A Study on the Sense of Burden and Body Ownership on Virtual Slope

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Abstract

This paper provides insight into the burden when people are walking up and down slopes in a virtual environment (VE) while actually walking on a flat floor in the real environment (RE). In RE, we feel a physical load during walking uphill or downhill. To reproduce such physical load in the VE, we provided visual stimuli to users by changing their step length. In order to investigate how the stimuli affect a sense of burden and body ownership, we performed a user study where participants walked on slopes in the VE. We found that changing the step length has a significant impact on a burden on the user and less correlation between body ownership and step length.

Index Terms: Human-centered computing—Virtual Reality;

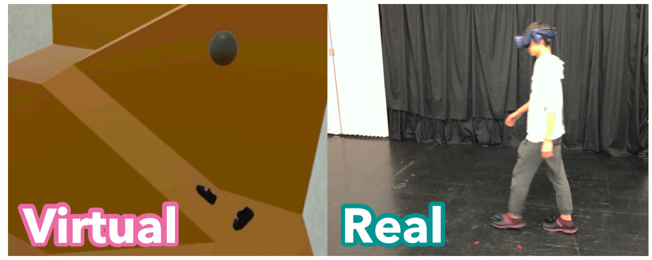

Figure 1: We investigated the sense of burden and body ownership when people are walking up (or down) virtual slopes (left) while actually walking on a flat floor in the real environment (right).

1 Introduction

Hop, step, and jump – virtual environment (VE) allows us only such a vertical motion while there are demands for stepping up and down stairs and slopes. Several works have tackled to expand the playing area vertically in the VE [1–4]. The challenging point of this study is to simulate and reproduce the perception of physical load during a vertical motion. Playing the virtual reality (VR) without that kind of perception lowers the immersion and realistic feeling in VE. Previous works tried to solve this problem in two approaches: (1) use specific devices and (2) adapt visual stimuli to a head-mounted display (HMD).

(1) Using specific devices: Iwata *et al.* used a treadmill to allow users to walk up and down while actually taking physical steps [1]. Nagao *et al.* proposed *"Infinite stairs"*, which simulated the sensation of walking up and down the stairs by getting users to step on small bumps [4]. Although these systems were effective in reproducing the perception of walking up and down, these systems restricted the speed and stride of walking.

(2) Adapting visual stimuli: Marchal *et al.* simulated the sensation of walking up and down in the VE by modifying the camera's height, orientation, and velocity [2]. This work revealed that these visual stimuli are effective for allowing users to perceive bumps and holes in the VE. Matsumoto *et al.* proposed a system that creates the feeling of walking up and down slopes in the VE by changing user's step length according to the gradient of slopes [3]. Through their preliminary user study, they found out that applying such visual stimuli make the virtual slope steep.

In this study, we focused on the sense of burden and body ownership using only visual stimuli by changing the step length in the VE [3]. Despite its conceptual novelty, their knowledge has plenty of room to improve the immersion and realistic feeling in the VE. To extend their knowledge is useful in the safety; to prevent an accident such that a user falls from the devices, comfort; walking freely in the VE without any constraints in RE, and ease; to be released from setting some devices. In our user study, we asked 12 participants to walk on slopes in 18 conditions by changing the gradient of the virtual slope and the step length in the VE while walking on a flat floor in RE (Fig. 1) . Our main findings are summarized as follows:

1. Users feel a heavier burden when changing their step length shorter.
2. Changing the step length longer in the VE is not a significant factor affecting the burden.
3. There is less correlation between a sense of body ownership and step length.

2 Experiment

We conducted a multi-grade evaluation and questionnaire survey to elucidate the perception of a burden while walking on slopes in the VE. The experiments followed the policy of the institutional review board (No. 2018-262). Participants were twelve university students (males: 11, females: 1, age: 23 ± 0.37) without neurological injuries, gait disorders or blind eyes.

We explained the tasks in brief, not details of our experiment including the experimental objectives. We accepted participants to take a rest whenever they desire.

Conditions: We focused on following two experimental parameters: (a) a gradient of the virtual slope and (b) a step length in the VE manipulated from the RE. The experiment consists of 18 conditions (six gradients: $-25°, -15°, -5°, 5°, 15°, 25°$ and three manipulated step length: $\times 0.6, \times 1.0, \times 1.4$ of those in RE).

Tasks: Participants climbed up (or down) four slopes subsequently (see Fig. 2) with an HMD (HTC Vive Pro[1]) and position trackers on shoes. The order of experiments was basically random (see algorithm 1). We asked several questions when participants arrived at the top (or bottom) of slopes in each condition. To conduct the experiments without bias to a room design in RE, there were blackout curtains surrounding the experimental room and participants cannot see inside the room. This experiment took about 1.2 hours in total per participant. Participants took five-minute breaks per six trials.

Metrics: We asked participants to answer the questions with seven-point Likert scale as followings[2]:

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[1] https://www.vive.com/jp/product/vive-pro/

[2] All of the communications with participants were done in their native language. In this paper, we describe any translated content in the form of "*translated content*".

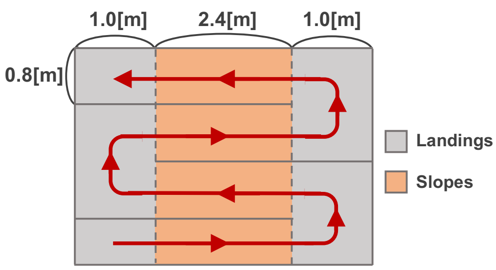

Figure 2: The floor plan of the virtual environment, where we used in our user study. (Red arrows indicate the path form start to finish).

Algorithm 1 The order of experiments

Ensure: $g \in$ gradients, $m \in$ step lengths
  shuffle the order of gradients
  for g in gradients **do**
    shuffle the order of step lengths
    for m in step lengths **do**
      conduct the experiment $\{g, m\}$
      ask Q1 and Q2 (see **Metrics in EXPERIMENT**)
    end for
    ask open-end questions
  end for

Q1: *"How did you feel a burden while walking on slopes in the VE, compared with a physical load on a flat floor in RE? (1: feel lighter, to 7: feel heavier than that in RE)"*

Q2: *"Did you feel the sense of body ownership in the VE during the experiment? (1: disagree strongly, to 7: agree strongly)"*

In addition, we conducted the Wilcoxon signed-rank test with 10% levels of significance between 1.0-times step length and 0.6(or 1.4)-times step length for each gradient. We also asked participants open-ended questions to reveal the difference between the three types of step length.

3 Results and Discussion

3.1 Burden

Fig. 3 shows the result of a burden. The Wilcoxon signed-rank test, done at 10% levels of significance, reveals that shortening the step length gave a heavier burden than without changing the step length. Indeed, participants reported that they feel the burden reproduced by shortening the step length: *"I felt the burden pulling me back."*; *"I felt my own body is heavier than usual."*; and *"The burden I felt when I walked up the slopes in the VE is similar to the physical load I feel in RE."*. However, the Wilcoxon signed-rank test indicates no statistically significant difference in -15° ($p = 0.105$). this is possibly due to the large variance arising from the shortage of the number of participants. We also observed no statistically significant difference between conditions with lengthening the step length and without the visual stimuli. The result shows that it is difficult to reduce a burden in the VE while walking on a flat floor in RE. This result indicates that people are more sensitive to shortening the step length than lengthening the step length.

3.2 The sense of body ownership

Through this experiment, we find that both visual stimuli significantly reduce the sense of body ownership in gentle slopes (5° and -5°) compared with no visual stimuli ($5^\circ : p = 0.014, 0.012$ and $-5^\circ : p = 0.014, 0.021$ for shortening and lengthening the step length). In steep slopes (25° and -25°), the availability of visual stimuli is decided by whether the slope is uphill or downhill. The

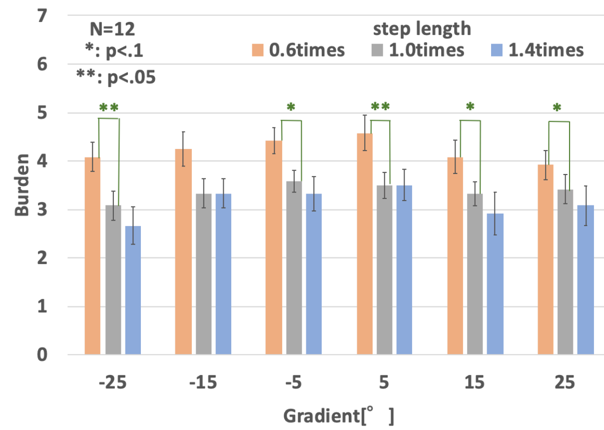

Figure 3: A burden felt while walking up and down slopes in the VE (Mean $\pm$ SE). p: p-value of the Wilcoxon-Signed-rank test done on the scores of the burden ($**$ and $*$ indicate 0.05 and 0.1 levels of significance respectively).

visual stimuli of changing the step length longer significantly reduce the ownership while walking up slopes ($p = 0.031$). On the other hand, while walking down slopes, the visual stimuli of changing the step length shorter significantly reduce the ownership ($p = 0.086$). From these results, the ownership depends on the gradient of slopes. In addition, there is the optimal combination between visual stimuli and the gradients of slopes.

4 Conclusion

We researched how users feel during walking uphill and downhill in the VE in terms of the burden and the sense of body ownership. We found that changing the step length could affect the perception of a burden. Shortening the step length makes users feel a heavier burden. On the other hand, lengthening the step length does not affect the feeling of a burden.

We also clarified that the body ownership depends on the gradient of slopes when the visual stimuli are adapted to users. In gentle slopes, the visual stimuli cause the reduction of the body ownership. On the other hand, lengthening (shortening) the step length reduce the body ownership while walking up (down) slopes in the VE. In the future work, we will investigate the perception on not only a flat floor but also an inclined floor in RE.

Acknowledgments

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