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A User Experience Questionnaire for VR Locomotion: Formulation and Preliminary Evaluation

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Abstract. When evaluating virtual reality (VR) locomotion techniques, the user experience metrics that are used are usually either focused on specific experiential dimensions or based on non-standardised, subjective reporting. The field would benefit from a standard questionnaire for evaluating the general user experience of VR locomotion techniques. This paper presents a synthesised user experience questionnaire for VR locomotion, which is called the VR Locomotion Experience Questionnaire (VRLEQ). It comprises the Game Experience Questionnaire (GEQ) and the System Usability Scale (SUS) survey. The results of the VRLEQ's application in a comparative, empirical study ($n = 26$) of three prevalent VR locomotion techniques are described. The questionnaire's content validity is assessed at a preliminary level based on the correspondence between the questionnaire items and the qualitative results from the study's semi-structured interviews. VRLEQ's experiential dimensions' scoring corresponded well with the semi-structured interview remarks and effectively captured the experiential qualities of each VR locomotion technique. The VRLEQ results facilitated and quantified comparisons between the techniques and enabled an understanding of how the techniques performed in relation to each other.

Keywords: locomotion; questionnaire; user experience; virtual reality;

1 Introduction

Virtual reality (VR) locomotion is an essential interaction component of navigation in VR environments [11, 17]. Since the early days of VR, various locomotion techniques have been developed and studied to enable seamless and user-friendly navigation in virtual environments [11, 9]. In recent years, major hardware-driven advances have had significant effects on how the users experience and use VR [38, 46, 6]. The technical and interaction progress in the new era of VR have also marked a new era for VR locomotion [6]. As a result, new locomotion techniques have been developed, and past ones have been significantly updated [6].

VR locomotion techniques are evaluated by testing in different environments that involve a variety of tasks and various user experience (UX) metrics. The

Locomotion Usability Test Environment (LUTE) [40] addresses the need for a standard testing environment to evaluate different locomotion techniques. It also helps analyse and identify the techniques that work better for different tasks. Regarding UX metrics for VR locomotion, the metrics that are used are either focused on specific experiential dimensions, such as the Presence Questionnaire [50] and the Slater-Usoh-Steed Questionnaire [45] for presence [8, 44], and the Simulator Sickness Questionnaire [19] for motion sickness [44, 32, 14], or based on non-standardised, subjective reporting [36, 23, 32, 22, 43]. A standard questionnaire for evaluating the general UX performance of VR locomotion techniques would help researchers and practitioners produce and communicate UX results within a consistent and shared framework.

This work presents a synthesised UX questionnaire for VR locomotion, consisting of the Game Experience Questionnaire (GEQ) [18] and the System Usability Scale (SUS) survey [12], hereafter called the VR Locomotion Experience Questionnaire (VRLEQ). The results of the VRLEQ's application in a comparative, empirical study of three prevalent VR locomotion techniques are also presented. Finally, a preliminary assessment of the questionnaire's content validity is performed based on the correspondence between the questionnaire items and the qualitative results from the study's semi-structured interviews. Researchers and practitioners in the field of VR and VR locomotion can benefit from this work by being introduced to a new UX metric tool specifically tailored for VR locomotion while getting specific instructions on how to apply it in their projects.

The rest of this paper is organised as follows. Section 2 provides the background relating to VRLEQ components. Section 3 describes VRLEQ, its formulation process (Section 3.1) and the results of its application (Section 3.2). Section 4 presents a preliminary evaluation of the tool's content validity. Section 5 discusses the results, the study limitations, and the future directions for VRLEQ's development.

2 Background

A paper by Boletsis and Cedergren [7] presented a comparative, empirical evaluation study of three prevalent VR locomotion techniques and their user experiences. They studied the following techniques:

- *Walking-in-place (WIP)*: The user performs virtual locomotion by walking in place, that is, using step-like movements while remaining stationary [23, 6].
- *Controller / joystick*: The user uses a controller to direct their movement in the virtual environment [31, 6].
- *Teleportation*: The user points to where they want to be in the virtual world, and the virtual viewpoint is instantaneously teleported to that position. The visual 'jumps' of teleportation result in virtual motion being non-continuous [11, 10, 6].

Walking-in-place (WIP), controller-based locomotion, and teleportation were used by 26 adults in order to perform a game-like task of locating four specific places (called checkpoints) in a virtual environment. The study employed a mixed-methods approach and used the synthesised VRLEQ questionnaire, consisting of the GEQ and SUS questionnaires, to quantitatively assess UX and semi-structured interviews to assess it qualitatively.

GEQ [18] is a user experience questionnaire that has been used in several domains, such as gaming, augmented reality, and location-based services, because of its ability to cover a wide range of experiential factors with good reliability [25, 35, 33, 34, 24]. The use of GEQ is also established in the VR aspects of navigation and locomotion [28, 30], haptic interaction [1], VR learning [4], cyberpsychology [47], and gaming [42]. GEQ is administered after the session and asks the user to indicate how they felt during or after the session with a series of statements. The GEQ comes in different versions depending on the kind of experience the experimenter is trying to document. Apart from the core version (33 statements), there are in-game (14 statements), post-game (17 statements), and social-presence (17 statements) versions of the questionnaire. All GEQ versions cover UX dimensions such as Competence, Sensory and Imaginative Immersion, Flow, Tension, Challenge, Negative Affect, Positive Affect, et al.

SUS [12] allows usability practitioners and researchers to measure the subjective usability of products and services. In the VR domain, SUS has been utilised in several studies on topics such as VR rehabilitation and health services [27, 39, 49, 20, 29], VR learning [26], and VR training [16]. SUS is a 10-statement questionnaire that can be administered quickly and easily, and it returns scores ranging from 0 to 100. A SUS score above 68 is considered above average and that below 68 is considered below average [12]. SUS scores can also be translated into adjective ratings, such as 'worst imaginable', 'poor', 'OK', 'good', 'excellent', and 'best imaginable' and into grade scales ranging from A to F [5]. SUS has been demonstrated to be reliable and valid, robust with a small number of participants and to have the distinct advantage of being technology agnostic – meaning it can be used to evaluate a wide range of hardware and software systems [12, 13, 48, 21]. Apart from the original SUS survey, there is also a positively worded version that is equally reliable as the original one [41].

3 VR Locomotion Experience Questionnaire

3.1 Questionnaire Formulation

Statements and Dimensions: The VRLEQ (Table 1) utilises all the dimensions and respective statements of the in-game GEQ version, that is, Competence, Sensory and Imaginative Immersion, Flow, Tension, Challenge, Negative Affect, Positive Affect, along with the dimension of Tiredness and statements relating to it from the post-game GEQ version. For the in-game GEQ statements (i.e., statements 1–14 in Table 1), the VRLEQ asks the user "Please indicate how you felt while navigating in VR". For the Tiredness dimension (i.e., statements

Table 1. The VRLEQ statements and the experiential dimensions they address.

#	**Statement**	**Dimension**
1.	I was interested in the task	Immersion
2.	I felt successful	Competence
3.	I felt bored	Negative Affect
4.	I found it impressive	Immersion
5.	I forgot everything around me	Flow
6.	I felt frustrated	Tension
7.	I found it tiresome	Negative Affect
8.	I felt irritable	Tension
9.	I felt skilful	Competence
10.	I felt completely absorbed	Flow
11.	I felt content	Positive Affect
12.	I felt challenged	Challenge
13.	I had to put a lot of effort into it	Challenge
14.	I felt good	Positive Affect
15.	I felt exhausted	Tiredness
16.	I felt weary	Tiredness
17.	I think that I would like to use this VR navigation technique frequently	Perceived Usability
18.	I found the VR navigation technique unnecessarily complex	Perceived Usability
19.	I thought the VR navigation technique was easy to use	Perceived Usability
20.	I think that I would need the support of a technical person to be able to use this VR navigation technique	Perceived Usability
21.	I found the various functions in this VR navigation technique were well integrated	Perceived Usability
22.	I thought there was too much inconsistency in this VR navigation technique	Perceived Usability
23.	I would imagine that most people would learn to use this VR navigation technique very quickly	Perceived Usability
24.	I found the VR navigation technique very cumbersome to use	Perceived Usability
25.	I felt very confident using the VR navigation technique	Perceived Usability
26.	I needed to learn a lot of things before I could get going with this VR navigation technique	Perceived Usability

15–16 in Table 1) the VRLEQ asks "Please indicate how you felt after you finished navigating in VR". The in-game GEQ version was chosen because of its brevity compared to the core version (14 versus 33 statements, respectively), the coverage of the same UX dimensions as the core GEQ and its good reliability. Its smaller size is preferable so that responders do not get frustrated or exhausted or impatient from a long survey, especially after an immersive VR experience and during a comparative study of VR locomotion techniques where several applications of the VRLEQ (one per technique) would be necessary. Tiredness was considered an appropriate post-session dimension to capture since fatigue is considered a major challenge for VR locomotion [2, 37] that would not be fully or clearly covered by the other negative dimensions of the in-game GEQ (e.g. Tension, Negative Affect, Challenge). The original SUS survey adds the dimension of Perceived Usability to the VRLEQ. For the SUS statements (i.e., statements 17–26 in Table 1), the user is asked "Please check the box that reflects your immediate response to each statement." The phrasing of several statements of the GEQ and SUS were modified so that they address VR locomotion and are easily understandable by users with varying knowledge (e.g., "VR navigation" was used instead of "VR locomotion").

Scales and Scoring: VRLEQ uses the scales and the scoring of the original GEQ and SUS questionnaires. The GEQ statements of the VRLEQ (i.e., statements 1–16 in Table 1) were rated on a five-point Likert scale of 0 (not at all), 1 (slightly), 2 (moderately), 3 (fairly), and 4 (extremely). Then, the average score per dimension was calculated and scaled between 0 and 4. The SUS statements of the VRLEQ (i.e., statements 17–26 in Table 1) were also rated on a five-point Likert scale of 0 (strongly disagree), 1 (disagree), 2 (neutral), 3 (agree), and 4 (strongly agree). The scores associated with the negative statements 18, 20, 22, 24, and 26 (in Table 1) should be inverted; therefore, their points were subtracted from 4. The points associated with the positive statements 17, 19, 21, 23, and 25 were not altered. This scaled all values from 0 to 4. Then, all points from the 10 statements were added and multiplied by 2.5, which converted the range of possible values from 0 to 100.

3.2 Application and Results

Twenty-six participants ($n = 26$, mean age: 25.96, SD: 5.04, male/female: 16/10) evaluated the three VR locomotion techniques by filling out the VRLEQ questionnaire and through interviews. The VRLEQ results are shown in Figure 1. GEQ dimensions' scores are plotted on the same scale as the SUS scores (Perceived Usability), that is, scaled between 0 and 100, for clearer visualisation.

The non-parametric Friedman test was used to detect differences between the techniques' performances. It showed statistically significant differences in the scores of: Competence ($X^2(2) = 16.455, p < 0.001$), Immersion ($X^2(2) = 6.099, p = 0.047$), Challenge ($X^2(2) = 34.587, p < 0.001$), Negative Affect ($X^2(2) = 15.459, p < 0.001$), Tiredness ($X^2(2) = 23.011, p < 0.001$), and Perceived Usability ($X^2(2) = 16.340, p < 0.001$). The Friedman test indicated no statistically significant differences in the Flow, Tension, and Positive Affect components between the three techniques.

4 Evaluation

In this section, the content validity assessment of the synthesised VRLEQ is presented. This helped assess whether the VRLEQ represents all facets of UX for VR locomotion. Content validity can be assessed through literature reviews, expert opinions, population sampling, and qualitative research [3, 15], the latter

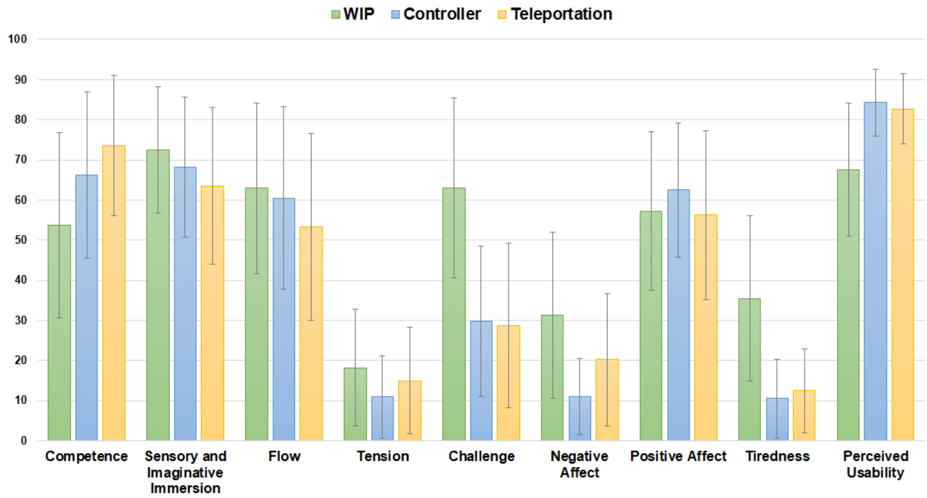

Fig. 1. Mean VRLEQ values (with standard deviation bars) across the experiential dimensions. GEQ values are scaled from 0 to 100 (i.e. values multiplied by 25) for uniform visualisation.

being the case herein. The interview remarks by the VR locomotion users of the three techniques are used as groundtruth. Then, the correspondence between the test items (i.e., VRLEQ dimensions) and the interview remarks was examined (Table 2). The VRLEQ and the semi-structured interviews evaluated UX at two different levels. The former provided an overview of UX performance and the latter provided specific insights in addition to a general overview.

During the semi-structured interviews, participants were asked about what they liked and did not like about the evaluated VR locomotion techniques and why. The interviewer followed up on the participants' comments until each topic was covered. In the end, the interview responses were coded by two researchers. The inter-rater reliability showed high agreement.

5 Conclusion

Table 2 shows that the VRLEQ dimensions' scoring corresponded well with the semi-structured interview remarks and captured and reflected the experiential qualities of each VR locomotion technique. In our assessment, VRLEQ documented all facets of the VR locomotion techniques' UX performance and demonstrated satisfactory content validity. Moreover, the VRLEQ results facilitated and quantified the comparisons between the techniques and illuminated how the techniques performed in relation to each other. When these results are combined with the related results from interviews, then the experimenter can potentially pinpoint the interaction strengths and weaknesses of the techniques that impacted the experiential performance, thus collecting valuable information

Table 2. Correspondence between the VRLEQ dimensions and the semi-structured interview remarks.

Interview remarks	**Dimensions and scoring**
–WIP–	
WIP offered high levels of immersion owing to its natural and realistic way of moving.	- Moderate-to-high Immersion - Moderate-to-high Flow
Many participants found that the translation of real body movement to VR motion made the technique tiresome.	- Moderate-to-high Challenge - Moderate-to-high Negative Affect - Moderate-to-high Tiredness - "OK" Perceived Usability
Others found that the translation of real body movement to VR motion added a certain level of physical training, fun and entertainment.	- Moderate-to-high Positive Affect
WIP caused fear of colliding with physical objects in real life and motion sickness, especially for novice VR users.	- Low-to-moderate Tension - Moderate-to-high Challenge - Moderate-to-high Negative Affect - "OK" Perceived Usability
Participants were able to go on with the tasks despite their interaction difficulties.	- Moderate Competence - "OK" Perceived Usability
–Controller–	
It was found to be easy-to-use and was characterised as "familiar", "intuitive", and "comfortable".	- Moderate-to-high Competence - Low-to-moderate Challenge - Moderate-to-high Positive Affect - "Excellent" Perceived Usability
It was reported that during the first seconds of use, the technique caused motion sickness. However, after a few seconds, the participants were able to adjust and master the technique.	- Moderate-to-high Competence - Low-to-moderate Challenge - Low Tension - Low Negative Affect - Low Tiredness - "Excellent" Perceived Usability
The technique achieved satisfying levels of immersion for participants.	- Moderate-to-high Immersion - Moderate-to-high Flow
–Teleportation–	
It was described as the least immersive of the three techniques, owing to its visual "jumps" and non-continuous movement.	- Moderate Immersion - Moderate Flow
"Blinking" – the teleporting transition from one place of the virtual environment to another – made the technique tiresome and put extra strain on the participants vision.	- Moderate-to-high Challenge - Low-to-moderate Tension - Low-to-moderate Negative Affect - Low-to-moderate Tiredness
Participants found teleportation to be effective when time was of the essence for the task owing to its fast navigation.	- High Competence - Moderate-to-high Positive Affect - Low-to-moderate Challenge - "Good" Perceived Usability
Using the method and mastering its interaction aspects were considered straight-forward and easy; the visual cues, i.e., the direction arc ray and the marker on the virtual ground, were clear and understandable.	- High Competence - Moderate-to-high Positive Affect - Low-to-moderate Challenge - "Good" Perceived Usability

for future improvements. It is suggested that an interview like the one described above should be included following the use of VRLEQ since the interview addresses additional, specific issues of the technical and interaction kinds. A UX questionnaire such as VRLEQ can answer the question "What is the effect that a VR locomotion technique has on UX?". The interview sheds more light on the "why" and reveals the specific factors that together form the UX performance.

Regarding the formulation and evaluation of VRLEQ in this paper, it is important to acknowledge the limitations. The evaluation is of a preliminary nature and based on qualitative comparisons. The small sample size does not assure reliable internal consistency and does not permit the construction of validity measurements. Moreover, the GEQ and SUS dimensions do not operate on the same conceptual UX level. Perceived Usability (SUS) exists at a higher level than the GEQ dimensions, and it contains sub-dimensions or sub-elements that are thematically relevant to those of the GEQ. This issue also arises when examining the relevant questions in both questionnaires (e.g., statements 9 and 25 in Table 1).

Accordingly, the future work on VRLEQ will: 1) include a larger sample size to enable reliable quantitative evaluation (reliability and validity), 2) develop a new UX model describing the relationship between the GEQ and SUS dimensions, 3) develop a shorter version of the VRLEQ by eliminating similar questions that measure the same dimension and 4) assess the reliability and validity of the shorter VRLEQ.

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