Enhanced Perception of Speed in Textured VR Environments with Unchanged Sensitivity

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***Abstract*—The perception of self-locomotive speed in virtual spaces varies depending on the available visual information. Prior research indicates that self-locomotive speed is perceived more rapidly in virtual reality (VR) environments that feature wall textures or objects compared to more barren spaces. In our study, involving 99 participants, we examined the impact of visual information on the perception of self-locomotive speed in VR. We designed two VR environments: a barren hallway and a textured-wall hallway. We investigated the discrimination threshold for movement speed in each environment and the point of subjective equality between the two conditions. Our findings reveal minimal difference in the discrimination threshold between the two environments, indicating that the wall texture in VR space does not significantly influence the sensitivity of perceiving self-locomotive speed. However, a walking speed of 1.6 m/s in the barren hallway was subjectively equivalent to a 14.7% slower walking speed in the textured-wall hallway. The self-locomotive speed was felt faster with the textured background image. These findings provide insights for presenting appropriate speeds in virtual environments.**

***Index Terms*—speed perception, differential threshold**

I. Introduction

In virtual reality (VR) spaces, self-locomotive speeds are not correctly judged [1]–[3]. Specifically, background visual information influences the perception of the speed [4]–[6]. For instance, Zheng et al. [6] observed that visual stimuli with higher spatiotemporal frequencies resulted in a faster perception of speed. Similarly, Otake et al. [4] found that the relationship between perceived and actual velocity is more linear in VR spaces featuring textured walls or objects, compared to more barren environments.

Previous studies have not extensively explored how visual cues in VR environments affect the discrimination threshold and the point of subjective equality (PSE) in speed perception. The discrimination threshold refers to the minimum difference in intensity between two stimuli that is required for them to be distinctly recognizable. Stimuli are considered subjectively equivalent when their intensities, under different conditions, are perceived as equal. A quantitative analysis of the discrimination threshold and PSE can enhance our understanding of how VR background settings influence speed perception. This study provides vital information to VR application designers by utilizing a psychophysical approach to examine the discrimination thresholds and PSE when moving through barren and textured-wall virtual hallways.

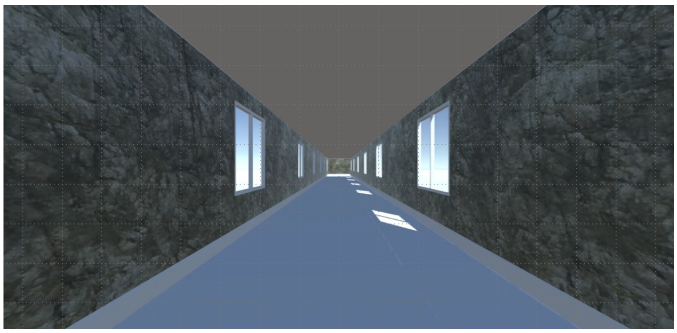

Fig. 1: View from the start point of the textured-wall hallway.

II. Methods

A. Stimuli: Virtual space

We created two types of virtual hallways, one with barren walls and the other with textured walls, using Unity (version 2020.3.10f1, Unity Technologies, CA). Fig. 1 displays the first-person view from the starting point of the textured hallway. Each hallway was designed to be 4.0 m wide, 3.0 m high, and sufficiently long to ensure that the avatar could not reach the end during a trial. The avatar, providing the first-person perspective, was set to a height of 1.6 m. Windows were placed on both the left and right sides of the hallways to serve as minimal cues for estimating locomotive speed. Each window measured 2.0 m in width, with a distance of 8.0 m between the centers of adjacent windows. This virtual environment setup was similar to that used by Otake et al. [4].

B. Participants

Ninety-nine university students in their 20s (mean age: 22.3 years) participated in the experiment. The participants were unaware of the purpose of the experiment. All participants provided written informed consent before participation.

C. Ethical statement

The protocol of the study was approved by the local review committee at Hino Campus, Tokyo Metropolitan University (H23-9).

D. Procedures

We conducted three experiments using the method of constant stimuli, a psychophysical approach, to determine the

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discrimination thresholds and the PSE for speed perception. In Experiments 1 and 2, we assessed the discrimination thresholds for speed in the barren and textured hallways, respectively. Experiment 3 was designed to examine the speed perceived as subjectively equivalent across the two hallway conditions.

Participants viewed first-person perspective scenes in which an avatar moved straight ahead at a constant speed. In each trial, participants were presented with a standard stimulus ($v_n = 1.0$) and a test stimulus and were required to select the faster one in a forced-choice manner. The speed scale of $v_n = 1.0$ corresponded to 1.6 m/s in the virtual environments. In Experiments 1 and 2, the test stimuli included seven levels: $v_n = 0.85$, 0.90, 0.95, 1.00, 1.05, 1.10, and 1.15, presented in random order. The speed in the VR space was v_n times 1.6 m/s. In Experiment 3, participants viewed the avatar moving in the barren hallway at $v_n = 1.0$ as the standard stimulus. The test stimuli in the textured hallway were $v_n = 0.65$, 0.70, 0.75, 0.80, 0.85, 0.90, and 0.95.

Participants sat 3 m away from a large screen (1.4 m $\times$ 2.5 m) displaying the hallway. They were given a three-minute break after every seven trials, totaling 21 trials. Unlike the general constant method where participants judge a single test stimulus multiple times, in our university class setting, each comparative stimulus was judged only once.

E. Data analysis

Using data obtained from Experiments 1 and 2, we calculated the discrimination thresholds in the following manner: The discrimination threshold represents the speed difference between two stimuli that allows them to be correctly distinguished at 84% of the time. Initially, for each test stimulus, we calculated the proportion of responses where the test stimulus was reported as faster than the standard. These proportions were then converted into z-scores, which were approximated as linear functions of the speed scale v_n. To predict the discrimination threshold using this linear approximation, the v_n value corresponding to $z = 1$ represents the upper threshold, and the difference between this v_n and $v_n = 1.0$ constitutes the upper discrimination threshold. Similarly, the lower threshold was determined from the v_n value at $z = -1.0$. Finally, the average of the upper and lower discrimination thresholds was defined as the discrimination threshold.

From Experiment 3, we calculated the proportion of responses indicating that the speed in the textured-wall hallway was perceived as faster than the reference speed. These proportions were also converted to z-scores and approximated as a linear function of v_n. For predicting the PSE using this linear model, v_n at $z = 0$ was identified. The PSE is the speed scale in the textured hallway condition that is judged to be equivalent to 1.6 m/s in the barren hallway.

III. Results

Fig. 2 illustrates the psychophysical curves—approximated cumulative normal distribution functions—derived from the answer proportions of Experiments 1 and 2. The vertical axis represents the proportion of participants who judged the comparison stimuli to be faster than the reference stimuli, while the horizontal axis corresponds to the speed of the comparison stimulus. The greater the deviation of v_n from the standard stimulus ($v_n = 1.0$), the easier it was to judge the speed; that is, the probability more closely approached 0 or 1. From the data acquired in Experiment 1, the discrimination threshold for the barren hallway was found to be 0.1216 (upper threshold: 1.112, lower threshold: 0.8689). In Experiment 2, the discrimination threshold for the textured hallway was 0.1231 (upper threshold: 1.126, lower threshold: 0.8797). These thresholds were similar under both conditions.

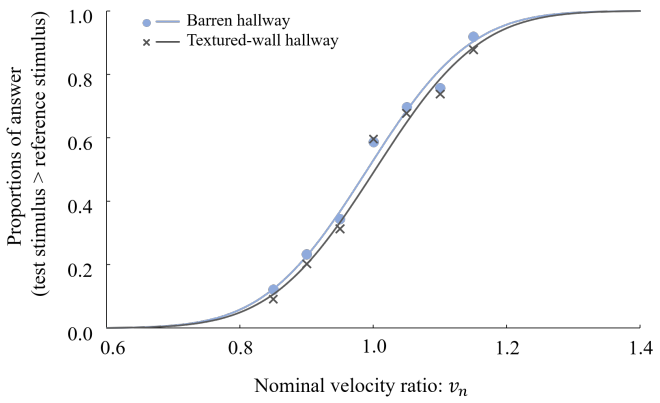

Fig. 2: Psychometric curves of the speed perception under the barren and textured-wall hallways. Proportions at which the test stimulus was perceived faster than the reference stimulus, that is, $v_n = 1.6$ m/s.

Data from Experiment 3 revealed the PSE at $v_n = 0.853$, indicating that speeds were perceived as faster in the textured hallway compared to the barren hallway.

IV. Discussion

Human internal responses to stimuli show probabilistic variations, which typically conform to a normal distribution. The shape of this probability function influences discrimination thresholds. A lower discrimination threshold for speed perception indicates a lower variance in the probability distribution, meaning enhanced sensitivity to discern velocities. Results from Experiments 1 and 2 revealed no substantial differences in discrimination thresholds between the barren and textured hallway environments. This suggests that internal response patterns to speed are similar across different visual settings, indicating minimal impact of wall texture on sensitivity to speed perception. Notably, the PSE demonstrated a 14.66% shift towards the slow velocity in the textured-wall hallway. The self-locomotive speed was perceived faster in the textured wall condition. Virtual reality designers should consider how wall texture affects the perceived speed, rather than the sensitivity to changes in movement speed.

V. Conclusion

We researched the effect of wall textures in virtual space on self-locomotive speed perception. We found that the presence

of the textured wall had minimal influence on the discrimination thresholds or sensitivity against the speeds. However, in the textured hallway, the speeds were felt faster than those in the barren hallway. The speed of 1.6 m/s in the barren hallway was subjectively equal to 1.36 m/s in the textured hallway.

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