The Sloped Shoes: Influence Human Perception of the Virtual Slope

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ABSTRACT

At present, there is little research on redirected walking in the direction of the slope. In this study, people were allowed to walk uphill or downhill in virtual environments by changing the slope of users' shoes, while they walked on a flat wooden board in physical environments. We can explore the impact of the shoe slope on users' perception of walking uphill or downhill in the virtual world. We find that the slope of the shoes affects participants' perception, increasing their sense of realism when walking uphill and downhill in the virtual world. With increasing or decreasing the shoe slope, participants' perception of the possibility of walking uphill or downhill will also change and establish corresponding detection thresholds.

Keywords: Virtual reality, redirected walking, perception, shoe slope, detection threshold.

Index Terms: Virtual reality and Human computer interaction—haptic feedback—perception

1 INTRODUCTION

Kinesthetic and tactile feedback through one's feet is an important factor for attaining immersion in virtual environments(VE) or creating rich interactive experiences[1, 2]. However, human perception of VE is not accurate[3]. In order to enable users to experience more scenarios in VE, researchers have proposed various methods. For instance, Je et al.[1] designed a walkable pin-array floor, Schmidt et al.[4] presented "Level-Ups", a pair of mechanical brake-actuated shoes. Although much research has focused on identifying thresholds which indicates just-noticeable differences between vision and proprioception while the user is moving[5, 6], there is little research on human sensitivity to walking on a slope[7]. The way for users to perceive uphill or downhill by the Sloped Shoes has not been reported yet.

2 EXPERIMENT AND MATERIAL

2.1 The Sloped Shoes

The body is capable of perceiving the slightest variation in inclination and bumps in the terrain, with the feet feeling a unique yet powerful haptic experience[2, 8]. We hypothesized that within a certain slope range, the influence of the users' perception of the virtual slope was mainly determined by the slope of the shoes. We designed the Sloped Shoe, as shown in Figure1(a).

The material of the Sloped Shoes is a light wood, and the size is larger than the participants' shoes. There are six holes on the front of the board, three on each side. A bungee cord was passed through each hole and pass the sticky strap through the bungee cord. We can adjust sticky straps according to the user's shoes.

Figure 1: The experiment equipment. (a)The model of participants wearing the Sloped Shoes. (b) A user is walking on the flat path by the Sloped Shoes in the real world. (c) The user's view in the virtual environment with the slanted path.

2.2 Slope Gains

Generally, the conversion formula for slope *(i)* and angle *(θ)* is as follows.

$$i = \Delta y / \Delta x = \tan(\theta), \quad (1)$$

$$\theta = \arctan(i). \quad (2)$$

Where Δy is the height varying vertically and Δx is the length varying horizontally.

We define the *slope gains* as: $g_\theta := \theta_{virtual} / \theta_{shoes}$, $g_\theta \in \mathrm{R}$, $\theta_{virtual}$ denotes the inclination angle of the virtual path, and θ_{shoes} denotes the inclination angle of the Sloped Shoes worn by the participants. Therefore, we define the *gains* as the inclination angle of the virtual path divided by the inclination angle of the Sloped Shoe.

2.3 Experiment Procedure

We performed the preliminary study in a 5m × 4m space in the laboratory, illustrated in Figure 1 (b). The participant wore the VR headset, walking on a wooden board (2m × 1m). The wooden board is placed horizontally, without slope, and two chairs with adjustable height are placed at both ends. The virtual scene seen by the participants is shown in Figure 1(c).

We recruited 20 participants (22-25 years old, mean age 23.2, 15 females, 5 males). The participants were told the purpose of this experiment (an experiment about human perception of virtual slopes, but did not tell the physical environment to be flat). The participants who were blindfolded entered the experimental site. All participants had normal or corrected-to-normal vision.

According to the pre-experiment and related researches [7], we chose six different slope values in the physical world. The Sloped Shoes with the angles of 2°, 4°, 6°, -2°, -4° and -6°. In each experiment, we set six gains (0.5, 1, 1.5, 2, 2.5, 3) for virtual slope. For each test group, the applied gains were presented three times randomly and were uniformly distributed, and they do all the trials with one pair of shoes and only then change the shoe. Every participant completed a total of 6 x 6 x 3 = 108 trials. The experiment duration for each participant is 3 to 4 hours. During the experiment, in order to avoid visual fatigue or cumulative effects, each participant can rest 2 to 3 times, and each time is 20

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978-1-6654-8402-2/22/$31.00 ©2022 IEEE
DOI 10.1109/VRW55335.2022.00264

to 30 minutes. After the experiment, we paid each of them 200 RMB as the experiment remuneration.

Before the start of the experiment, we adjusted the size of the Sloped Shoes and virtual slope. To measure the amount of deviation that is unnoticeable, we used a standard psychophysical procedure based on the 2AFC task. This experimental method is a common procedure in redirected walking research[9]. Participants have to choose between one of two answers possibilities in our case "*physical slope is greater*" and "*virtual slope is greater*". Answers like "I don't know" are not allowed. The question is as follows.

Q: Do you perceive that the physical slope is greater or the virtual slope is greater?

The gain at which the participants respond "*physical slope is greater*" in 50% of the trials with uphill scenes was adopted as the point of subjective equality (PSE), at which they perceive virtual and physical movements as identical[10]. We set the detection threshold (DT) for gains at which 25%~75% of participants probability to choose the incorrect answer[11]. Inside the detection threshold, participants cannot accurately judge the difference between virtual and physical slopes.

3 Results

Figure 2 shows the probability that the participants perceive the "*physical slope is greater*" as the gain changes when θ_{shoes}= 2°, 4°, and 6°. For the tested gains, the mean detection rates and standard error bars for all participants are displayed in the plots, and each plot is fitted with a logistic psychometric function that shows PSE and DT.

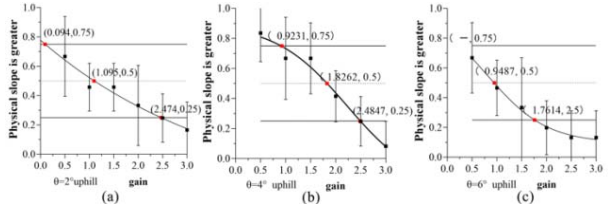

Figure 2: Plotted results of the uphill scenes. The psychometric function shows PSE and DTs for angle gains that are applied to (a) θ_{shoes} =2°, (b) θ_{shoes} =4° and (c) θ_{shoes} =6°.

When the tilt angle of the Sloped Shoes is 2°, the PSE is 1.10, and the DTs are at the gains of 0.09 and 2.47, which indicates that gains are at 0.09 and 2.47, and users cannot reliably estimate the difference between the virtual and physical slopes. The PSE in Figure 2(b) is 1.83, and the DTs are at the gains of 0.92 and 2.48, which indicates that when the angle of the Sloped Shoes is 4°, the users cannot distinguish the physical and virtual slopes between 3.68° and 9.92°. The PSE in Figure 2(c) is 0.95, and the DT is 1.76, which indicates that the participants have less than 75% probability to give the wrong answer with all the angle gains ≥ 0.5.

In downhill scenes, Figure3 shows the probability that the participants perceive "*physical slope is greater*" as the gains change when the angles of the Sloped Shoes are -2°, -4°, and -6°.

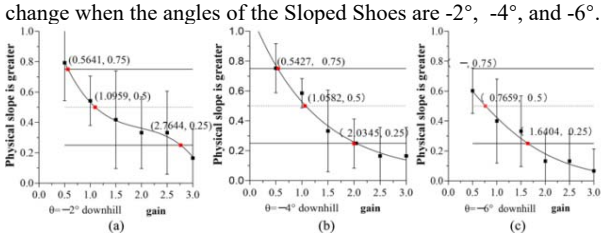

Figure 3: Plotted results of the downhill scenes. The psychometric function shows PSE and DTs for angle gains that are applied to (a) θ_{shoes} = -2°, (b) θ_{shoes} = -4° and (c) θ_{shoes} = -6°.

The PSE in Figure 3(a) is 1.10, and the DTs are at the gains of 0.56 and 2.76, which indicates that when the angle of the Sloped Shoes is -2°, the users cannot distinguish the physical and virtual slopes between -5.52° and -1.12°. The PSE in Figure 2(b) is 1.06, and the DTs are at the gains of 0.54 and 2.03. The PSE in Figure 3(c) is 0.77, and the DT is at the gain of 1.64, which indicates that the participants have less than 75% probability to give the wrong answer with all the angle gains ≥ 0.5.

4 Conclusion

In this paper, we presented the Sloped Shoes, which make users experience the feeling of going uphill and downhill. And then, we conducted a psychophysical experiment, through which we analyzed the influence of the Sloped Shoes on human perception of the virtual slope. Our study results suggest that the Sloped Shoes allow users to experience uphill and downhill in VE and establish a detection threshold.

Acknowledgements

This paper is supported by National Social Science Foundation of China, under grand number: 21VSZ124

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