Evaluating User Performance, Workload, and Presence of Virtual Reality Questionnaires Using Joystick and Raycasting Selection Techniques

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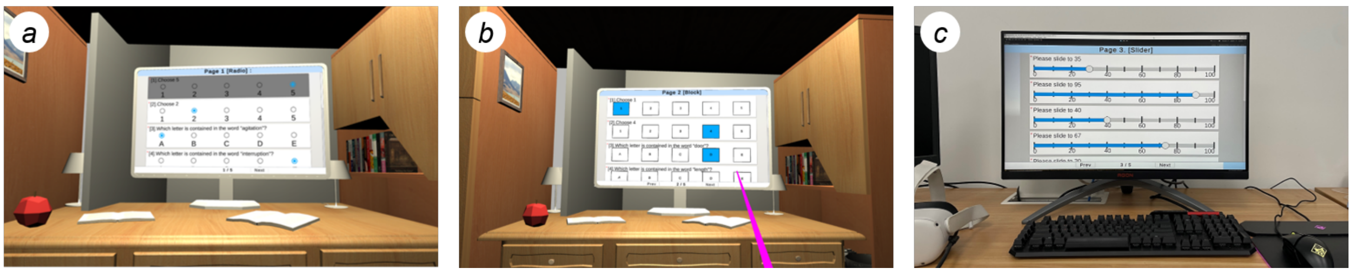

Figure 1: Participants taking questionnaires using (a) joystick selection technique in VR, (b) raycasting selection technique in VR, and (c) point & select technique in PC.

ABSTRACT

Understanding users' subjective feelings is vital for Virtual Reality (VR) research, and questionnaire is one of the common used approaches to obtain subjective feedback. Embedding questionnaires into VR systems has been shown effective in reducing the break in presence (BIP) and systematic bias compared to filling out questionnaire outside VR. However, it is not clear how users perform and perceive workload and presence of VR questionnaires, and there is no clear guideline for choosing appropriate selection techniques. In this paper, we present an experimental study that examined user performance, workload, and presence of VR questionnaires, and compared them to the use of PC. We investigated two commonly-used selection techniques in VR (joystick selection and raycasting selection) and three question types (radio, block, and slider). Our results showed that despite the benefits of in-VR questionnaires, user performance was better and workload was lower outside VR using a PC. Comparing joystick and raycasting, user workload is slightly lower using raycasting selection, whereas joystick better supports precise selections. There is room for optimizing existing VR questionnaire design and developing novel selection techniques for VR questionnaires.

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ICVARS 2023, March 03–05, 2023, Sydney, Australia

ACM ISBN 978-1-4503-9746-9/23/03...$15.00
https://doi.org/10.1145/3603421.3603426

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; **Interaction design**; **Empirical studies in HCI**.

KEYWORDS

Virtual Reality, workload, 3D interface, interaction technique

ACM Reference Format:
Xingbo Wei and Yue Li. 2023. Evaluating User Performance, Workload, and Presence of Virtual Reality Questionnaires Using Joystick and Raycasting Selection Techniques. In *2023 the 7th International Conference on Virtual and Augmented Reality Simulations (ICVARS) (ICVARS 2023), March 03–05, 2023, Sydney, Australia.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3603421.3603426

1 INTRODUCTION

Virtual reality (VR) technology and head-mounted display (HMD) are developing rapidly in the recent decades. VR has been applied to many areas such as computer graphics, gaming, and education [6, 13]. During the 2020 fourth quarter alone, there were over one million Quest 2 units sold worldwide [18]. The notable rise of a new generation of VR systems opened up new methods and interventions for researchers across different areas. VR development and research often need to understand users' subjective feedback, which is usually assessed through post-experiment questionnaires. Since the current VR applications require users to wear an HMD, users have to take off the headset and leave the VR scene when filling in questionnaires. When doing so, users reposition themselves in the real world, which causes the break in presence (BIP) [16]. Putze et al. argued that the switching between VR and physical reality leads to the BIP that might alter the outcomes. Furthermore, for experiments with multiple session, leaving and re-entering the VR takes extra time as participants need to take off the HMD, re-orientate in the real world, put on the HMD, enter the VR environment again. Embedding question items in VR offers a way to stay closer to the context of an ongoing experience [1, 11]. Previous work [1, 5, 14] demonstrated the strength of in-VR questionnaires in avoiding BIP, providing high consistency of measures, and obtaining ecological valid results. Significant potentials were shown for in-VR questionnaires to be used in future user studies. However, research that adopted VR questionnaires showed heterogeneous designs; limited work has explored the design of questionnaires in VR; and there is no clear standard or guideline for VR questionnaire design. One of the reasons is that VR questionnaires afford various question types, interaction techniques, and presentation approaches. Extensive studies are required to understand their effects on user performance and subjective user experience (e.g. workload and presence), and gradually establish the standards and guidelines. In this study, we developed a questionnaire system (see Fig. 1) and investigated two selection techniques in VR (joystick and raycasting) and three question types (radio, block, and slider). These are typical techniques and question types that have been adopted in previous research, and are representative of the majority of evaluations in VR user studies. The results were compared against filling in questionnaires using a PC. We conducted a user study that recorded objective user performance data and collected self-report measures of workload [7] and presence [17]. The findings showed that 1) users had higher task performances, less workload, and greater presence using PC compared to VR; 2) the differences between joystick and raycasting were insignificant, with a slightly lower workload using raycasting selection technique; 3) precise control over high granularity options (such as slider questions rated from 0 to 100) is better achieved and preferred using joystick, despite the longer time. Our research makes three contributions. First, we measured and compared user performance and workload using two commonly adopted selection techniques (joystick and raycasting) in VR, explicitly indicating their strength and weakness for different types of questions. Second, we explored three different question types (radio, block, and slider) for collecting Likert-scale and numerical responses, the results of which is applicable to the majority of subjective evaluations of VR research. Third, we discuss the current limitations in VR questionnaire design and identify directions of improvements, informing future research that attempts to use VR questionnaires and the design guidelines.

2 RELATED WORK

Compared to collecting participant evaluation outside VR environments, researchers found that having participants answer questions inside VR showed some advantages. First, it maintains the context of the exposure and avoid the break in presence [16]. This is especially important for evaluations that need to be obtained right after an experimental session, such as immersion and presence. Second, measures obtained in VR is of higher consistency, indicated by the significantly lower variance of results shown in [14]. Third, compared to post-experiment data collection that may lead to bias in recall, conducting evaluation on-the-go in VR resembles the in-the-wild evaluations, which is more likely to show ecologically valid results. A recent study [1] on VR questionnaire design found that although experts have expressed concerns about technical challenges, implementation effort, potential biases, and participant overload, the overall attitude towards VR questionnaire is positive and it is urging to explore appropriate design guidelines for VR questionnaires.

2.1 Virtual Reality Questionnaire Design

We reviewed previous work that adopted questionnaires inside VR, with a specific focus on the question types, the selection techniques, and the input devices. Schwind et al. adopted joystick selection with an Oculus Touch for radio questions (7-point Likert scale) that assess perceived presence. Similarly, Kang et al. presented a block question with three options, where participants used an Oculus Touch with a joystick to make the selection. Aside from the radio and block question types, two studies [2, 4] adopted joystick selection for slider questions (from 1 to 10) to assess real-time VR comfort using a gamepad. In addition to joystick selection, raycasting selection has also been adopted in previous questionnaire design. Putze et al. set up 7-point Likert scale questions to evaluate game experience, and Oberdörfer et al. embedded slider questions of NASA-TLX into VR to assess user workload. Both adopted a raycasting selection technique using the HTC Vive controller.

2.2 Selection Techniques for VR Questionnaires

Raycasting selection was identified as an intuitive method to interact with user interfaces in VR [9, 10, 12]. The interaction with menus in commercial VR devices (such as Meta Quest and HTC Vive) is based on raycasting by default, indicating its effectiveness and acceptability. However, the need of hand and arm movements for pointing could lead to fatigue during long-time interactions [3]. Joystick selection, on the other hand, takes advantage of the UI layout to make the selection and requires no arm movements for pointing.

Despite that efforts can be seen in previous work to adopt questionnaires in VR, there is no standardized design for these types of interactions with VR questionnaires and the design rationale was not well explained in the articles. Given the state of the art, Alexandrovsky et al. compared two presentations (world-anchoring and body-anchoring) and two interaction techniques (pointer and trackpad) for VR questionnaires. The evaluation of usability showed that world-anchoring and raycasting selection are easier to use than body-anchoring and trackpad. However, the device adopted for the comparison was HTC Vive, and the trackpad is different from joystick selection. Arguably, joystick provides more distinctive physical and directional feedback than trackpad, and is commonly used in consumer-level devices, such as gamepads, Meta Quest 2, and Valve Index. In addition, the authors compared in-VR questionnaires with an out-VR questionnaire realized in LimeSurvey. It could be problematic as the layout variations in VR and the survey platform may have brought new variables (e.g. font sizes, display layouts, etc.) and led to biased results.

Previous work showed some limitations and gaps that need to be further investigated. First, both joystick selection (e.g. [2, 4, 15]) and raycasting selection (e.g. [1, 11, 14]) have been adopted for VR questionnaires. However, their efficiency and users' perceived workload are not well understood. Second, most VR questionnaire research tend to collect numerical responses. These responses can be collected using different question types (e.g. radio, block, and slider). Current understanding of these question types is limited. Third, there is a lack of valid comparison of the same questionnaire system inside and outside VR.

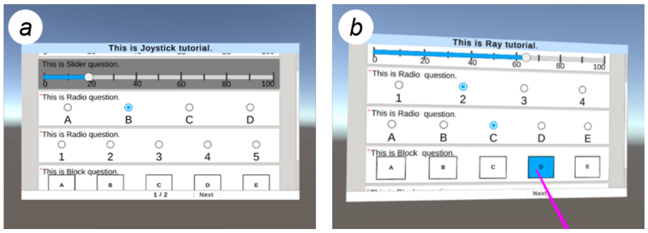

Figure 2: Tutorial scene demonstrating (a) joystick selection and (b) raycasting selection in VR.

3 SYSTEM DEVELOPMENT AND IMPLEMENTED SELECTION TECHNIQUES

3.1 Apparatus

We developed the VR questionnaire systems using a computer with Intel Core i9-10900K CPU 3.70GHz, 64GB RAM, and the NVIDIA GeForce RGX 2080Ti graphics card. The systems were built using the Unity engine (version 2019.4.18) and the QuestionnaireToolkit[1]. The questionnaires were displayed using a Meta Quest 2 VR HMD for the VR selection techniques, and a 27-inch quad high-definition monitor with a resolution of 2560 × 1440 is used for the PC display.

3.2 Experimental Environment and Question Types

We simulate a workplace environment, where participants fill in a world-referenced questionnaires on a virtual desktop in VR (see Fig. 1a and 1b), and use a monitor to fill in the questionnaires outside VR (see Fig. 1c). The same questionnaire system is used for VR and PC to obtain a valid comparison. The questionnaire system includes three types of questions: radio, block, and slider, as shown in Fig. 1a-c, respectively. These were most common seen types of questions in previous work that can collect Likert scale responses and numerical responses.

3.3 Joystick Selection

We implemented the joystick selection control based on the four directions: up, down, left, and right. Users could navigate the questions by pushing the joystick up and down, and navigate the options by pushing the joystick to the left and right. The question under selection is highlighted in gray and an option is highlighted in blue when selected (see Fig. 2a). The selection is saved when existing the question so there is no need to confirm the selection. Users will move to the next page when pressing down on the last question on the current page.

3.4 Raycasting Selection

For raycasting selection, users can use the Quest controller to point to an option (see Fig. 2b). Users need to confirm an option selection by pressing on the `A` button on the controller or the trigger button using the index finger. Users can scroll the page by pointing and selecting the scroll bar or the empty space on the page. To move to the next page, users need to point and select the `Next` button.

[1]https://assetstore.unity.com/packages/tools/gui/questionnairetoolkit-157330

4 USER STUDY

A user study is designed to answer the following research questions:

RQ1. How do users perform in questionnaire selection tasks in VR and PC?

RQ2. How do users perceive workload in questionnaire selection tasks in VR and PC?

RQ3. Displaying the same virtual environment for questionnaire selection tasks, how do users perceive presence in VR and PC?

Based on the related work, we implemented two techniques in VR: joystick selection and raycasting selection, and set up three commonly used question types: radio, block and slider (see Fig. 1 and 2). To answer the proposed research questions, we recorded user task performance in time and collected self-reported workload and presence. This study is approved by the University Ethics Committee at the Xi'an Jiaotong-Liverpool University.

4.1 Task Design

We designed a questionnaire of Simple Selection Tasks (SST). Table 1 shows the five SST types and example questions for each type of SST. Similar to the question settings in [1], we kept the questions simple and objective, and there is only one correct answer out of the five multiple choices. As mentioned in the related work, most questionnaires adopted in VR research are Likert scale and numerical questions that can be answered using radio, block, and slider question types. Therefore, this study included these three question types in evaluations. A page of ten questions (5 SST types × 2 repetitions) were set up for radio questions. The same setting was adopted for block questions. Considering the fact that only numbers are valid options for slider questions, five *find and select (number)* questions and five *calculate and select* questions were displayed.

4.2 Measures

This study has three dependent variables: task performance, workload, and presence. Task performance is an objective measure; workload and presence are self-reported subjective measures.

Task performance. We recorded the time participants spent to complete each trial. This was captured using a built-in C# script along with the questionnaire system.

Workload. To evaluate workload, participants were asked to fill in the NASA Task Load Index (NASA-TLX) [7] in VR right after they completed the simple selection tasks. The NASA-TLX consists of 6 item on a slider from 0 to 100, measuring the six dimensions of workload: mental demand, physical demand, temporal demand, performance, effort, and frustration.

Presence. We adopt the questionnaire developed by Slater, Uosh, and Steed (SUS) [17] to measure users' perceived presence. SUS consists of 6 items on a 7-point Likert scale.

4.3 Procedure

Fig. 3 shows an example experimental procedure. At the start of the experiment, we welcomed participants, collected their consent and some demographic information. We explained the purpose of this research and give a brief introduction to VR technology and

Table 1: Simple Selection Task (SST) types and example questions.

Type	Example Question
Find and select (number)	Choose 2.
Find and select (letter)	Which letter is contained in the word “agitation”?
Find and select (word)	What is the color of a banana?
Count and select	How many countries occurred: Joy was born in England. Her mother took her to the United States when she was 3 years old.
Calculate and select	45 + 29 =

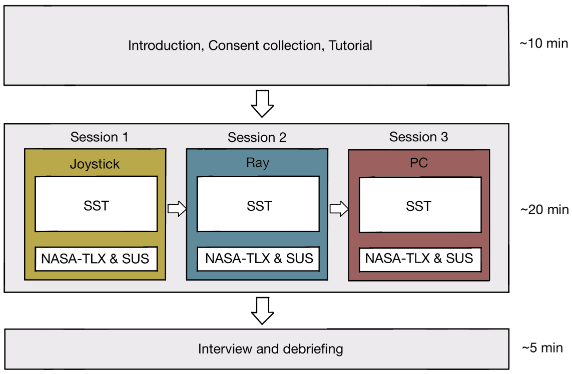

Figure 3: Example experimental procedure.

the device (Meta Quest 2) we used. A tutorial session is provided to participants for them to get familiar with the joystick and raycasting selection controls (see Fig. 2). Each participant attended three experimental sessions to evaluate the three selection techniques: joystick, raycasting, and PC. A Latin square design was adopted to balance the experimental sequences. For each session, participants completed thirty SSTs (10 trials × 3 question types), and then evaluated their perceived workload and presence. At the end of the experiment, we had a short interview and debriefing. We asked two questions regarding their subjective preferences: 1) Which approach do you prefer to do questionnaires: VR or PC? 2) For each question type (radio, block, and slider), which selection technique do you prefer: joystick or raycasting? We concluded with an open-ended question: 3) Do you have any other suggestions? The experiment took 35 minutes on average.

4.4 Participants

Sixteen participants (8 males, 8 females, age M=22.25, SD=1.25) voluntarily signed up for this study. Rated on a 5-point Likert scale, participants were slightly familiar with VR (M=2.44, SD=1.257), and familiar with 3D technology (M=3.611, SD=1.11). All participants have normal or corrected-to-normal vision and did not report any simulator sickness during the experiments.

5 RESULTS

In this section, we present the analysis of the data collected in the user study, including both objective (time) and subjective (workload and presence) data. We used one-way ANOVA and performed post hoc pairwise comparisons using Bonferroni adjustment.

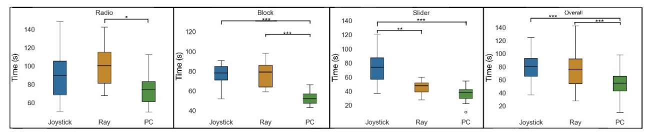

Figure 4: Task completion time of the Simple Selection Tasks (SST) using different selection techniques. From left to right: radio, block, slider questions, and the overall performance.

5.1 Task Completion Time

Fig. 4 shows the results of participants’ task completion time for each type of questions. Overall, participants spent 80.57s (SD=24.9) when using Joystick, 75.80s (SD=28.03) when using Ray and 54.85s (SD=20.4) when using PC for completing the ten SST. There were significant differences among three selection techniques F(2,141)=14.469, p<0.001. Post hoc tests showed significant differences between PC and Joystick (p<0.001), and between PC and Ray (p<0.001). Users spent less time using PC than in VR.

We further performed analysis to compare the task completion time for each question type. The results showed significant differences in radio questions (F(2,45)=5.532, p=0.007), block questions (F(2,45=15.558), p<0.001), and slider questions (F(2,45=12.974), p<0.001). Specifically for radio questions, Ray (M=100.578, SD=22.652) required more time than PC (M=74.117, SD=17.314). The difference between Joystick and PC was insignificant. For block questions, significantly less time is required using PC (M=52.231, SD=6.466) than Joystick (M=78.242, SD=18.463) and Ray (M=78.884, SD=18.185). For slider questions, less time is required using Ray (M=47.922, SD=13.310) and PC (M=38.192, SD=17.053) than Joystick (M=73.839, SD=28.074).

5.2 Workload

A one-way ANOVA showed that there was a significant difference among the three interaction techniques, F(2,285)=4.358, p=0.014. Post hoc tests revealed a significant difference between Joystick and PC (p=0.004). Participants experienced greater workload (M=8.27, SD=5.788) using Joystick than using PC (M=5.71, SD=6.53). Analysis of the subscales showed significant differences for all subscales, except for Temporal Demand. Post hoc tests found significant differences between Joystick and PC on Mental Demand (p=0.03), Physical Demand (p=0.034), Performance (p=0.001), Effort (p=0.004), and Frustration (p=0.007). The differences between Ray and PC on Performance (p=0.013) and Effort (0.044) were also found significant. Users perceived less workload using PC than in VR.

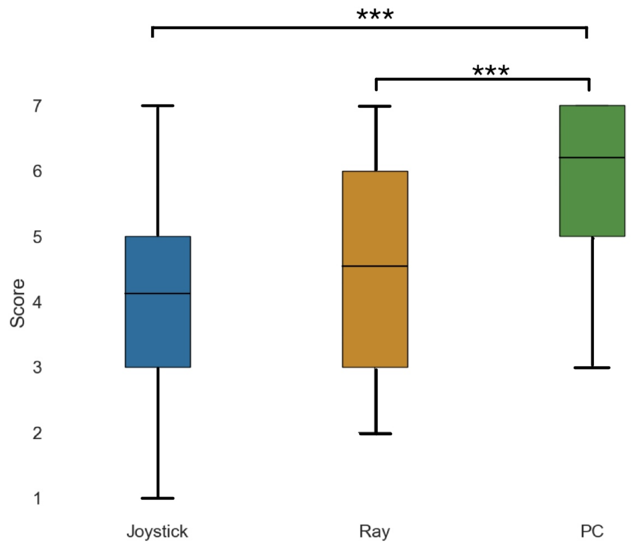

Figure 5: Results of the presence questionnaire in the three conditions.

5.3 Presence

Fig. 5 shows the results of the presence questionnaire. A one-way ANOVA showed significant differences among three interaction techniques, $F(2,285)=54.50$, $p<0.001$. Post hoc tests showed significant differences between Joystick and PC ($p<0.001$), and between Ray and PC ($p<0.001$). Participants perceived the greatest sense of presence using PC ($M=5.79$, $SD=1.04$), followed by Ray ($M=4.54$, $SD=1.57$) and Joystick ($M=4.12$, $SD=1.73$).

5.4 Interview Results

In our interview with participants, fourteen participants preferred using PC to complete the questionnaires whereas only two preferred VR. When comparing Joystick and Ray for each question type, participants preferred Ray for radio questions (N=11) and block questions (N=12), but preferred Joystick for slider questions (N=9). We discuss participants' comments in the next section.

6 DISCUSSION

6.1 Performance: PC >*** VR, Joystick = Ray

Comparing the task performance using the same questionnaire system, we found that participant spent significantly less time using PC than VR (**RQ1**). This is inconsistent with the findings in previous work [1]. One notable reason is that the comparison conducted by Alexandrovsky et al. was not based on the same questionnaire system, but the LimeSuvery system for the PC condition. For this study, participants' familiarity with the point & select technique using a mouse and the lack of familiarity with VR may have contributed to the greater performance in PC.

Comparing Joystick and Ray, our study showed some interesting findings in the contrasts between the statistics and users' subjective preferences. For radio and block questions, although the differences were not statistically significant, Joystick showed slightly better performances than Ray. However, in the interview, more participants preferred Ray over Joystick. Similar contradictory results were shown for the slider questions. Although participants spent significantly longer time using Joystick for the slider questions, more of them reported preferences of Joystick over Ray in the interview, the reason of which lies in the trade-off between precision and time. Participants (N=6) reported that the continuous selection using Joystick provided a greater sense of control, which made it easier to make trivial adjustment and locate an exact number (e.g. from 59 to 60). On the other hand, it was more difficult to make a precise selection and corrections using Ray. Based on this, we speculate that participants' performances and preferences are closely related to the number of options. The radio and block questions had five options whereas the slider questions were set up on a scale from 0 to 100. When the options are limited, a precise and quick control can be achieved with both techniques. However, when the options are of a higher granularity, Joystick offering a greater sense of control is a preferred option, despite the cost of a longer time.

6.2 Workload: PC <** VR, Joystick = Ray

The finding of lower NASA-TLX scores for PC than VR is consistent with the findings in previous work [1], where the authors found greater physical and mental demand in VR. No statistically significant difference was found between Joystick and Ray in terms of workload, although the subscale results showed that Ray resulted in an overall lower workload than Joystick. These findings contribute to the understanding of **RQ2**.

We discuss two lessons learned from our observations and participant feedback in the interview. During the experiment, we found that some participants had difficulty making precise selections due to the high sensitivity of the Joystick interaction, which may have caused negative emotions such as impatience, thus causing higher mental workload and affecting their evaluations. This issue was also mentioned by four participants in the interviews. Participants commented that the Joystick control was so sensitive that have caused offsets when making selections, and thus a correction was needed under such circumstances. This could have led to the greater mental demand, effort, and frustration. Five participants commented that they would prefer Joystick for all types of questions if it was less sensitive. In addition, unlike the Ray that allows users to quickly switch between options (such as from A to D), Joystick requires users to move continuously from A to B, C, and D. This was identified by two participants as the reason for preferring Ray over Joystick for radio and block questions. On the other hand, some participants (N=4) identified that they could relax and rest their arms on their legs when using the Joystick, whereas it was tiring to hold the arms in mid air when using the Ray.

6.3 Presence: PC >*** VR, Joystick = Ray

In response to **RQ3**, we found that participants perceived greater presence using PC than in VR. P13 reported that *'I would feel more immersed if the VR environment is more realistic and interactive. Personally I felt it is unfair to compare it with the real world as I know I am indeed in the office when using the PC'.* Based on participants' comments, the main reason for their lower presence in VR is that the VR sessions were seated and stationary. We did not include an interactive session (such as a shooting game in [14]) that takes advantage of 3D interactions. Instead, we simulated a canvas-based questionnaire system that can be achieved outside VR.

Nevertheless, the significant difference between the reality using PC and VR indicates that participants could clearly perceive the real environment outside VR, and confirms the needs to conduct questionnaires in VR for evaluations that necessitate being in the context to avoid break in presence and bias in recall.

7 LIMITATIONS AND FUTURE WORK

Our research shows some limitations. First, in addition to Joystick and Ray, there are also other novel and natural interaction techniques in VR, such as those based on eye gazes, head movements, gestures, and voice inputs. These were not considered in the current study, but offer opportunities for questionnaires to be completed using hands-free approaches in future work. Significant efforts are needed to establish standardized interaction method with questionnaires to facilitate a valid comparison of results across studies. Second, our observations and interview comments showed that Joystick sensitivity is likely to influence performance and workload, and there are clear individual differences. This is a factor that needs to be taken into account and carefully tested when adopting Joystick selection technique in VR. Third, we studied three typical question types that are often used to collect numerical responses. Future work should look into other question types, such as open-ended questions that require text entry.

8 CONCLUSION

Based on the previous work, our study explored two selection techniques and three question types in VR questionnaires, and compared the performance, workload, and presence with the PC condition. We asked **RQ1** to investigate the impact of different interaction techniques on task performances. We implemented joystick and raycasting selection techniques in VR and compared them with user performance using PC. The results showed that there was no significant difference in task completion time between the two VR interaction techniques, but PC outperformed VR. To understand the effect of the different interaction techniques on workload (**RQ2**), we collected NASA-TLX evaluations and found that the self-reported workload in VR was greater than using PC. The difference between Joystick and Ray remained insignificant. Our investigation of **RQ3** showed that users could clearly perceive the real environment when exiting VR, which confirmed the necessity of in-VR questionnaires to avoid BIP. For practitioners who consider to adopt VR questionnaires, our results showed that raycasting selection led to comparatively less workload and is generally preferred by participants for Likert scale questions (radio and block). On the other hand, joystick selection technique is preferred when precise selection is expected for slider questions, but researchers should be aware of the longer experimental time.

ACKNOWLEDGMENTS

We would like to thank our participants for their time and valuable comments. This work is partially supported by the National Natural Science Foundation of China (62207022), Natural Science Foundation of the Jiangsu Higher Education Institutions of China (22KJB520038), and the Xi'an Jiaotong-Liverpool University (RDF-20-02-472).

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