lack thereof) as a 3D user interface. We recruited from two different populations: 11 PMIs and another 11 Persons without Mobility Impairments (PNMIs) as a control. Each PNMI was matched to a PMI based on age, weight, height, and prior VE exposure. Results of this study indicate that avatars elicit a higher sense of presence for PMIs than for PNMIs. In addition, results suggest that PMIs are easier to immerse in VEs than PNMIs, which may further motivate the future use of VE technology for PMIs.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented and virtual realities

1. Introduction

One of the primary sources of information on how the Persons with Mobility Impairments (PMIs) can benefit from virtual reality (VR) is from research on VR rehabilitation games [ALMK10, BBD*10, BDN*07, BBC*08, BMC*09, FTC*08]. VR Rehabilitation games have not been completely incorporated into common therapy practice, but they do seem to have significant benefits to rehabilitation. For example, a virtual environment (VE) is not subjected to the dangers and limitations of the real world, which expands the types of exercises that patients can practice, while still having fun. In general, research suggests that VR games have significant benefits for rehabilitation effectiveness and motivation. Minimal research has investigated how motivation relates to presence. If users experience higher presence, they may focus more on the VE and less on the pain and repetitiveness of rehabilitation, thereby increasing motivation. However, the factors which affect PMIs' presence are not well understood, which is the primary focus our research.

Factors that are well known to affect presence of Persons without Mobility Impairments (PNMIs), such as the inclusion of full body avatars, may have different effects on PMIs. For example, many PMIs have proprioceptive deficits (i.e., the sense of where ones arms and legs are located in space), which could affect their body perception in immersive VR. Thus, inaccurate movements and tracking of avatars may not be as noticeable to PMIs, which may make them more easily subjected to perceptual illusions, such as embodiment through avatars [KBS13].

Figure 1: *Participant's view of the virtual pit.*

Specifically, in this paper we present results of a study that investigated how a responsive, full-body avatar can affect the presence of PMIs. The study utilized a virtual pit [GQ12, MIWBJ02, MRWFPB03, RDI03, UWB*99] (Figure 1). We recruited PMIs who require the use of a cane (see section 4.4

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for detailed selection criteria); for each PMI we recruited a healthy control of similar demographics (e.g., age, height, weight, previous VE exposure). Results give insight into how avatars (or lack thereof) can differently affect the presence of PMIs and suggest how to increase presence specifically for PMIs.

2. Background And Related Work

2.1. Presence

Presence is the suspension of disbelief in the VE, and refers to a feeling of actually 'being there' in a VE.

Measuring Presence with Questionnaires: Questionnaires are a common method used to measure presence. Over the years, there have been many different presence questionnaires (e.g., [SSA*01, SU93, SULK96] for an extensive survey), but the Witmer-Singer Presence Questionnaire (PQ) [WS98] and the Slater-Usoh-Steed (SUS) Questionnaire [SUS94] are the most common, which use Likert scales and open ended questions, respectively. These questionnaires have been used to identify many of the VE design factors that affect presence.

Measuring Presence with Physiological Measures: Presence questionnaires are very subjective, which can sometimes make it difficult to yield repeatable results [BdVLB11]. In an effort to utilize more objective measures of presence, physiological measures are also commonly used. Michael Meehan et al. hypothesized physiological responses should be evoked in a VE similarly to the real environment [MIWBJ02]. They used three common physiological metrics of measuring stress in real environment to measure the presence in VE: 1) ΔHeart Rate, 2) ΔSkin Conductance, and 3) ΔTemperature. They found that presence was correlated to the physiological responses. Dong P. Jang, et al. also found skin resistance and heart rate could be used as measures in monitoring reaction to VE for non-phobic participants [JKN*02]. Both studies were within-subjects studies, and showed the physiological measures could be used for quantitatively measuring presence in a VE.

Gait measures of presence: PMIs and persons without disability have different gait patterns in a real environment. In a VE gait may be indicative of their sense of presence. Specifically, our previous research found correlations between gait and presence in PMIs and PNMIs [GSQ13], albeit through different gait parameters. Specifically, for PNMIs, the score of natural of movement and both of the Left ($p = 0.045$, $R = -0.718$) and Right ($p = 0.019$, $R = -0.794$) Heel to Heel Base Supports showed strong inverse correlation only when there were no human avatar or cane avatar. When testing the group of the PMIs, the score of natural of movement and the Right Double Supports showed strong inverse correlation only when there were no human avatar or cane avatar ($p = 0.043$, $R = -0.723$). However, the impact of avatars on presence of PMIs in this study was inconclusive, which motivated the study in the current paper.

2.2. Avatars

Typical avatar systems track participants' motions and make the avatar move according to the participants' movements in real time (i.e., a registered avatar). For example, in 2010, Gonzalez-Franco et al. suggested that synchronous mirror reflection was able to give participants a significantly greater body ownership illusion (i.e., embodiment) than an asynchronous condition [GFPMSS10]. Betty et al. found that a fully registered avatar could help participants make more accurate distance estimation [MCRTB10]. Several other studies have shown that a first person experienced, registered avatar could temporarily affect participants' presence [SSSVB10, NGSS11, KNSVS12]. In fact, seeing merely a virtual hand avatar can induce a hand ownership illusion [SVSF*10, PMSVS12] (i.e., embodiment).

Researchers also found interesting correlations between participants behavior and avatars [FTJT12]. Konstantina et al. [KBS13] suggested that the effects caused by avatars in a VE might be task-dependent or VE dependent. Their research showed that participants behaved differently when they had avatars with different appearances for the same task. However, this study was conducted with only PNMIs.

To our knowledge, our previous research works were the only studies on the presence of PMIs. The results showed that the differences of presence existed between PMIs and PNMIs [GSQ13]. Based on a presence questionnaire, PMIs reported that manipulating objects was more difficult than PNMIs reported, but the mechanism of movement control (i.e., real walking) was more natural for PMIs. In addition, from their walking trajectory, we found that avatars made their movements more realistic. For example, the PMIs tried to keep their walking path as short as possible, which is similar to how they behave in the real world. That is, they walked in shorter paths with the avatar than without.

3. Materials

3.1. Study Task and VE Description

We aimed to design a study task that would elicit a high sense of presence. Thus, we used a pit VE (Figure 3) similar to VEs researched before (e.g., [MRWFPB03]). The pit is an environment that is known to elicit a high sense of presence and its results have been validated across multiple studies with users.

We designed a task specifically to keep the users within a narrow walkway, walking back and forth in straight lines to facilitate quantitative gait analysis with a GAITRite mat. The task is to pick up a virtual ball from a dispenser on one side of a narrow walkway over an 11 ft pit, carry the ball to the other side of the walkway, and drop the ball into a box. The participant can only pick up one ball at a time from the dispenser. At both ends, the participant hears a sound to indicate they reached the end of the walkway (i.e., to keep them within the tracking volume in order to minimize tracking error and to make sure that they walked far enough for adequate gait analysis). To increase usability and immersion, the participant also hears 3D enabled sounds when: the dispenser generates a ball, the drop box opens, a ball is successfully dropped into the drop box, or a ball falls into the water in the pit.

Our environment included two scenes: 1) Training Scene and 2) Experiment Scene. The participant's experience always begins with the Training Scene. After participants finish training, the experimenter transforms it into the Experiment Scene.

3.1.1. Training Scene

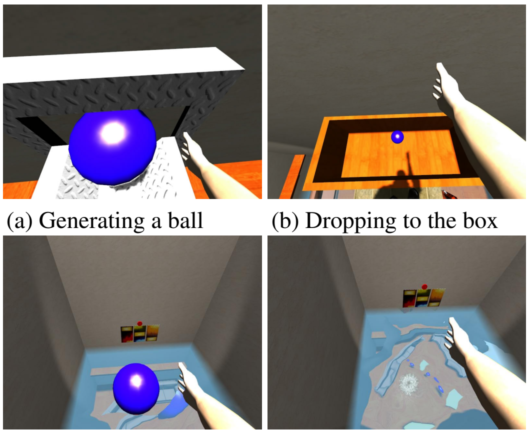
Figure 2: *The virtual environment for training.*

The main purpose of the training scene is to instruct participants on how to interact with the environment. They are instructed on using a Head Mounted Display (HMD) for viewing, walking in the VE, and using a Wiimote to pick up, hold, and drop balls. The Training Scene is a 10 ft. by 20 ft. room. It has two different types of ground - floor and tile (Figure 2). The tile is a 2.5 ft narrow walkway across the center of the room that the participant walks on. During the training, we ask the participants to pick up several balls, guiding them to drop or throw the balls. We also raise the walkway up by several inches, and let them know if they walk off the walkway, then they will fall off to the floor. We expected that this would increase presence throughout the study, especially when the walkway was raised higher.

3.1.2. Experiment Scene

After the participants successfully drop two balls into the drop box in the Training Scene, we ask them to move to the center of the walkway and the experimenters transform the Training Scene to the Experiment Scene. We slowly raise the walkway up approximately 7 ft high, and then open up the floor. The open floor reveals a 4 ft drop, so that the Experiment Scene is a 10 ft. by 20 ft. by 11 ft virtual pit (Figure 3). On the bottom of the pit, (similar to Usoh et al. [UWB*99]) there are virtual objects to give additional depth cues - a sofa, a chair, a love seat, a TV with a TV stand, and a coffee table. Also there is 1.5 ft high water that has flooded the pit.

Different from the Training Scene, once the Experiment Scene has been fully transformed, the participants cannot fall off onto the floor, even when they walk off the walkway. However, we do not inform the participant of this change. Allowing participants to fall into the pit at this point could break the task and potentially disturb participants. Note that no participants tried to walk off the walkway in the experiment scene during the study.



(a) Generating a ball (b) Dropping to the box

(a) Dropping a ball (b) Dropping into the water

Figure 3: *The virtual environment for the study.*

In the experiment scene the walking mechanism (i.e., real walking), ball picking, ball holding, and ball dropping mechanisms are the same as in the Training Scene.

In order to encourage participants to look down at their avatar and into the pit, there is interactive virtual water at the bottom. When a participant drops a ball into the drop box in the experiment scene, the water level rises by 1ft. Moreover, if a participant throws a ball into the water, the water level rises less than 1 inch. Successfully dropping five balls into the drop box will make the water level high enough, as indicated by a red marker on the wall. The red marker will then turn to green; all the water will be flushed out; the opened floor will close; and the walkway will move down to the floor.

3.2. System Description

Display: An eMagin Z800 HMD was used as the display unit to view the VE. The display weighs 8oz and is particularly comfortable compared to most HMDs. The field of view was 40 degrees diagonal.

The view was not stereoscopic. It is known that stereoscopic view can increase people's presence [MBZB12].

However, some people cannot see in stereo, which would have excluded them from this study. We wanted to avoid additional exclusion because the study already had very strict selection criteria (See section 4.4) - hence the small sample sizes. We intend to investigate stereoscopic view in future work.

We blocked the peripheral vision for the bottom of the HMD, but users could still see the real environment from the periphery on the sides. We kept the side periphery open because most virtual rehabilitation would be using HMDs under these viewing conditions due to safety issues. Based on pilot testing, for some PMIs, blocking the entire periphery can cause them to fall. In virtual rehabilitation, users require an open periphery because otherwise they would not be able to stand and perform the exercises safely. Thus, we kept the periphery open in our study to make it more generalizable to virtual rehabilitation.

Audio: Participants wore noise-cancelling headphones during the study. The headphones blocked out all of the ambient sound from the real world to keep the participant focused on the VE. All of the sounds in the VE were 3D enabled. Meanwhile, the communication between the experimenter and the participant was conducted through a microphone.

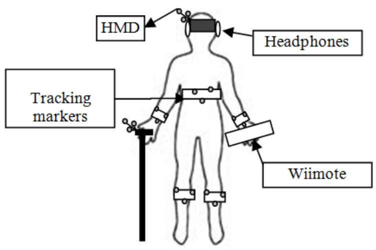


Figure 4: *Schematic of body tracking: Reflective markers were attached to the body, cane, and headphones. The Wiimote and cane may be in opposite hands, depending on participant preference.*

View and Avatar Tracking: Using an eight-camera Natural Point OptiTrack outside-looking-in vision based system (http:// www.naturalpoint.com/optitrack/), we were able to facilitate a responsive avatar (Figure 4).

We tracked seven objects on the human body - head, torso, two hands, one cane (if needed) and two feet. Interactive movement of the avatar's arms and legs was facilitated by an IK solver (http:// u3d.as/content/dogzer/inverse-kinematics/2fP). The IK solver estimates the angles of the joints based on the tracked positions of the hands and knees. Tracking markers were also attached to participants' torso, head and the cane for 6 degrees of freedom tracking (i.e., tracked orientation and position). The markers for head tracking were affixed to the headphones and the markers for the cane were affixed to the cane. All of the other markers were attached to the participant's body by using Velcro straps. The VE allowed the participants to use the cane with either their right or left hand, while the other hand used the Wiimote. We asked each participant to perform a calibration procedure (Section 4.6) to improve the avatar registration.

Physiological and Gait Data Gathering Devices: We used two physiological sensors: Bioharness BT - a chest strap to monitor heart rate and breath rate (http://www.zephyr-technology.com /bioharness-bt).

We also used a GAITRite System (http://www.gaitrite.com) to collect gait information. It is a 14 ft long by 2.5 ft wide floor mat, which precisely measures gait information, such as step time/length, stride length, and velocity.

Wiimote: Only the Button B, which located on the bottom of the Wiimote, was used for picking, holding and dropping balls. All of the other buttons and the accelerometers did not affect the VE.

4. Methods

In a mixed design study, we compared two populations: 1) PMIs and 2) PNMIs who were of similar demographics to the PMIs.

4.1. Conditions

Between-subjects independent variable: There were two matched groups of participants: 1) PMI group and 2) PNMI group.

Within-subjects independent variable: Avatars 1) AVATAR: with the human avatar and the cane avatar if needed; 2) NO AVATAR: without the human avatar and without the cane avatar. The avatar conditions were experienced in random order to counter-balance any learning effects.

4.2. Metrics

To determine the time window of the physiological data, we used the time of when the participants started their first step after they picked the first ball as the start point. The end point was when the walkway was lowered and participants were back on the floor.

Double support percentage - This is related to the amount of time that both feet are touching the ground in the double support phase (Figure 5), as measured by the GAITRite, which is a walking mat with thousands of pressure sensors on it. (http://www.gaitrite.com/). The pressure sensors were also used to measure users' gait other information, such as step length, stride length, single support time, and etc.

Heart Rate (HR, beats/min) - A Bioharness BT device was

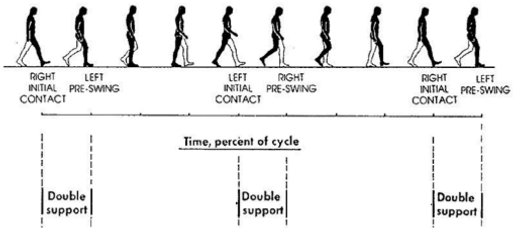


Figure 5: *Gait parameters: double support (see http://atec.utdallas.edu/midori/Handouts/walkingGraphs.htm).*

used to measure the heart rate during the study and send the data to a computer.

A presence questionnaire - we used the Witmer-Singer presence questionnaire to investigate the effects of presence caused by the avatar in the VE.

An interview questionnaire - A final questionnaire after finishing all sessions to let the participant explain the differences they felt between walking with the avatar and without the avatar in the VE.

4.3. Hypothesis

We base our hypotheses on the fact that PMIs are known to depend more on the visual sense than the proprioceptive sense. That is, we expect that they will believe in the visual representation of their avatar more than PNMIs will. This is related to the realism questions in our presence questionnaire. Thus, we hypothesize:

- PMIs will experience a stronger sense of presence than the PNMIs with the avatar in the VE.

4.4. Population

The sample size of most studies with PMIs is small, due to an effort to ensure homogeneity and since the population itself is smaller and less available than PNMIs. Thus, we recruited 12 PMIs), based on a rigorous selection process, and paired each one with a PNMI of similar demographics (e.g., age, height, weight and prior VE exposure).

Our selection process is as follows: First, every potential participant was interviewed by phone to verify if the person was qualified for this study in an effort to keep the participants homogeneous. For example, potential participants were asked several simple questions, such as the name, year, date (to loosely assess mental faculties) and demographic information. We only selected persons who could understand the questions and answer them fluently. Those persons, who answered the questions well, were asked to disclose their physical/mental impairments and the effects on major life activities. They were also asked questions about their use of assistive devices required for walking. After the entire interview, the PMIs finally selected as our participants 1) had no other disabilities besides mobility impairments, 2) were able to walk with a cane (not double canes or a walker), and 3) did not have any mental/cognitive impairment. The age range of the selected participants is from 37 to 72, the mean value is 53.17, and standard deviation is 9.98. The root causes of the mobility impairments in the participants were MS (10), Parkinson's (1), and stroke (brain hemorrhage) (1). Although their disabilities had different causes, they were all symptomatically similar and very close in their level of mobility impairments, as confirmed by baseline assessments of gait. Participants were paid $50 for one hour of time and effort.

Persons with cognitive disabilities were not included in the study. We discarded one participant's and their control's data for this reason. In total, 11 PMIs paired with 11 PNMIs were included in the analysis of the study results.

4.5. Environment

The study was conducted in a room with dimensions of 16.7 × 23 ft. Each study session was conducted with only one participant and the experimenters present in the room. It was a quiet air-conditioned environment.

4.6. Procedure

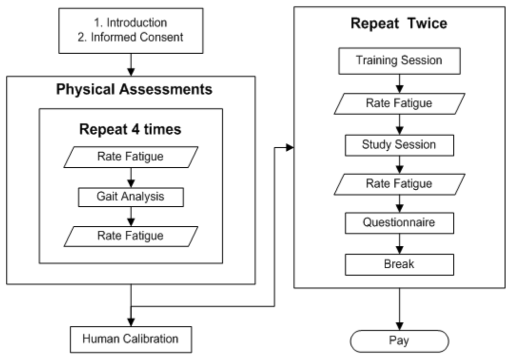


Figure 6: *The flowchart of the study procedure.*

The study procedure is shown in Figure 6. It took about one hour for each participant.

Introduction and Informed Consent - The study started with a brief introduction. The participants were asked to read the informed consent and sign it if there were not any questions.

Baseline Physical Assessments - First, we helped the participant put on the Bioharness BT strap. Then the participant was asked to walk casually on the GAITRite and cross the mat four times. We did this to get a baseline and ensure that participants had a similar level of gait disability. After that, we set up the trackers on the participant's body(Figure 4).

Human Calibration - Human Calibration was performed to improve the registration of the avatar to each participant's real limbs. Additionally, because different persons have different arm lengths and different leg lengths, the avatar in the VE was scaled to match the participant's proportions more closely.

However, the trackers needed to be attached to the participants' body by Velcro. We could not guarantee the trackers were set up at the same relative positions for every participant. Therefore, we had to manually fine-tune the Human Calibration to ensure the avatar was adequately registered.

Then, we gave the Wiimote to the participant and helped the participant wear the headphones and the HMD with the visor up - i.e., they saw visual feedback from the real environment instead of visual feedback from the VE. Then, the participant was asked to walk across the GAITRite six times again. The purpose of this was to ensure the participant felt comfortable with the setup.

The following part was then repeated twice in random order to compare AVATAR vs. NO AVATAR.

- *Training Session* - See section 3.1.1.
- *Study Session* - See section 3.1.2.
- *Presence Questionnaire*

Final Interview and Payment - After they finished the study task sessions, the participants were asked to answer a final interview questionnaire about their experiences in the virtual environment compared to the real world. At the end, we paid the participants $50.

5. Results

Analysis Methods and Justification: We performed ANOVAs for normally distributed data. For post hoc tests, we performed paired t-tests for within-subjects data and paired samples t-tests for between subjects because this was a study of matched pairs, using Bonferroni correction when appropriate. For ordinal data (e.g., the presence questionnaires) we used Wilcoxon signed ranks tests. Also, we performed Pearson correlations for normally distributed data.

5.1. Differences Between PMIs and PNMIs

5.1.1. Gait

There were many differences between the populations in gait, but the same differences were present in both conditions and in the baseline. For example, in the NO AVATAR condition we found a significant difference for double support percentage between PMIs (mean = 46.9%) and PNMIs (mean = 38.4%) (t(10) = -3.610, p = .005). Similarly, in the AVATAR condition we found a significant difference for double support percentage between PMIs (mean = 46.1%) and PNMIs (mean = 41.1%) (t(10) = -2.769, p = .02). There were no significant differences within subjects for gait between the AVATAR and NO AVATAR conditions.

Table 1: *Results of Q5*

Conditions	p Value	Z
AVATAR - Between PMIs and PNMIs	**0.016**	-2.45
NO AVATAR - Between PMIs and PNMIs	1	0
Healthy participants Between AVATAR and NO AVATAR	0.084	-1.73
PMIs Between AVATAR and NO AVATAR	0.157	1.41

Table 2: *PMIs Correlations between Q5 and Heart rate (HR) in the NO AVATAR condition.*

Correlation with Q5	p Value	Correlation coefficient
HR Avg	0.032	0.646
HR Max	0.032	0.646

5.1.2. Presence

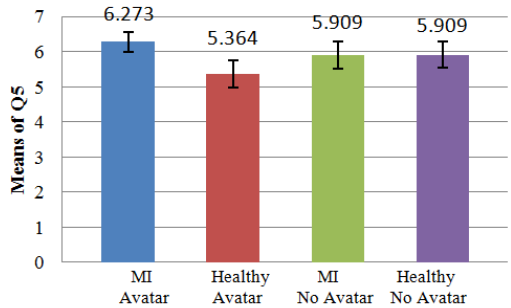


Figure 7: *The mean values of Q5.*

In the AVATAR condition, PMIs found the VE to be more realistic than the Healthy participants did (Figure 7, Table 1), based on the presence question:

Q5: "How much did your experiences in the virtual environment seem consistent with your real-world experiences?"

That is, we found a significant difference between PMIs (mean = 6.27, median = 6) and PNMIs (mean = 5.36, median = 6) in the AVATAR condition (Wilcoxon Signed Ranks: Z = -2.45, p = .016, r = .52). *Thus, our hypothesis cannot be rejected.*

We did not find any other significant differences within or between populations with respect to presence (Table 1).

5.2. PMIs Correlations Between Presence and Heart Rate

We found significant correlations between Q5 and heart rate but only in the NO AVATAR condition for PMIs (Table 2 and Figure 8).

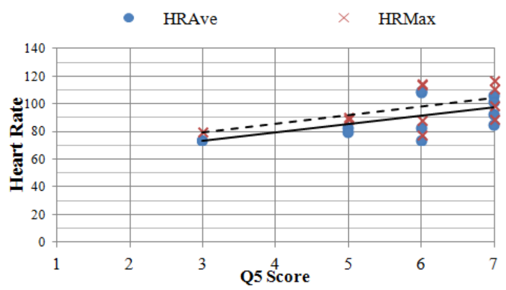


Figure 8: *PMIs Correlations between Q5 and Heart rate (HR) in the NO AVATAR condition.*

5.3. Interview

We observed that participants did not look down at the avatar often. The interview confirmed this. We asked them "Did you notice any differences between your experiences with and without the avatar?" They reported that "just knowing it was there was enough." Of note, many PMIs said that if they knew there was an avatar, it gave them more confidence in their balance while they were walking. Most of them thought that this increased confidence helped them more than the visual feedback from the avatar itself.

6. Discussion

In the current study, PMIs found the VE more realistic than the PNMIs did in the AVATAR condition (i.e., based on Q5 in the presence questionnaire). However, future work is needed to discover why. One potential reason for this difference is the PMIs' proprioceptive deficits and increased dependence on visual feedback [KG03]. PMIs may not have noticed the inaccuracy of an IK driven avatar as much as PNMIs did. IK often results in inaccurate joint angles because there can be many solutions to an IK equation. Moreover, hand orientation was not tracked. This was visible to the participants due to the task, even if not looking directly down at the body. Interestingly for PMIs, avatars may effectively increase presence regardless of the inaccuracy. If true, this could enable VE designers to effectively utilize lower accuracy and lower cost tracking systems for avatar movement, thereby making VR more accessible for a wider range of users. More research is needed to verify the effects of proprioceptive deficits and the inaccuracies of avatars on PMIs' presence.

In the NO AVATAR condition, PMIs' presence data were correlated to heart rate data. However, we were surprised that we did not find significant correlations between heart rate and presence in all the conditions across both groups. Previous studies on presence and physiological measures [MIWBJ02] report higher presence in the pit correlates with increased heart rate. It is unclear why we did not see these correlations in all the conditions. Based on the standard deviations, walking in the AVATAR condition seemed to decrease the variability of the PMIs' responses. This effect is exhibited in the narrower variability of PMIs' presence scores in the AVATAR condition (NO AVATAR std. dev. = 1.22; AVATAR std. dev. = .90) and the narrower variability of PMIs' HR in the AVATAR condition (NO AVATAR std. dev. = 2.12 bpm; AVATAR std. dev. = 1.39 bpm). Thus, it is likely that the lack of an avatar did not decrease presence as much in some PMIs. This suggests that these PMIs might be easier to immerse in a VE, which could be due to differences in attention [WMS13] or personality [KN13], but more research is needed to verify this.

7. Conclusion

How do avatars affect presence for PMIs? To address this question, we conducted a study on how a full-body avatar (or lack thereof) can affect the presence of PMIs as compared to PNMIs. The study utilized a virtual pit [MRWFPB03] (Figure 1). We recruited 11 PMIs who required the use of a cane for each and 11 PNMIs of similar demographics to the PMIs (e.g., age, height, weight, previous VE exposure). Results indicate that a full-body avatar may increase presence in PMIs even more than PNMIs. Based on our findings, we suggest that rehabilitation designers should utilize avatars to increase PMIs' sense of presence, even if the avatars seem to decrease PNMIs' presence.

The results of this study combined with our previous two studies points to more general conclusions about how PMIs experience presence. It seems that many PMIs are easier to immerse in VEs than PNMIs. This further motivates the future use of VE technology for PMIs. Thus, for future work, we plan to continue to investigate how aspects of VEs (e.g., latency, FoV, stereoscopy) can be configured to increase PMIs' sense of presence.

Acknowledgments

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