Magnitude estimation of self-speed under different visual cue conditions in virtual space

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***Abstract*—In recent years, the concept of the metaverse has spread, and the demand for virtual reality (VR) technology has increased. We focused on human perception in VR spaces, particularly their own locomotive velocity. The amount of visual information in the VR space was changed, and the subjective velocity perception was evaluated using the psychophysical method of magnitude estimation. When walking in a bleak hallway, the velocity was felt slower than when walking in a hallway with many objects. However, the exponent of Stevens' power law was not significantly changed by visual cues in the hallways.**

***Index Terms*—Virtual reality, Speed perception, Locomotion**

I. Introduction

Virtual reality (VR) technology has been a keyword in the information society, and will be increasingly useful as a fundamental technology in the future. However, the human perceptual properties in VR spaces are different from those in actual spaces because the amount of information available to humans is reduced in the latter. One example is the perception of one's own locomotive speed. It is known that one's perceived speed is slower in a VR space because there is less visual information available than in an actual space [1], [2]. This makes it difficult to provide the user with a VR space that provides the experience that the creator of the VR space originally intended.

Previous studies have mainly conducted matching tasks to investigate the perception of speed in a VR space [2], [3], [4]. For example, [3] reported that a speed of 12 km/h in a VR space was underestimated by 31% compared to that in an actual space. However, because human perception is generally nonlinear, the human perception of speed may exhibit different characteristics depending on the speed itself. We investigated the perception of locomotive speeds over a broader range of speed by using the psychophysical method of magnitude estimation. We expected to acquire insights into the effect of background information on the perceived speed within a VR space, which has yet to be investigated. This study was approved by Institutional Review Board, Hino Campus, Tokyo Metropolitan University (H21-034).

II. Methods

A. VR space

To investigate the human perception of speed in VR spaces, virtual hallways were constructed using Unity (Unity 2020.3.12f1, Unity Technologies Co., Ltd., USA). Fig. 1 shows the scenery viewed from a first-person perspective. The left figure shows a bleak hallway, and the right figure shows an object-filled hallway. The length of the hallway was 150 m, the width was 4.0 m, and the height was 3.0 m. The height of the avatar providing the first-person perspective was 1.6 m. The distance between the centers of the neighboring windows was 24 m.

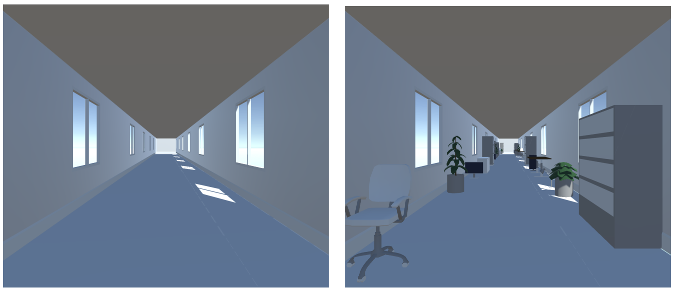

Fig. 1. VR space for this study. The left figure shows a bleak hallway, and the right figure shows an object-filled hallway.

B. Task

The magnitude estimation method was used to investigate the perceived speed of locomotive movement. The reference stimulus was a condition in which the avatar moves at 5.0 m/s in a bleak hallway. As test stimuli, we used velocity stimuli ranging from 2.0 to 14.0 m/s with the intervals of 1.5 m/s in the bleak and the object-filled hallways. After experiencing the reference stimulus, participants watched a randomly displayed test stimulus and answered how many times faster the test stimulus was than the reference stimulus. Individuals conducted two trials under each of the two stimulus conditions. They were able to watch the reference stimulus at any time. The participants were seated such that the distance between the display and their faces was 40 cm.

C. Participants

Eighteen university students (in their 20s) participated in the task after providing written informed consent. None of the participants were informed of the purpose of the experiment.

TABLE I

REGRESSION ANALYSIS USED TO COMPUTE THE COEFFICIENTS IN (2) FOR TWO EXPERIMENT CONDITIONS. THE COEFFICIENT, STANDARD ERRORS, t, AND p ARE ALL SHOWN.

(a) $\log k$

	value	s.e.	t	p
Bleak	0.002	0.15	0.013	0.99
Object-filled	0.21	0.097	2.12	0.04

(b) a

	value	s.e.	t	p
Bleak	0.87	0.078	11.04	1.3×10^{-12}
Object-filled	0.89	0.05	17.91	1.4×10^{-18}

D. Analysis

The subjective speeds reported in the experiment were modeled using Stevens' power law [5]:

$$v_s = kv_r^a \tag{1}$$

where v_s is the subjectively perceived speed, v_r is the speed in the VR space, and k and a are constants. To compute the two constants using a linear regression analysis, the logarithm of (1) was used:

$$\log v_s = \log k + a \log v_r. \tag{2}$$

The t-tests were then applied to compare the differences in $\log k$ and a between the two experiment conditions.

III. RESULTS

The coefficients obtained through the regression analysis of the perceived speeds for the Stevens' power law equation in (2) are shown in Table I. In addition to the coefficients, the standard errors, t-values, and p-values are listed. The value of $\log k$ was 0.002 for the bleak hallway, which is not much different from 0, but was 0.21 for the object-filled hallway, which is statistically different from 0. a were 0.87 and 0.89 for the bleak hallway and objects-filled hallway, respectively. These values were statistically different from 0, but were not statistically different from each other ($t = 0.31, p = 0.38$).

Fig. 2 shows the perceived speeds and the regression curves in accord with Stevens' power law. The regression curve for the object-filled hallway ($v_s = 1.23v_r^{0.89}$) was larger than that for the bleak hallway ($v_s = 1.00v_r^{0.87}$).

IV. DISCUSSION

Two suggestions were obtained from this experiment regarding the perception of walking speed in a VR space.

The first is the perceived magnitude over a wide speed range. The speed perceived when walking in the bleak hallway with little visual information was smaller than that in an object-filled hallway with relatively large visual cues. We believe that this is due to the effect of the optical flow of the background caused by walking. The difference in perceived speed between the two conditions was greater within the high speed range. In other words, the faster the speed, the more important the landscape information is to fill in the gap between the actual and perceived speeds in a VR space.

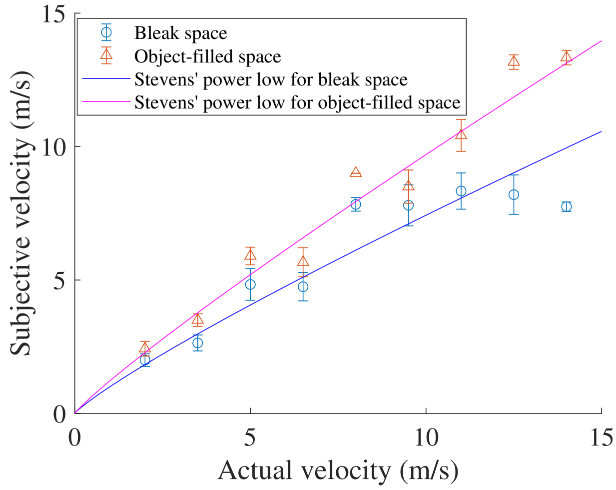

Fig. 2. Means and standard errors of subjective velocities obtained using the magnitude estimation for two different virtual space conditions and Stevens' power curves.

The second concern is the power exponent. In this study, the exponent of Stevens' power law ranged 0.87–0.89, and no difference was found between the two conditions. In general, when the exponent is greater than 1, humans are hypersensitive to large physical stimuli, and when the exponent is less than 1, we are hypersensitive to small physical stimuli. The speed perception in a VR space is approximately linear within the low-speed range and becomes slightly less sensitive in the high-speed range.

V. CONCLUSION

In this study, we used the psychophysical method of a magnitude estimation to investigate the human perception of speed under different visual cue conditions in a VR space. Unlike previous studies, this method allowed us to investigate broadband speeds. The perceived speeds tended to be slower when the amount of visual information was low. Regardless of the visual cue conditions, a linear relationship between the actual speed and the perceived speed was maintained, with the exponent of Stevens' power law being 0.87–0.89. These findings may help in designing VR spaces that are perceptually consistent with the actual spaces.

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