Proceedings of IOE Graduate Conference, 2017
Volume: 5 ISSN: 2350-8914 (Online), 2350-8906 (Print)

Difference Between User Experience in Referenced Environment and Unreferenced Environment With Implementation of Redirected Walking

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Abstract

In redirected walking, mapping of user motion in the real world to virtual world is scaled to other than a one-to-one ratio. Many studies have been performed to determine conservative thresholds for the amount of rotational and translational gain that can be safely applied to a person's motion in a virtual environment without their noticing. In this paper, we purpose a noble method of using graphical cues to explore if those thresholds can vary. We evaluate the thresholds in the referenced environment (deliberate clues helping to sense the application of gain) and unreferenced environment. For rotational and translational gain in redirected walking technique, it was concluded that the magnitude of the mapping ratio can be increased in an unreferenced scene for the similar probability of user perceiving non-natural movements due to the application of the technique.

Keywords

Virtual Reality (VR), Redirected Walking (RW), Gain Threshold, Referenced

1. Introduction

In immersive virtual environments, realistic simulation of real-world navigational techniques like walking and running is difficult to achieve[1]. Such locomotions within a Virtual Environment (VE) initially involved the use of hand-held input devices such as joystick, mouse and trackball and hand-worn gloves[2]. However, studies[3][4] show that real walking in Immersive Virtual Environments (IVEs) increases naturalness of VR based interactions.

One of the ways to provide the experience of walking is by transferring the user's tracked head movements to changes of the camera in the virtual world by means of a one-to-one mapping. Real-walking locomotion interfaces enable better user navigation, however, the user must be tracked, restricting the VE size to the tracked space[1]. It makes exploring the large virtual worlds difficult. Thus, the concept of virtual locomotion methods is needed that enable walking over large distances in the virtual world while remaining within a relatively small space in the real world.

Various physical devices have been developed to limit the distance covered in the real world. These devices include torus-shaped omnidirectional treadmills[5][6], motion foot pads[7], robot tiles[8] and motion carpets[9]. However, being physical technological devices, they will be expensive and support only a single user requiring multiple devices for multi-player interaction. Due to these limitations, in spite of being tremendous technological achievements, they are less likely to be adopted as the universal solution. Cognition and perception research suggests that cost-efficient, as well as natural alternatives, exist.

1.1 Redirected Walking

Researchers' attempt to formulate a software-only solution that would address the problem of locomotion has received significant attention. One of the most promising solutions is a technique called redirected walking.

Perceptive psychology suggests that vision often dominates proprioception and vestibular sensation when they disagree[10]. When users were confronted in perceptual experiments, they showed low performance in perceiving their travel path, when they judged their motion based only on vision through a virtual scene[11][12]. Since user self-corrects small inconsistencies during the walk, it should be possible to make them walk along a different path in the virtual world than in real world by tweaking their camera motion or other alternative techniques. This kind of change brought by *redirected walking* enables the users to explore a virtual world much larger than the confined real world in which they are being tracked[13]. Through the changes in the motion mapping of the user in both linear path and rotational movement, radically different virtual path can be achieved from the real physical path.

The redirected walking technique is based on the disability of human to perceive the inconsistency in their real motion and observation. It follows that there must exist a limit to which this inconsistency can be maintained. Steinicke et al[14] experimented to give numerical values to which the users can be redirected without observing inconsistencies between real and virtual motions. In this article, we present a series of experiments in which we have tried to find if those thresholds vary according to the Virtual Environment. We performed four experiments in two types of motion, i.e. two sets in each type of motion.

1.2 Terminology in Redirected Walking Techniques

Translation Gain

The translational gain $g_{trans} \epsilon$ R is defined as in Equation 1.1, i.e. by the quotient of the applied virtual world translation $translation_{virtual}$ and the tracked real world translation $translation_{real}$. Tracking system detects and updates the vector *translation*, which is updated as $translation = current\_position - previous\_position$. Then, the *translation* is applied to the virtual camera.

$$g_{trans} = \frac{translation_{virtual}}{translation_{real}} \tag{1.1}$$

When a translation gain g_{trans} is applied to a translational movement $translation_{real}$, the virtual camera is moved by the vector $g_{trans}.translation_{real}$ in the corresponding direction. With $g_{trans} > 1$, the real world area would be smaller than virtual environment area.

Rotational Gain

A real-world head turn can be specified by a vector consisting of three angles, i.e., yaw, pitch and roll. The tracked orientation change is applied to the virtual camera. Analog to translation gains, a rotation gain g_{rot} is defined as in Equation 1.2 i.e. by the quotient of the considered component (yaw/pitch/roll) of a virtual world rotation $rotation_{virtual}$ and the real world rotation $rotation_{real}$.

$$g_{rot} = \frac{rotation_{virtual}}{rotation_{real}} \tag{1.2}$$

When a rotation gain g_{rot} is applied to a real world rotation the virtual camera is rotated by $g_{rot}.rotation_{real}$ instead of $rotation_{real}$. This means that if g_{rot} = 1 the virtual scene remains stable considering the head's orientation change. For $g_{rot} > 1$ the virtual scene appears to rotate against the direction of the head turn, and$g_{rot} < 1$ causes the scene to rotate in the direction of the head turn.

2. Related Works

Many researchers have already established that in virtual worlds in comparison to the real world, distances are underestimated[15], the distance one has traveled is underestimated[16] and speed during walking is underestimated[17].

In 2006, Williams et al studied the effects of applying a fixed translational gain in the virtual environment. The users' were asked to walk in virtual space with different translational gains from 1:1 to 10:1. Then, they were asked to rotate with graphics turned off to observe if their perceptual accuracy was affected by the application of gain. No difference was observed in the user's perception of the applied gain[18].

In 2008, Steinicke et al [19] conducted experiments to determine the threshold to which users cannot accurately perceive various visual manipulations in virtual environments and repeated it in 2010[14]. They asked users to perform certain tasks then choose whether they felt the gain being applied was greater or less than normal in two-alternatives-forced-choice (2AFC). They concluded that users can be turned physically about 68% more or 10% less than the perceived virtual rotation in 2008 and changed the figures to 49% more or 20% less in the experiment of 2010. Similarly, they showed the users can be manipulated physically by about $\pm$22% than the perceived virtual translation in 2008 updating figures to 14% more and 26% less than the perceived virtual translation in 2010. Their observation for curvature gains along a circle was at least 24m in 2008 and decreased to 22m in 2010.

In 2008, Engel et al explored the possibility of dynamically computing rotational gain rather than applying stationary gain factors[20]. Instead of using strictly predetermined path for users as in previous experiments, they developed an algorithm, that allowed for some deviation in user path and adjusted the rotational gains dynamically to prevent the user from running into walls in the physical space.

A substantial effort has been spent on determining the threshold of gain that can be applied to the redirection technique. Those thresholds being determined are not compared on the basis of the virtual environment created. In summary, numerous attempts have been made to explore the options of redirected walking, but much area is still to be covered in this emerging technique.

3. Experiment

In this section, we present two pairs of experiments in which we have quantified how much variation in the thresholds of redirected walking can be achieved with the difference in virtual environments.

3.1 Experimental Design

Since the main objective of our experiments is to differentiate the thresholds of redirected walking without user perceiving the changes in varying environments, for each kind of gain associated there were two distinct virtual scenes.

Hardware Setup

We performed all experiments in a 5m x 7m laboratory room. The participants wore a Head Mounted Display (HMD) (HTC Vive, 2160x1200@90Hz) for the stimulus presentation. The virtual and real location of a participant was constantly fetched from MSI VR One backpack laptop with 16GB DDR4 RAM, Intel Core i5-7500 processor and NVIDIA Geforce GTX 960M graphics card.

The virtual scene was rendered using Unity3D with the frame rate of 60 frames per second. The participants received instructions both from the slides presented in the HMD and oral instructor. For input of participant's motion, we used a controller that came along with HTC Vive. Since the computer used was VR targeted backpack, there were no problems of wire entanglement or reorientation due to it.

Participants

10 male and 5 female (age 21-40) participants were involved in the experiment. Most of the participants were students or computer programmers. All had normal or corrected to normal vision; 4 wear glasses. 6 had considerable exposure to virtual reality and were accustomed to the virtual environment, 4 had a little experience and 5 had never tried virtual reality before. 14 participants were right-handed, 1 was left-handed. Two of the authors served as participants, two other were acquainted with the idea of redirected walking and all other were naive to the experimental conditions. The total experimentation time including pre-questionnaire, instructions, training and experiment took about 2 hours.

For all experiments, we used the method of constant stimuli in two-alternative forced-choice (2AFC) task. In this method, applied gains are randomly and uniformly distributed among the trials. The participant chooses between one of the two possible responses. The answer was limited to scaling being *more* or *less* than the actual movement. The gain at which the participant responds 'less' in half of the trials is taken as the *point of subjective equality* (PSE), at which the participant perceives the physical and virtual movement as identical. A threshold is the point of intensity at which the participants can just detect a discrepancy between physical and virtual motion. We define the detection threshold for gains less than the PSE to be the vale of gain at which the participant chooses 'less' response correctly 75% of the time and the detection threshold for gains greater than the PSE to be the value of gain at which the participants have 25% probability of choosing 'less' (i.e. 75% probability of choosing more). These ranges give us an interval of possible manipulations which can be used for redirected walking.

3.2 Experiment 1 (E1): Threshold Variation in Referenced and Unreferenced Environment for Straightforward Translation

In this experiment, we investigated the threshold variation for translational gain.

3.2.1 Materials and Methods for E1

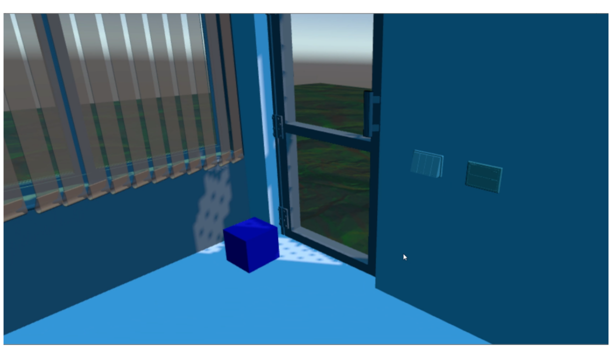

Figure 1: Game-play Design for referenced environment, translational gain.

For this trial, we chose the referenced environment to be an exact virtual replication of the physical room (5mx7m) where the experiment is performed as shown in Figure 1. This would allow users to feel the changes in scale more readily. For the unreferenced scene, an open area was used. After the participant wore HMD, in both experimental design, targets appeared at certain locations in the environment. They were orally instructed to point and shoot at the targets using controllers. The user had to go near the target and shoot it, experiencing the translational gain while in motion to reach the target. Afterwards, a written prompt would be displayed in a virtual scene which instructed them to choose the translational motion scaling to be 'more' or 'less' than the real world. We tested each gain 10 times in randomized order. All 15 participants participated in this experiment.

3.2.2 Results of E1

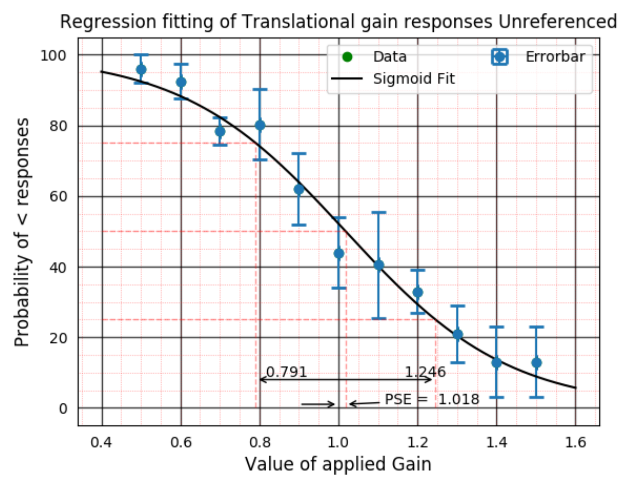

Figure 2: Sigmoid fit of translational response data I(Unreferenced)

Figure 3 shows the mean detection thresholds for unreferenced setting with the standard error over all participants for the tested gains while Figure 2 shows the same for the referenced setting. The x-axis shows the applied translational gain and the y-axis shows the probability for estimating a physical translation greater than the mapped virtual translation. The solid line shows a sigmoid curve which equation is given in equation 3.1.

$$y = \frac{1}{1 + ae^{b(x-x_0)}} \tag{3.1}$$

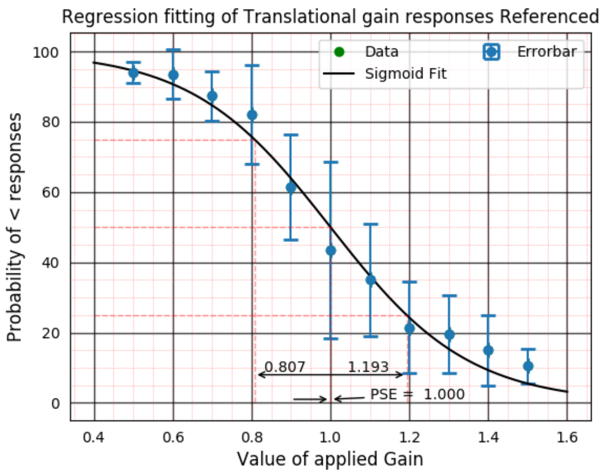

Figure 3: Sigmoid fit of translational response data II(Referenced)

$$PSE = x_0 - \frac{log_e(a)}{b} \tag{3.2}$$

As illustrated in the graph, and calculated using equation 3.2 we found the PSE = 1.018 for the unreferenced environment while PSE = 1.00 for the referenced environment. We can see that the upper and the lower thresholds of the gains for Figure 2 are 1.193 and 0.807. Similarly, for Figure 3, the upper and the lower thresholds of the gains are 1.246 and 0.791.

3.2.3 Discussion of E1

In our experiment for the unreferenced environment of the straightforward movements the application of gain remained undetected from the range of 0.791 to 1.246. However, for the referenced environment the detection threshold was shrunk and given at 0.807 and 1.93. This corresponds to that 4.19m to 6.20m is undetectable to a user in a 5m walk at the referenced environment. 4.01m to 6.32m is undetectable in the unreferenced environment for the same length of the walk. Even considering the difficulty of the task in VE and associated uncertainty of participants, the difference is significant to state that absence of graphical clues makes perceiving application of gain harder.

3.3 Experiment 2 (E2): Threshold Variation in Referenced and Unreferenced Environment for Rotational Gain

In this experiment, we investigated the threshold variation for rotational gain.

3.3.1 Material and Methods for E2

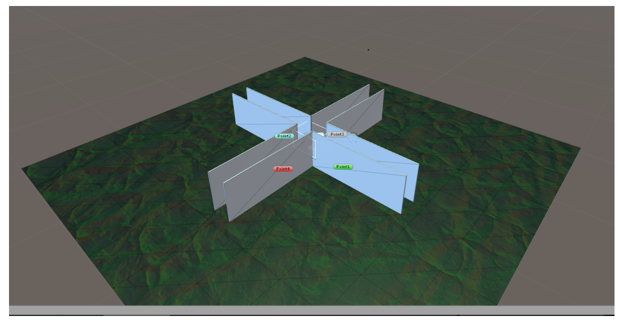

Figure 4: Game-play Design for referenced environment, rotational gain.

In this trial, for the referenced environment the game-play area was partitioned by two perpendicular corridors as shown in Figure 4. The right-angled walls help the user to have an easier perception of rotational change and served as the point of reference. The participant stood at the intersection of those two corridors. As with the translational gain, when the participant wore the HMD, targets sprouted in the environment. The participant had to physically turn towards the target and shoot. For the unreferenced environment, an open area was chosen.

After the participants had successfully hit 5 targets the virtual scene showed a prompt to choose if the virtual rotation was 'more' or 'less' than the real world turn. We varied the physical and virtual rotation randomly in the range of 0.5 (180° physical rotation resulted in a 90° virtual rotation) and 1.5 (60° physical rotation resulted in a 90° virtual rotation) in steps of 0.1. We tested each gain 10 times in randomized order. All 15 participants took part in this trial.

3.3.2 Results of E2

Figure 5 shows that the mean detection thresholds for unreferenced setting with the standard error over all participants for the tested gains while

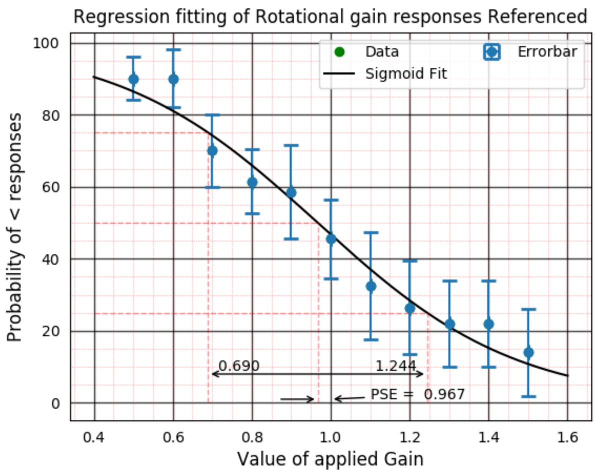

Figure 5: Sigmoid fit of rotational response data I(Referenced)

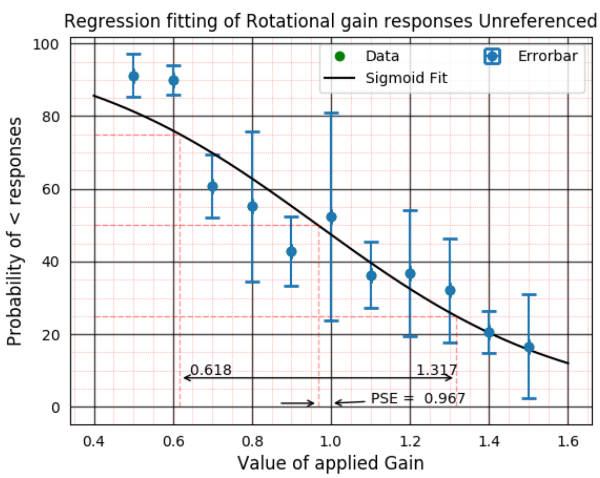

Figure 6: Sigmoid fit of rotational response data II(Unreferenced)

Figure 6 shows the same for the referenced environment. The x-axis shows the applied translational gain and the y-axis shows the probability for estimating a physical rotation greater than the mapped virtual rotation. We fitted the data with the same sigmoidal function as in experiment E1. The PSE for the pooled data of all 15 subjects is 0.967 for the unreferenced environment while 0.951 for the referenced environment. Detection threshold on the unreferenced environment was reached at gains of 0.625 for greater responses and at 1.32 for smaller responses.Similarly, for the referenced environment the detection threshold was reached at gains of 0.67 for greater responses and at 1.26 for smaller responses.

3.3.3 Discussion of E2

In our experiment, the detection threshold for rotation was significantly smaller for gains greater than one than that in Steinckie's study [14]. The response for gain smaller than one remained, however, closer to the original study. The difference may have been observed for varied reasons of difference in equipment being used to the perception of rotation in the different cultural background, which needs to be studied. Nevertheless, the differences in the threshold between the referenced and unreferenced environment itself changed significantly. For unreferenced environment participants had problems to discriminate between a 90° virtual from real rotations ranging from 68.2° to 144°. This range shrank between 71.4° and 134.3° for referenced environment. In summary, the experiment shows that subjects could not discriminate physical form virtual rotations over the reported range of gains. Consequently, the users can be redirected to the given range without them noticing.

4. Conclusion and Discussion

In this article, we analyzed the difference in threshold of detection for referenced and unreferenced environment. We introduced the generic concepts for redirection techniques and tested the corresponding gains in a practical useful range for their perceptibility. The findings include detection thresholds for two types of environment for each gain.

4.1 Summary of the Results

The result from the unreferenced and referenced environment shows that the degree of user perceiving the changes being applied to the virtual environment increases by 2.0% for the upper limit and decreases by 4.5% for the lower limit in translational gain for the unreferenced environment. Similarly, the rotational gain can be further scaled down by 6.7% in smaller gains for the unreferenced environment while can be further scaled up by 5.6% for greater gains in the unreferenced environment. So, higher ratios of mapping can be applied without the user noticing a significant difference in experience by providing no visual clues about the environment.

The above results indicate that vision has an impact on feeling the naturalness of walking in the virtual environment. The space perception is not factored alone by proprioception and the vestibular sensation.

4.2 Future Enhancement

In the future, we will consider embodying self-avatar to minimize the simulation sickness for the virtual environment. The studies[21][22] show that the user feel more oriented in presence of avatar. Similarly, we used static gain in this experiment. We believe that adaptive gain can have a more natural feel to the redirected walking as it can differentiate between the gradual and sudden movement of the user.

References

[1] Sing Bing Kang. Hands-free navigation in vr environments by tracking the head. *International Journal of Human-Computer Studies*, 48(2):247–266, 1998.

[2] Eric Hodgson, Eric Bachmann, and David Waller. Redirected walking to explore virtual environments: Assessing the potential for spatial interference. *ACM Transactions on Applied Perception (TAP)*, 8(4):22, 2011.

[3] Frank Steinicke, Gerd Bruder, Klaus Hinrichs, Jason Jerald, Harald Frenz, Markus Lappe, Jens Herder, Simon Richir, and Indira Thouvenin. Real walking through virtual environments by redirection techniques. *Journal of Virtual Reality and Broadcasting*, 6(2), 2009.

[4] Martin Usoh, Kevin Arthur, Mary C Whitton, Rui Bastos, Anthony Steed, Mel Slater, and Frederick P Brooks Jr. Walking¿ walking-in-place¿ flying, in virtual environments. In *Proceedings of the 26th annual conference on Computer graphics and interactive techniques*, pages 359–364. ACM Press/Addison-Wesley Publishing Co., 1999.

[5] Laroussi Bouguila and Makoto Sato. Virtual locomotion system for large-scale virtual environment. In *Virtual Reality, 2002. Proceedings. IEEE*, pages 291–292. IEEE, 2002.

[6] Laroussi Bouguila, Makoto Sato, Shoichi Hasegawa, Hashimoto Naoki, Naoki Matsumoto, Atsushi Toyama, Jelel Ezzine, and Dalel Maghrebi. A new step-in-place locomotion interface for virtual environment with large display system. In *ACM SIGGRAPH 2002 conference abstracts and applications*, pages 63–63. ACM, 2002.

[7] Hiroo Iwata, Hiroaki Yano, and Hiroshi Tomioka. Powered shoes. In *ACM SIGGRAPH 2006 Emerging technologies*, page 28. ACM, 2006.

[8] Hiroo Iwata. The torus treadmill: Realizing locomotion in ves. *IEEE Computer Graphics and Applications*, 19(6):30–35, 1999.

[9] Martin Schwaiger, Thomas Thümmel, and Heinz Ulbrich. Cyberwalk: Implementation of a ball bearing platform for humans. *Human-Computer Interaction. Interaction Platforms and Techniques*, pages 926–935, 2007.

[10] Alain Berthoz. *The brain's sense of movement*, volume 10. Harvard University Press, 2000.

[11] RJV Bertin, I Israël, and M Lappe. Perception of two-dimensional, simulated ego-motion trajectories from optic flow. *Vision Research*, 40(21):2951–2971, 2000.

[12] Markus Lappe, Frank Bremmer, and AV Van den Berg. Perception of self-motion from visual flow. *Trends in cognitive sciences*, 3(9):329–336, 1999.

[13] Sharif Razzaque, Zachariah Kohn, and Mary C Whitton. Redirected walking. In *Proceedings of EUROGRAPHICS*, volume 9, pages 105–106. Manchester, UK, 2001.

[14] Frank Steinicke, Gerd Bruder, Jason Jerald, Harald Frenz, and Markus Lappe. Estimation of detection thresholds for redirected walking techniques. *IEEE transactions on visualization and computer graphics*, 16(1):17–27, 2010.

[15] Victoria Interrante, Brian Ries, and Lee Anderson. Distance perception in immersive virtual environments, revisited. In *Virtual Reality Conference, 2006*, pages 3–10. IEEE, 2006.

[16] Harald Frenz, Markus Lappe, Marina Kolesnik, and Thomas Bührmann. Estimation of travel distance from visual motion in virtual environments. *ACM Transactions on Applied Perception (TAP)*, 4(1):3, 2007.

[17] Tom Banton, Jeanine Stefanucci, Frank Durgin, Adam Fass, and Dennis Proffitt. The perception of walking speed in a virtual environment. *Perception*, 14(4), 2006.

[18] Betsy Williams, Gayathri Narasimham, Tim P McNamara, Thomas H Carr, John J Rieser, and Bobby Bodenheimer. Updating orientation in large

virtual environments using scaled translational gain. In *Proceedings of the 3rd Symposium on Applied Perception in Graphics and Visualization*, pages 21–28. ACM, 2006.

[19] Frank Steinicke, Gerd Bruder, Jason Jerald, Harald Frenz, and Markus Lappe. Analyses of human sensitivity to redirected walking. In *Proceedings of the 2008 ACM symposium on Virtual reality software and technology*, pages 149–156. ACM, 2008.

[20] David Engel, Cristóbal Curio, Lili Tcheang, Betty Mohler, and Heinrich H Bülthoff. A psychophysically calibrated controller for navigating through large environments in a limited free-walking space. In *Proceedings of the 2008 ACM symposium on Virtual reality software and technology*, pages 157–164. ACM, 2008.

[21] Lane Phillips, Brian Ries, Michael Kaeding, and Victoria Interrante. Avatar self-embodiment enhances distance perception accuracy in non-photorealistic immersive virtual environments. In *Virtual Reality Conference (VR), 2010 IEEE*, pages 115–1148. IEEE, 2010.

[22] Bobby Bodenheimer, Sarah Creem-Regehr, Jeanine Stefanucci, Elena Shemetova, and William B Thompson. Prism aftereffects for throwing with a self-avatar in an immersive virtual environment. In *Virtual Reality (VR), 2017 IEEE*, pages 141–147. IEEE, 2017.