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Report

How do different locomotion techniques affect the experience of walking in a virtual environment

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ABSTRACT

Technologies have enabled walking in VR environments to be pleasant and immersive. VR controllers, natural walking and Walking in Place (WIP) are some of the most popular walking techniques in VR. In order to discover how walking experience is affected by these technologies, a comprehensive evaluation was conducted. The user experience was investigated in terms of game experience, immersive level and motion sickness level respectively, of which were measured through questionnaires. In the process, participants were required to finish the corresponding questionnaires after experiencing one estimated technology, and were invited to interviews after all three tests. Quantitative data such as speed and distance was also measured automatically during the game. The evaluation indicated that Cybershoes, i.e the WIP technology used here, was the most challenging, but most tensive and tiresome technology; VR controller was the most dizzying one; and natural walking was the least tiring, but the least challenging one. The reason behind the motion sickness was also discussed in the view of multimodal interaction, followed by a possible future development, e.g a deeper investigation on motion sickness and the modification of the controller's technical details.

INTRODUCTION

Many studies worked on different aspects of walking activity in VR environments. Two main challenges arise when trying to provide a user with a natural walking experience in VR: “enabling unconstrained walking in virtual worlds that are larger than the tracked physical space and providing users with appropriate multisensory stimuli” [1]. There are various walking techniques solutions for VR and can be classified into three categories: repositioning systems, locomotion based on proxy gestures, and redirected walking [1]. Repositioning systems are for example linear treadmills. The forward movement gets neutralized and the user stays in a relatively fixed position. Linear treadmills (e.g. [2]) allow forward-moving in place, but turning has to be done using other approaches (e.g. joystick). Omnidirectional treadmills allow the user to walk in all directions and have a more natural walking experience [3]. Other approaches use motorized floor tiles moving in the opposite direction of the user's walking direction [4] or a human-sized hamster ball [5]. All the mentioned techniques actively reposition the user. Passive reposition techniques are for example friction-free platforms [6], [7]. The cyber shoes we use in our project belong to this category.

Another approach is proxy gestures, the user performs gestures representing the actual steps. The user does stepping-like gestures on one spot, this is therefore called walking-in-place. The gesture can be detected either by a physical interface [8] or by using motion tracking systems [9].

Redirected walking is another form of solving walking in VR. It includes physical walking, but manipulates the user’s path through the virtual environment. An example is to slowly and imperceptibly rotate the virtual environment, causing the user to walk in circles instead of straight.[1]

In this paper, we focus on answering the following research question:

How do three different locomotion techniques; Natural walking, controller and the cybershoes affect the walking experience in a VR environment?

In detail, we will investigate:

1. *How is the user’s Immersion sense affected in the VR Environment by using each of these three different walking techniques?*
2. *How is the Game Experience affected by using each of these three different walking techniques?*
3. *How do these three different walking techniques influence the user’s feeling of Motion Sickness?*

BACKGROUND

A related study that we are going to duplicate was done by Boletsis and Cedergren (2019) [10]. Four different VR locomotion types were scientifically identified, studied and compared in their study, named as *motion-based*, *room-scale-based*, *controller-based*, and *teleportation-based* locomotions. Because the room-scale-based locomotion limited the user interactions they selected the other three to be included in their experiment. According to the three remaining types they defined three techniques to compare these VR locomotion types. *Walking-in-place:* as a continuous *motion-based* technique that used *step-like* movements of the player while she was stationary. *Controller/ joystick*: defined based on the *controller-based* locomotion type in which the controller is used to direct the movement into the virtual world continuously. *Teleportation:* as a noncontinuous technique that provides a visual "jump". The player should point to the target viewpoint. [10]

Based on the user test and evaluations, they concluded that WIP (walking in place) technique was an appropriate choice for VR locomotion, however, it was tiresome and users were afraid of colliding physical objects. The controller based locomotion provided different experiences for the users based on their familiarity with the VR controllers. This technique has the problem of motion sickness and can be solved by some techniques, for example the dynamic field-of-view adjustment [10], [11]. The teleportation technique was not a convenient type of locomotion as it needs to be improved to provide a continuous motion. Furthermore based on the user experiments, WIP was the best in immersion and flow and controller/ joystick locomotion appeared to be very easy to use and master. For doing the tasks assigned to the users, teleportation was the best for competence and sense of effectiveness. About psychological discomfort, WIP and controller/joystick caused motion- sickness. WIP caused fear and tiredness as well without affecting the immersion, while teleportation caused eye strain that interrupted immersion. [10]

METHOD

This study focuses on how different locomotion techniques would affect the walking experience in a VR environment. Therefore 3 conditions have been used to further explore this question: Controller, Cybershoes and Natural Walking. The conditions are visualized in Figure 2.

EXPERIMENTAL SETUP

To test these different conditions, a virtual environment has been created in Unity (Version 2019.4.22f1). The participants were tasked to pass 5 checkpoints which were spread out over the map. The virtual environment has been designed to be visually appealing and contains auditory

feedback in order to keep the player engaged and to encourage them to explore it (see Figure 1). The environment was big enough to allow for the creation of 3 different routes (A, B and C). The cybershoes and the controller were paired randomly with route A or B for each participant. While route C was specifically designed for the natural walking condition. It has been adjusted for the dimensions of the room where the experiment took place to prevent participants from colliding with objects or walls. The conditions were tested in a random order. The experiments lasted between 25 and 40 minutes including the interview afterwards.

Figure 1: Virtual Environment.

For the duration of the study, we have been supplied with Cybershoes and a HTC Vive Pro, which comes with a controller. The hardware has been connected to a desktop computer with Windows Operating System, the performance of which allowed for impeccable execution of the game and its connection to the VR headset and the controllers. The experiment took place in the Akvariet at KTH Institute of Technology.

INITIAL TESTS

Before conducting the experiment a pilot test was carried out to ensure that no variables affected the user experience, such as the stability of the system, the components in the virtual environment, the controller and the Cybershoes. This test led to the adjustment of speed in order to achieve a more realistic walking experience. Additionally, the positions of the checkpoints have been adapted to make certain that the player can see at least one at a time and therefore not get lost in the environment.

Figure 2: The user test. left: the cybershoes technique, middle: The controller technique, right: natural walking technique

ANALYSIS METHODS

Throughout the experiment, quantitative data has been collected. For each condition, the walking speed and distance have been documented. Before recording the participants' performance, they have been given some time to get themselves familiar with the VR environment and the condition.

Furthermore, demographic data has been collected including age and gender.

Additionally, questions about the frequency of VR use, and experience with VR technology have been asked.

Participants have been tasked with evaluating each condition right after completing it using Google Forms. To make sure to answer the research question, we follow the research structure of a similar previous study that aligned with our aims [10]. To assess each condition, the GEQ (Game Experience Questionnaire) [12] has been used, which is a reliable user experience questionnaire in the VR and locomotion domain. Our questionnaire contains different sections. The In-game GEQ and the Core Module GEQ, which consists of several relevant questions, and the immersive experience questionnaire (IEQ) [13] have been used. These questions have been adapted to fit the game and the setup of this study. Further, the Fast Motion Sickness Scale [14] has been used in order to let the participants rate the state of their sickness from 0 to 20 after each condition. Through this standard question, we were able to receive explicit information about the impact of the controller on the participants' feelings of sickness. In this study, the dimensions of Competence, Sensory and Imaginative Immersion, Tension, Challenge, Negative Affect, Positive Affect (from the In-Game and Post-Game versions of the GEQ) have been used to evaluate the locomotion techniques. Finally, a semi-structured interview has been conducted in which participants have been asked to express what they liked and did not like about each condition.

Throughout the experiment, statements of the participants have been written down in order to evaluate them afterwards. Participants have been encouraged to voice their thoughts during the process.

This report focuses on the analyses of the data of 7 participants. The data of one participant couldn't be used, as he got motion sick during the first trial and ended the experiment. Another participant got motion sickness in his last trial. The data of the trials, which he finished, was used in the evaluation.

RESULTS

For the study, 8 participants have been recruited to test each of the three conditions. They were aged 22 to 32 years. Of the 8 participants half identified as male, the other half as female, 2 participants (25 %) stated that they had experience with VR and used it rarely in the past. These 2 participants had utilized a joystick/controller to move around within the VR environment.

In the following, we will evaluate the Immersive Experience and the Game Experience Questionnaire as well as the Interview and the talk-aloud notes.

IMMERSION

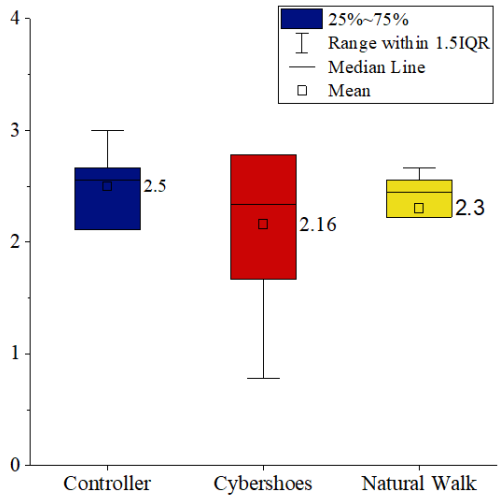

Figure 3: The immersive level from IEQ. (Scale: 0=Not at all; 4= Extremely)

The results of the IEQ-questionnaire are shown in Figure 3. All three conditions lead to a similar feeling of immersion in the virtual world. A Student's paired sample t-test indicated that the feeling of immersion is not significantly different ($p<=0.05$) for the three tested conditions.

GAME EXPERIENCE

Figure 4 shows the mean values and the standard deviation of the GEQ questionnaire results. An individual analysis of the GEQ components follows using the Friedman test to compare the three locomotion techniques:

1) Negative Affect. This component includes Tiredness and Boredom. The Friedman test showed statistically significant differences ($p=0.048$). Comparing the condition pairwise reveals a significant difference ($p=0.011$) for the cybershoes compared to the controller and a tendency ($p= 0.056$) for the controller compared with Natural Walking. Both are in favour of Natural Work which was rated less tiresome and boring.
2) Competence. The Competence category didn't reveal any significantly different results.
3) Tension. This category combines the questions about frustration and irritation. The Friedman test revealed a significant difference ($p=0.025$). The Cybershoes have a significantly different tension not in favour of them compared to the controller ($p=0.013$) and to the Natural Walk ($p=0.003$).
4) Positive Affect. For the Positive Affect, there is no significant difference.
5) Challenge. A significant difference ($p=0.021$) for the Challenge factor comparing the Natural Walk and the Cybershoes in favor of the Cybershoes was shown.
6) Sensory and Imaginative Immersion. No significant difference could be shown in this category.

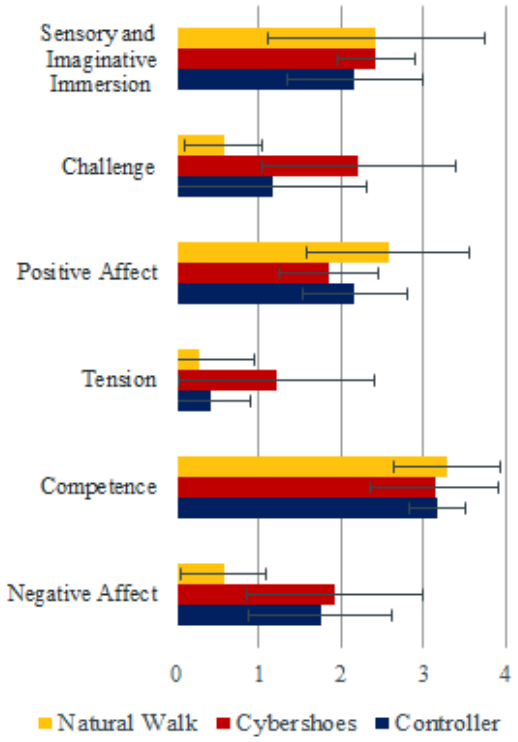

Figure 4: GEQ categorized result. (Scale: 0=Not at all; 4= Extremely)

Summarizing the results of the GEQ the Cybershoes are perceived to be the most challenging and have the highest tension rating. Natural walking has the lowest negative aspects, it is perceived as not tiring and not boring. This matches the result of the talk-aloud and the interview, where people described the Cybershoes as physically demanding and got exhausted, whereas the controller was perceived as boring as you only have to press a button, but easy to use.

INTERVIEW AND THINK ALOUD

Right after the experiment, the participants were asked to express their feelings about the three locomotion techniques they had experienced. Their comments and comparison were grouped, rated and illustrated in Figure 5. As shown in the diagram the Cybershoes were described as tiresome by 57% of the participants. 42.80% of them found it slow and the same percentage of participants indicated that it felt more natural than other techniques. The controller caused motion sickness for half of the participants. Two of them who started with the controller experiment felt so sick that he had to quit the experiment in less than two minutes. 57.10% of the participants described the controller as not natural and two of them who had more experience with the game controller found it easy to use. 28.50% of the participants indicated that they had fear of collision while doing the natural walk. One of them found the natural walking experiment easy and small and another participant commented that the speed of the walking felt slower than the real walking therefore it felt not natural for him.

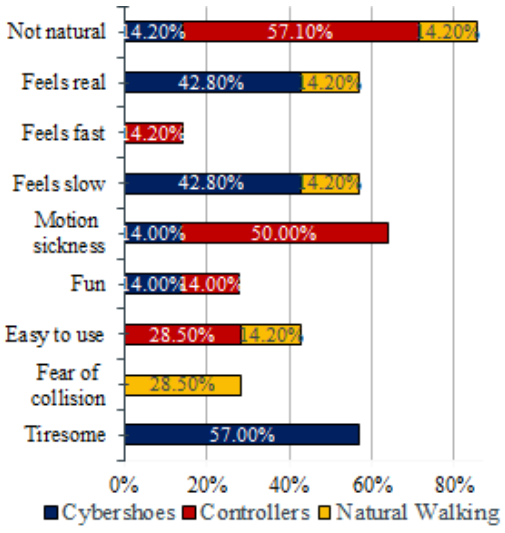

Figure 5: Interview keywords analysis.

The question of the overall pleasantness of the locomotion technique didn't show any

clear preferences (Controller: 5.7, Cybershoes: 5.3, Natural Walking 6.6; Scale:0-10).

Here, some quotes of the participants, gathered from the interviews, are listed;

1. Cybershoes:
   "Tiring, speed should be faster"
   "Compared to ice skating, moving is still unnatural!"
   "Felt like doing exercise."

2. Controller:
   "Most dizzy!!!"
   "This is quicker!"
   "Good for enjoying with the least effort!"
   "It is what I am used to and it is easier!"

3. Natural Walk:
   "Not dizzy."
   "It's scary, bumping objects."
   "Vision matches body movements."
   "Too slow! faster would be more immersive."

MOTION SICKNESS

Two participants ended the experiment while using the controller prematurely due to severe feelings of motion sickness (2 male). Participant 4 partook in the controller trail only. He felt dizzy and quit the experiment less than 2 minutes in. While participant 5 has been able to participate in the cybershoes and natural walking trail but felt sick after 1 minute of using the controller. However, the data of the trails which participant no. 5 completed (natural walking and cybershoes) have been retained for the statistical analyses.

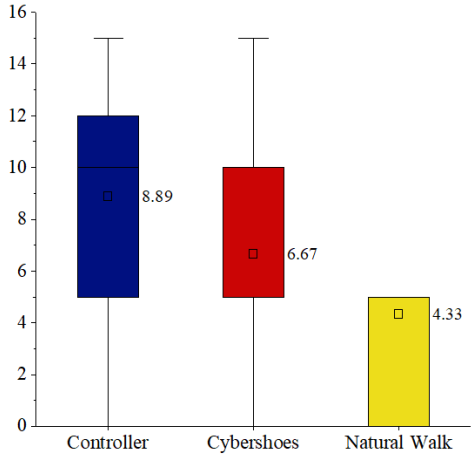

Figure 6: Motion sickness levels. (Scale 0=No sickness at all; 20= Severe Sickness)

Of the 3 locomotion techniques, the controller (Md = 10, SD = 5,19) led to more participants feeling uncomfortable or nauseous while partaking in the experiment. The cybershoes provided a better experience leading to less motion sickness compared to the controller (Md = 5, SD = 4,52). Natural Walking (Md = 0, SD = 5,47) resulted in the most pleasant experience for the player. (see Figure 6).

QUANTITATIVE DATA

The quantitative data measured during the experiments is visualized in Figure 7. The walking speed of the controller and Cybershoes was adjusted to be the same when walking with an average speed.

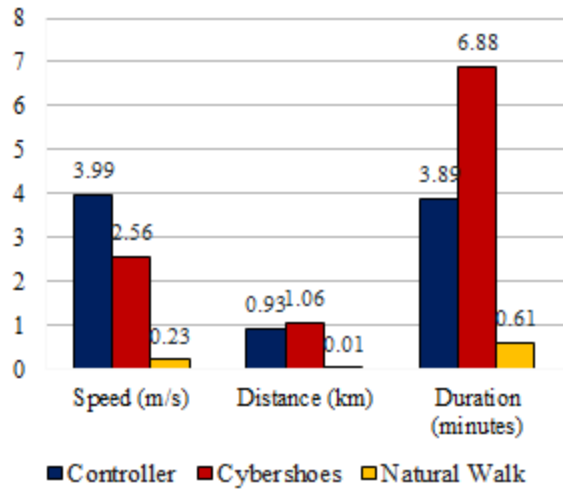

Figure 7: Speed, Distance and Duration comparison

Nevertheless the average speed during the experiment was lower for the Cybershoes compared to the controller. The Cybershoes allowed walking slower or faster depending on the movement of the feet, whereas the controller moved the player at a constant speed. Also it was observed during the experiment that the participants took more breaks to observe the environment and rest, as they described the cybershoes as tiresome. The walked distance for the Cybershoes and controllers is similar. With the cybershoes the participants stayed 6.88 minutes on average in the VR environment, with controllers only 3.89 minutes, this might have to do with the lower speed and the small breaks. Additionally, the participants described the Cybershoes as more fun and got less Motion Sickness, which might also be reasons for that. The data of the Natural Walk is not comparable to the data of the Cybershoes and the controller, as the room in which the experiment was conducted was quite small and the usage therefore limited. They moved with caution and spent more time observing the environment which resulted in a very low speed. As the area was so small the distance walked and the duration spent in VR is also very small.

DISCUSSION

In the following we will discuss our results based on our research question "*How do three different locomotion techniques; Natural walking, controller and the cybershoes affect the walking experience in a VR environment?*", focusing on the senses of Immersion, Game Experience and Motion Sickness.

Regarding the Immersive Experience, no significant differences between conditions could be found.

The Game Experience questionnaire revealed that Cybershoes are perceived as the most challenging and tensive walking technique. Natural Walking had the lowest negative affect. During the interview and talk aloud the Cybershoes were described as tiresome, nevertheless participants stated that they liked it to move by actually moving their legs. During the Natural Walk experiment, participants feared collisions and felt that they move rather slowly. The controller was described as not natural but easy to use. On the other hand, participants stated that they got dizzy and described this condition as weird.

Our results show that the Natural Walking technique leads to the lowest Motion Sickness, while the controller leads to the highest Motion Sickness. The considerable proportion of the participants suffering from motion sickness (25%) during the game aroused our interests. Thus a close study in the materials gathered from the interviews was made. This dizziness, concluded from the interviews, might be the consequence of the mismatch among different input modalities In particular, the Cybershoes were less dizzy than the controller, in that the visual changes in the VR environment driven by the movement of the participant's legs was relatively consistent with real-life walk, while the visual changes driven by pressing the button was perceptually uncommon in reality. In other words, the mismatch between vision and body gestures might be one of the factors that led to the sickness. This also explains why people were willing to stay in the Cybershoes-based game longer than the controller-based one.

Another factor that might have affected the Motion Sickness is the speed. In our pre-study, we adjusted the speed, so that the users were most comfortable and the Speed is on average the same for the controller and the Cybershoes. Nevertheless, the speed of the controller was perceived faster in the experiment, which might have influenced Motion Sickness. In the Section Future Work, we will briefly discuss further the possible adaptations to reduce Motion Sickness.

The collected quantitative data showed that participants using the controller were faster and walked a smaller distance. Therefore, the controller might be more efficient to use.

Our study and the study we were using as a guideline were game-oriented. However, other usage of locomotion techniques is possible. Bouguila et. al. predict great interest for locomotion techniques in the future for e.g. "building evaluation, urban planning, terrain exploration and military and vocational training" [15].

Boletsis et. al. [10] compared in a previous study walking-in place, controller/joystick and teleportation regarding Usability and the Game Experience. They found that walking-in-place offers the highest immersion, on the other hand it showed high levels of psychophysical discomfort. The controller/joystick was perceived as easy to use. The teleportation was perceived as effective as it allows fast navigation, on the other hand the teleportation-'jump' are not immersive.

Additionally, they found that using the controller to walk leads to a high level of motion sickness and is easy to use. Both results were also made in our user study.

As they used different walking techniques and a slightly different set-up the results are not directly comparable, but it allows comparison of the evaluated walking-techniques.

PERSONAL ASSESSMENT

The project was generally competitive. Firstly, a solid background study was conducted, during which we compared the state-of-art VR walking technologies with the equipment provided by the course. Methods and evaluation standards, e.g different questionnaires (GEQ, IEQ, etc.), were also taken into consideration when designing the experiment, which ensured the project to be theoretically robust.

Secondly, a more comprehensive analysis over the walking techniques were utilized, compared with the study of Boletsis et. al [10]. In their study, technologies were measured in terms of game experience (GEQ) and usability (SUS). And in our study, we considered a more thorough dimension, including the game experience, immersion level (IEQ) and motion sickness (questionnaire, interview and quantitative data). These dimensions offered us a broader view in seeing these technologies and in explaining the connections behind certain phenomena.

Thirdly, the knowledge learned in the Multimodal Interaction course was applied. When discussing the reason for motion sickness, we analyzed the interviews based on the input and output modalities involved in the interaction process. Audio input remained the same in all interactions, Thus the problem was highly likely to occur due to the relationship between vision and body gestures. In specific, the natural walking had the most harmonious relationship, the Cybershoes came second and the controller turned worst.

Fourthly, the project was well-organized. Ingemar, the research engineer in VIC worked closely with us, providing easy access to Akvariet during the development phase and user study phase. Besides, every researcher in this project contributed to it via the tasks they were specialized at. In particular, Larissa and Andrea were dedicated to the development of the VR environment for the user study and to helping the other members in learning Unity; Fatemeh focused on questionnaire and consent form design, and visualization of the project content; and Yawen mainly contributed to the communication between the researchers and the participants.

FUTURE WORK

Due to the Covid-19 situation, we were only able to recruit 8 participants, of which 6 participants were able to finish the whole experiment. This small number of participants allowed us to investigate the three walking conditions. In further work, a study with more participants needs to be conducted in order to get clearer and stronger results. Additionally, future studies could include additional walking techniques (e.g on a treadmill). Furthermore, a bigger room to allow the user to walk further in the natural-walking condition would be beneficial to fully explore this condition.

An aspect, which we briefly explored in our study, was Motion Sickness. This aspect showed to be quite important and affected the user and his/her experience in VR heavily. Future work could focus more on this aspect, also investigating how to avoid Motion Sickness (e.g adjustment of the field of view and speed).

Another aspect that could get investigated further is the movement with the controller. Participants said that they were missing acceleration and the possibility of controlling their speed. Different interactions and settings with the controller could be tested.

CONCLUSION

In this study, we compared three different locomotion techniques for VR (Controller, Cybershoes and Natural Walking). Aspects of Motion Sickness, Immersion and Game Experience got investigated. Regarding Motion Sickness Natural Walking leads to the lowest and controller to the highest Sickness. For the Immersive Experience, no significant difference between the conditions could be shown. Natural Walking has the advantage that the user doesn't get tired and bored quickly. On the other hand, participants feared colliding with objects in the room and were limited by the space of the room. Depending on the application Natural Walking is a good solution for locomotion in VR. If the application requires the user to walk long distances (e.g. exploring an area) this might not be a good solution. There the Cybershoes might be an option they lead to lower Motion Sickness than the controller and participants thought they feel more natural and real. On the other hand, they challenge and tense the user. In conclusion, all locomotion techniques have different advantages and disadvantages. The choice of the best locomotion technique depends on the VR-application and its requirements. depends on the VR-application and its requirements.

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APPENDIX

VIMEO VIDEO LINK

https://vimeo.com/665508433

QUESTIONNAIRE

DEMOGRAPHICS

Age

Gender

Do you have experience with VR (Virtual Reality)?

Which input modalities have you used before for moving around within the VR Environment?

GEQ

I felt successful

I felt bored

I felt frustrated

I found it tiresome

I felt irritable

I felt challenged

I had to put a lot of effort into it

I enjoyed it

It was aesthetically pleasing

IEQ

To what extent did you feel you were focused on the game?

To what extent did you feel consciously aware of being in the real world whilst playing?

To what extent were you aware of yourself in your surroundings?

To what extent did you notice events taking place around you?

Did you feel the urge at any point to stop playing and see what was happening around you?

To what extent did you feel as though you were separated from your real-world environment?

To what extent did you feel that the game was something you were experiencing, rather than something you were just doing?

At any point did you find yourself becoming so involved that you were unaware you were even using controls?

To what extent did you feel as though you were moving through the game according to your own will?

MOTION SICKNESS

How uncomfortable or nauseous do you feel right now? Rate your feeling with a number between (0: no sickness at all -20: severe sickness)

OVERALL PLEASANTNESS

How pleasant did you find walking around using the controller?

Do you want to tell us anything else about your experience with the Cybershoes?