Positive or Negative? The Effect of Self-motion Speed on Flow Experience is Moderated by Susceptibility to VR Sickness

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ABSTRACT

Future activities conducted within the Metaverse will require users to actively navigate in complex virtual reality (VR) environments. Users' sense of self-motion during active navigation may contribute to flow experience, but this also improves the risk of VR sickness. The effect of self-motion on flow experience is still unexplored. To explore this question, this paper developed an experimental VR environment supporting active navigation at different speeds and subsequently performed two experiments. Experiment 1 first examined the effect of self-motion speed on flow experience and VR sickness. Experiment 2 examined the potential moderating effect of VR sickness susceptibility in the relationship between self-motion speed and flow experience. The results showed that the effect of self-motion speed on flow experience was moderated by participants' VR sickness susceptibility. For participants with low susceptibility, self-motion speed had a significantly positive effect on flow experience; for participants with high susceptibility, the effect was not significant.

Index Terms: Virtual reality, Flow experience, VR sickness susceptibility, Self-motion, Moderating effect

1 INTRODUCTION

The metaverse is emerging to be the next-generation iteration of the internet. Activities conducted within the metaverse require users to actively move and navigate through complex virtual environments. To achieve a satisfying feeling of immersion and presence in VR activities, it is necessary to induce the user's sense of self-motion (also known as vection) [1]. Active navigation through a self-avatar can provides users the sense of self-motion even if no real physical motion occurs, which is the case concerned by this study. This conscious awareness (of self-motion) involves perceptions of its speed and direction [6].

Compared with passive navigation, active navigation provides users with more freedom and a greater sense of control, which is likely to contribute to a higher level of flow experience. The term of *Flow experience* refers to a highly enjoyable mental state. Individuals in this state are fully involved and engaged in the process of the ongoing activity, and it hence helps achieve an optimal user experience during VR activities [2]. However, the self-motion caused by navigation may also increase the risk of VR sickness [5], especially in VR world via wearing a head-mounted display. VR sickness is one of the most important risk factors for breaking the immersion and flow experience of users in VR.

Although previous work has performed some exploration about the effect of navigation or self-motion on VR sickness [8], as far as we know, whether self-motion speed has a significant (positive or negative effect for further) on the flow experience remains unclear. Resolving this question will be beneficial for designing better VR applications. Moreover, there exist individual differences in susceptibility to VR sickness [4]. Humans with different susceptibilities to VR sickness react to navigation and self-motion speeds differently. The individual factors that may affect VR sickness should also be considered when exploring the relationship between VR sickness and the flow experience. Therefore, this study aims to preliminarily examine the effect of self-motion speed on the flow experience and VR sickness, as well as to explore the beneficial factors contributing to positive outcomes of self-motion in VR.

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2 CONSTRUCTION OF AN EXPERIMENTAL VR ENVIRONMENT

To explore the research question, we developed an experimental VR environment which supported the flexible manipulation of navigation speed. It is an immersive VELE for students to learn English words of rare marine creatures. The participants need actively move to find target sea creatures (see Figure 2a) from alternative sea creatures (see Figure 2b) within a limited time.If participants approached the target creatures and shot them with a tiny bubble, the corresponding English words would appear. If participants approached and shot at non-target creatures, no word would appear.

Figure 1: The snapshot of the experimental VELE developed in this study, portraying a virtual underwater area where many sea creatures navigate.

The moving speed of the self-avatar (adopting the first-person view) determines the self-motion speed to a large extent. Therefore, to explore the effect of self-motion speed, the navigation speeds of the avatar should be appropriately set to make the participant perceive different self-motion speeds without experiencing VR sickness. Next, We performed a pilot study to evaluate participants' perceptions of self-motion speed in the VELE and use this as a basis to determine the proper speed parameters to be used in subsequent formal experiments.

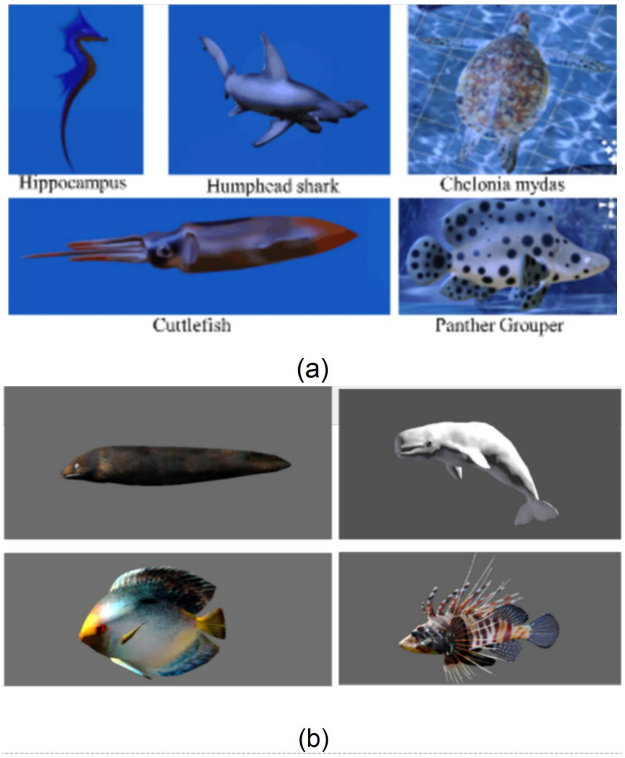

Figure 2: Examples of virtual sea creatures in the experimental VELE. (a) Examples of designated creatures; (b) examples of interference creatures.

3 THE PILOT STUDY

A total of 10 participants volunteered to participate in the experiment. The average age was 23.10±5.47 years. All were without color blindness and had normal or corrected-to-normal vision. The participants had not been exposed to any type of VR environment within the previous 4 weeks.

Self-motion can be induced by the active navigation in VR, thus perceived self-motion speed can be measured through estimating the participants' perceptions of different navigation speeds. For this purpose, we pre-set 11 levels of navigation speeds for the self-avatars (increasing progressively from level 0 to level 10, corresponding to speeds of $1m/s$-$10m/s$ in the virtual world). After the participants experienced all the speed levels, they identified only one level as the appropriate low-speed condition, and one level as the appropriate high-speed condition.

All participants finished the experiment. Results showed that the acceptable low-level of self-motion speed is almost level 3, and the acceptable high-level is almost level 6. Based on the results, the experiment 1 examined the effect of self-motion speed on the flow experience and VR sickness in the FPP VR environment.

4 EXPERIMENT 1

According to the sensory conflict theory and flow theory, we proposed the following hypothesis: self-motion speed may exert a significantly positive effect on VR motion sickness, but a significantly negative effect on flow experience.

Based on the experimental VR environment, we performed a single-factor within-subject experiment to examine the hypothesis. Self-motion speed was the independent variable which included two conditions: low-speed vs high-speed. The navigation speed in the two conditions were set based on the results of pilot study. The dependent variables were VR sickness and the flow experience.

A total of 30 adult volunteers were recruited to participate in the experiment. They first completed a pre-test questionnaire and remembered the pictures of target creatures to search for in the later formal task. Each participant then experienced the two self-motion speed conditions of the VELE following a counterbalanced order. When each round of the task was completed, the participants filled out the Simulator Sickness Questionnaire (SSQ) [7] and the Flow Short Scale [3].to measure their self-ratings of VR sickness and the flow experience.

To examine the effect of self-motion speed on VR sickness, a series of paired-sample T-tests were performed using the SSQ scores (including total score and three-factor scores) as the dependent variables. The results revealed that self-motion speed had a significant effect on the total score and factor scores of the SSQ ($ps < 0.01$). Therefore, higher self-motion speeds led to higher VR sickness levels, which supports the hypothesis.

To examine the effect of self-motion speed on the flow experience, one more paired-sample T-test was performed with the flow experience as the dependent variable. The results showed that the flow experience in the high-speed condition (M=61.14±1.72) was significantly higher than the flow experience in the low-speed condition (M=56.61±2.62) [$t = 3.233, p < 0.01$], showing an opposite trend to the hypothesis.

When combining this with the VR sickness results, it could be summarized that higher self-motion speeds contributed to both VR sickness and the flow experience. Therefore, we speculated that there may be individual factors playing a moderating in the relationship between self-motion speed and the flow experience. Next, experiment 2 further examined the effect of self-motion speed on the flow experience while considering participants' susceptibilities to VR sickness as a potential moderating factor.

5 EXPERIMENT 2

In this experiment, we proposed the following hypothesis: the effect of self-motion speed on the flow experience may be moderated by individual susceptibility to VR sickness. We conducted an experiment involving a 2 (self-motion speed: low/high) × 2 (susceptibility to VR sickness: low/high) factorial mixed design. Self-motion speed was the within-subject factor, and susceptibility to VR sickness was the between-subject factor. The dependent variable was the flow experience. The order of experiencing the two self-motion speed conditions was counterbalanced. Participants' familiarity with VR games was measured and controlled as an extra variable.

A total of 98 volunteers were recruited from a local university. They firstly accepted a pre-test to evaluate the susceptibility to VR sickness. Later, 22 participants were screened into the low susceptibility group while another 22 were screened into the high susceptibility group. The experimental environment, task, procedure and measures were the same as in experiment 1. The experiments were conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Human Experimentation at a local hospital.

To examine the hypothesis, we performed a repeated measures analysis of variance with flow experience as the dependent variable. The descriptive statistical results are shown in Table 1. The results showed that the main effect of self-motion speed on the flow experience was significant [$F_{(1,41)} = 4.533, p = 0.039, \eta_p^2 = 0.100$]. Moreover, there was a significant interaction effect of self-motion speed × susceptibility on VR sickness [$F_{(1,41)} = 4.920, p = 0.032, \eta_p^2 = 0.107$]. A further simple effect test revealed that for participants with low susceptibility to VR sickness, a higher self-motion speed led to significantly higher flow experience [$F_{(1,21)} = 9.010, p = 0.005$]. For participants with high susceptibility to VR sickness, there was no significant difference found between the high-speed and low-speed conditions [$F_{(1,21)} = 0.100, p = 0.749$]

Table 1: Descriptive statistical results of the flow experience in different conditions

Dependent variable	Self-motion speed	Low susceptibility $mean(S.D)$	High susceptibility $mean(S.D)$
Conditions	Low	61.00 (5.56)	57.05 (10.62)
	High	65.23 (6.15)	57.50 (9.70)

(the levels of flow experience in both conditions were low). These results supports the hypothesis.

6 CONCLUSION

We developed an experimental VR environment that supported active navigation in three dimensions. This proved effective in evaluating participants' sense of self-motion speed and was used to examine the effect of self-motion speed on the flow experience and VR sickness. The results obtained from the two experiments reveal that self-motion speed can exert significantly positive effects on both VR sickness and the flow experience, but this needs some certain preconditions. Then, we found that participant susceptibility to VR sickness should be considered as an important moderating factor when discussing the influence of self-motion speed on VR sickness and the flow experience. The effect of self-motion speed on the flow experience was moderated by individual susceptibility to VR sickness. Individuals with different susceptibility to VR sickness show significantly different pattern on the feeling of flow experience and VR sickness when facing different self-motion speed. These findings may help guide the personalized design of VR applications and achieve a better user experience.

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