Cybersickness and usability in immersive virtual clinical simulation for nursing students: omnidirectional pad vs touch controllers

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Abstract

One of the biggest challenges faced by immersive virtual reality users is cybersickness. While its cause has been widely debated, consensus has yet to be reached, and a permanent solution found. Previous studies in nursing found that nursing students are especially susceptible to cybersickness if they lack gaming platform experience. Methods: Forty-six undergraduate nursing students were exposed to a foreign body object scenario. Cybersickness scores with various usability and usability scores , were noted and compared within participants. Results: The touch controllers were superior in terms of overall usability (82.42%,); however, while the omnidirectional pad had a much lower overall usability score (72.24%), it did slightly decrease cybersickness in participants (15.36 vs 17.37). Conclusion: While the decrease in cybersickness was not statistically significant (P=0.57), qualitative data indicated that the omnidirectional pad was deemed an innovative navigation technique and with improvements, it could outperform the touch controllers and reduce cybersickness even further.

Keywords

cybersickness, immersive virtual reality, extended reality, virtual clinical simulation, human-computer interaction, usability, user experience, VR navigation techniques

1. Introduction

Cybersickness (CS), also referred to as Visually Induced Motion Sickness (VIMS) [1, 2] or Virtual Reality Induced Symptoms and Effect (VRISE) [3], is a condition which is commonly found in immersive virtual reality (VR) users. It includes symptoms similar to motion sickness, namely nausea, headaches, and dizziness [4, 5]. CS is not a disease, but rather a physiological response that an individual exhibits due to some form of unusual stimuli [6]. Due to the increased popularity of immersive VR, especially within a health science educational context, research on the causes and possible solutions for CS during immersive VR navigation should be explored to provide a more accessible and safer immersive VR experience.

The use of immersive VR in healthcare education is known by many terms, such as virtual simulation [7] and virtual reality simulation [8, 9]. However, for the purpose of this study, the term virtual clinical simulation (VCS) [10] will be used, as it actively depicts the clinical part of health science education. Even though significant advances have been made to provide "VR for the masses", much still needs to be done by means of experimentation to provide an effective CS deterrent during navigating in immersive VCS [11].

Various authors have researched CS while navigating immersive VCS to reduce the effects thereof, including, but not limited to, higher variability in the position of the user [12], lower levels of realism [13], and body orientation [14]. While there has been many debates on the exact cause of CS, five general theories were originally proposed as possible causes of CS, namely the Poison Theory [15], the

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Postural Instability Theory [16], the Rest-frame Theory [17, 18, 16], the Sensory Conflict/Mismatch Theory [19], and the Vertical Mismatch Theory [20].

Except for the Poison Theory, the other theories all have support and are widely debated and compared in literature in terms of ways to address CS. Seeing how CS is one of the major issues in immersive VCS without a concrete solution, the aim of this paper is to convey CS, usability, and user experience (UX) ratings of nursing students at a higher education institution in South Africa, navigating a virtual clinical scenario using two different immersive VCS navigational techniques (omnidirectional pad (ODP) vs touch controllers), to determine the best-suited navigation techniques to address CS [21, 22].

2. Theoretical framework

The researchers used the Framework for Cybersickness Prevention during Virtual Clinical Simulation (CyPVICS) [23] to guide the research. The CyPVICS framework shows various causes of CS, along with linked methods and their associated techniques for reducing or minimizing CS.

This research focused on the Sensory Conflict/Mismatch Theory as CS cause, as it is the most referred-to theory in literature. It was linked to the Postural Instability Theory and Vertical Mismatch Theory as CS causes in the CyPVICS framework.

The Sensory Conflict/Mismatch Theory theorizes that CS is caused by a mismatch between the perceived movement while using immersive VCS, and the actual movement in the real world, for example, remaining stationary in the real world while your brain perceives you as walking in the VCS [19]. One of the possible methods to reduce or eliminate CS in CyPVICS, refers to improved models of interaction, which implies that various navigational techniques can be used in different circumstances (depending on the VR setting and the needs of the user) as an attempt to reduce or limit CS [23].

3. Related work

Amidst debate and advances in CS research and its reduction, some researchers have found that participants using a head-mounted display (HMD), navigating with handheld controllers, reported a significant increase in presence and enjoyment compared to using a desktop mouse and keyboard. This, however, also led to an increase in CS. To address CS, an ODP) was incorporated in the hope that it would limit sensory conflict and postural instability. The results, however, did not show a significant improvement compared to using the HMD-touch controller combination. Users also indicated that the ODP did not feel more natural than using the controllers [24]. Another study where participants were exposed to various interaction techniques within VCS, namely the TiltChair, ODP, VRNChair, and a controller (joystick), indicated that the VRNChair had the lowest CS scores, while the ODP had one of the highest [25].

In gaming, the ODP has been referred to as a tool to enhance the gaming experience, but it did not reduce CS, as might have been expected when trying to limit sensory conflict [24]. Similar results were found with the KatWalk ODP [26], the Virtuix Omnia, and the Cyberith Virtualizer [27]. However, a pilot study conducted with five nursing students indicated that an ODP might have some promise as a method to reduce or eliminate CS (although the sample size was too small to make meaningful deductions) [28].

While research has been done on the use of an ODP to try to reduce CS, it has not yet been incorporated in a usability study in a nursing training context. By incorporating known usability evaluation methods along with validated CS measurement tools, the researchers attempted to determine whether:

An ODP (compared to touch controllers) could assist nursing students in participating in immersive VCS, while limiting the onset of CS as part of the Sensory Conflict/Mismatch Theory to reduce or limit CS [23].

Figure 1: KatWalktm mini (image used from KatWalk.com) and Oculus Rift S (used from Oculus.com)

4. Methods and materials

To test the Sensory Conflict/Mismatch Theory as a cause of CS and determine whether the ODP could prevent or minimize CS, four usability study types were incorporated, namely to 1) compare alternative designs, 2) create an overall positive UX, 3) problem discovery, and 4) evaluating navigation and/or information architecture [29]. Within these study types, questionnaires were used to gather data from participants before, during and after performing tasks.

4.1. Data collection tools

The first usability study type (comparing alternative designs) was employed to compare the usability and UX between the two chosen navigation techniques, namely the conventional touch controllers and the ODP. The questionnaires utilized for this purpose were the System Usability Scale (SUS) [30], Ease of Use [31], Expectation Measure [32], and the Net Promoter Score (NPS) [33]. The metrics that assisted in comparing the alternative navigation techniques were the time taken to complete the task (efficiency) and the task success (effectiveness).

The second usability study type (creating an overall positive UX) assisted the researchers to determine points of frustration and/or satisfaction in using the conventional controllers when compared to using the ODP. This was determined by means of an After-Scenario Questionnaire (ASQ) [34].

The third usability study type (problem discovery) involved questionnaires that assisted in determining problem areas, namely the SUS [30], Expectation Measure [32] and the ASQ [34]. The metrics that assisted in identifying problems with the navigational techniques were time on task (efficiency) and task success (effectiveness).

The fourth and final usability study type (evaluating navigation and/or information architecture) was used to determine the effectiveness and efficiency of the ODP compared to the touch controllers. To do this, the Virtual Reality Sickness Questionnaire (VRSQ) [35] was utilized to determine the CS level during the use of the various navigation techniques. The results were then compared within participants.

The data collection tools used were widely adopted and accepted in usability and UX studies. These methods have, over time, been valid and reliable sources of data. The VRSQ has a Cronbach alpha value of 0.92, which indicates that it is reliable.

4.2. Hardware

Along with the data collection tools, a variation of hardware was needed. The chosen consumer ODP was a KatWalktm Mini (see Figure. 1 - left). Three variants of this ODP were available. However, due to high costs, the premium variants could not be sourced, and the new Kat Loco, (a more affordable version of the KatWalktm Mini), was not available at the time of acquisition.

Figure 2: VE used for testing

The HMD that was used in combination with the chosen ODP (KatWalk Mini), was the Oculus Rift S (see Figure. 1 - right), which is the improved version of the Oculus Rift. The reason for using the Oculus Rift S was that the researchers were already in possession of this hardware component. Even though this brought about cost savings, it had all the required functionality for this research. The ODP and HMD were used in conjunction with a VR-capable computer with a total of 32 gigabytes of RAM, a Core i7 10th generation processor, a solid-state hybrid drive, and an NVidia GeForce RTX 2070 graphics card, which is in line with the recommended requirement for a VR-capable computer.

4.3. Software

To integrate the ODP with the original virtual environment (VE), software was needed. For this purpose, Unity 2020 was selected to integrate the ODP as a navigation technique. The VE (Figure. 2) consisted of two rooms, the first being a lounge (on the right) where the participant is first immersed when entering the VE. The lounge contained the briefing and the objectives that the participant had to read before proceeding through the door giving access to the ward. After the participant entered through the door, they were in the ward (Figure. 2 - on the left) where the patient was present, along with various tools needed to perform the scenario. These tools consisted of a stethoscope to listen to heart and lung sounds, a bed controller, a blood gas analyzer, a chest X-ray, an oxygen mask with a control panel, vital signs monitor, and an intercom to contact the attending physician.

The VE allowed the participants to perform a foreign body object simulation scenario. During the scenario, the patient coughed regularly. The participants could interact with the patient, read the patient file, interpret the chest x-ray, listen to the heart and lung sounds, and request the blood gas results to determine the best course of action to manage the patient. Once a diagnosis was made, the participant could use the oxygen therapy control panel in the room, along with the bed controls, to assist the patient. If the patient's condition did not significantly improve, they had to contact the physician.

4.4. Population and sampling

The target population was nursing students at a South African tertiary institution who had the theoretical knowledge and skills to manage a patient with a lodged foreign body object in the airway. Data was collected from 46 undergraduate nursing students in their 3rd year of study, that were conveniently sampled. Those that suffered from epilepsy were excluded from the study, due to the warnings in immersive VR headsets that the refresh rate might induce an epileptic attack.

The number of students that participated was more than the recommended sample size of 42, which was determined using values from a pilot study [28] along with G*Power 3.1.9.7 [36].

4.5. Data collection

Multiple usability test dates were made available from which participants could choose. The participants booked in groups of two per session (based on their availability rather than using a random selector), to allow time flexibility and more participants to join. Counterbalancing [37] was introduced as a measure to limit learnability or favor towards one navigational technique [38]. Counterbalancing allowed one participant to start using the touch controllers, while the other started using the ODP, after which they switched. This assisted in ensuring that not all participants were exposed to the same navigational technique first (23 started with the ODP and 23 with the touch controllers). Participants had to sign an informed consent form and were also asked to refrain from wearing dresses (as it interfered with the straps on the ODP) and flip flops or sandals (as it made walking on the ODP difficult).

Task set one:

- Walk towards the door of the ward and open the door.
- Wash your hands in the basin.
- Navigate to the left side of the patient.
- Apply the oxygen mask, set the flow to 40% and the flow rate to 10 L/min.

Task set two:

- Navigate to the bathroom.
- Open the bathroom door.
- Flush the toilet.
- Wash your hands.

Task set three:

- Navigate to the right side of the patient.
- Elevate the patient's bed to semi-fowlers using the bed controls.
- Navigate back to the room that you started in and face the door.

The researchers demonstrated the navigation techniques, after which both participants in the two-person group started by completing the Expectation Measure for their assigned navigation technique (touch controllers or ODP).

Participant One then started by navigating the VCS using the assigned navigation technique. Once Participant One completed the tasks on the assigned navigation technique, (s)he had to complete the VRSQ and the usability questionnaires.

Participant Two then started to complete the tasks by navigating using the assigned navigation technique. With the first rotation completed, the two participants had to switch navigation techniques (touch controllers and the ODP), and the whole process was repeated.

4.6. Data analysis

Data was analyzed using Microsoft Excel, as it is widely used and accepted in the HCI community [39], and it provided adequate data analysis functionalities for this study. The researchers were also familiar with the use of Microsoft Excel for statistical analysis and the results were verified by a qualified and registered biostatistician.

The SUS [30] provided insight into the overall usability of the touch controllers and ODP as navigation techniques in immersive VCS. A SUS score value from 70 up to 100, was considered truly usable, while a score below 70 was inadequate [30]. The SUS score is calculated by subtracting 1 from the scale position for all positive statements (a - 1), and by using 5 minus the position on the scale, for all negative statements (5 - y). The scores for the ten statements are then summed and multiplied by 2.5 [30].

The ease-of-use scores [31] for both groups were averaged across the number of participants to determine the average ease of use for the ODP and the touch controllers. The Expectation Measure [32] required participants to view the tasks (before attempting them) and rate the expected difficulty of each. Once completed, they had to rate the actual difficulty of the task. The expected ease of use scores for each task were averaged across the number of participants for each of the navigation techniques (touch controllers and ODP) who completed the tasks successfully. These scores were compared to their actual ease of use score. This assisted in determining areas that needed improvement, those areas that were good, and those that could be promoted. The tasks focused on navigation of the VE, rather than clinical learning.

For the ASQ [34], a score equal to or less than 3 was deemed to be inadequate and required immediate improvement. A score greater than 3, but lower than 4, was low, while a score greater than or equal to 4, but lower than 5, was considered an average score. An adequate score had to be greater than or equal to 5, but lower than 6, while a score of more than or equal to 6, was more than adequate. Each question was averaged according to the sample size to determine the ASQ average of the touch controllers and ODP.

The NPS [33] determines how likely users are to recommend an artefact to friends or family (making use of a 10-point Likert scale). The scores were separated as follows: detractors (0 - 6), passives (7 - 8), and promoters (9 - 10). The overall score was determined by subtracting the percentage of detractors from the percentage of promoters [40]. An NPS of zero to 50 is considered good, a value above 50 but below 75 is considered to be excellent, while a value of 75 or above is world class [40].

Task success refers to whether the participant completed the task sets. Levels of success were categorized as follows: only one of the task sets completed = 33.33% completion, two = 66.66% completion, while a 100% rate implied that all tasks in each task set had to be completed successfully. The time on task refers to the time taken to complete a given task during usability testing [39] and was measured for both navigation techniques of participants to enable a comparison between the times.

To calculate the VRSQ score, assisted in determining CS levels per navigational technique. Each main category was summed and then calculated as follows:

- Oculomotor = (Oculomotor Score/12) X 100
- Disorientation = (Disorientation Score/15) X 100.

The total score was calculated by adding the two scores and dividing them by two (Oculomotor score + Disorientation score)/2. Ultimately, the lower the score, the better [35].

The results from the VRSQ for the touch controllers and the ODP were compared within-subjects to determine whether CS was prevented or minimized, while the usability test results indicated the usability and UX of the ODP in comparison to the touch controllers. Before comparing the VRSQ results for the touch controllers and the ODP, a Shapiro-Wilk W test was conducted to determine equal variance of data distribution, thus determining if a numerical variable is normally distributed or not. The Shapiro-Wilk W test is the most commonly used test to determine equal variance [41, 42]. The value from the Shapiro-Wilk W test was lower than 0.05 (<0.0001), which indicated that the data was not normally distributed. A signed rank test was, therefore, used to compare the data of the touch controllers and the ODP. The signed rank test can be used to compare medians of paired data that are not equally distributed if an analysis variable is used (the difference between the two measurements) [41]. Data was gathered with approval from the institutional General Human Research Ethics Committee under ethical clearance number UFS-HSD2021/1126/21.

5. Results and discussion

The usability test results for this study are presented by navigation technique. For each of the metrics, the mean and standard deviation (STDEV) were used as the most common descriptive metrics. The means were used to compare the navigation techniques, while the STDEV provided the ranges where values deviated [41]. All the raw (anonymous) data and analysis files are available from a data repository (Link to repository).

5.1. Time on task and task success

In this study, time on task was measured in seconds. All the participants' task times were averaged for those who successfully completed the tasks. The task times for all three levels of success were averaged separately. Two participants (one in each of the navigation techniques) did not complete any of the

Table 1
Touch controllers: averages for time per task and overall time on task

	Task 1	Task 2	Task 3	Overall time
Average task times (in seconds) (n=45)	104.50	58.48	42.32	205.30
STDEV (in seconds)	52.59	19.73	15.28	87.60

Table 2
ODP: averages for time per task and overall time on task

	Task 1	Task 2	Task 3	Overall time
Average task times (in seconds) (n=45)	112.64	54.89	50.18	217.70
STDEV (in seconds)	34.48	14.66	14.65	63.79

tasks. Therefore, the mean for 100% completion was only calculated using the 45 participants that completed all the tasks on both navigation techniques (since values were not comparable) [38].

5.1.1. Time on task and task success: touch controllers

For the touch controllers, a total of 45 participants completed all the tasks (three out of three) successfully. The touch controller non-completer was immersed for a total of 91 seconds before requesting to stop due to feeling extremely nauseous and dizzy. The average times and STDEVs for the participants that successfully completed all the tasks (n=45) can be found in Table 1.

5.1.2. Time on task and task success: ODP

The task success rate for the ODP was 100% (three out of three tasks) for 45 of the participants, while one participant had a success rate of 0% (0 out of 3 tasks). The total time on task for this participant was 122 seconds. The reason provided for not completing the tasks was that it "felt weird" using the ODP. The participant could, however, not provide specifics on what was meant by "weird". The average time per task and standard deviations (STDEV) when using the ODP are presented in Table 2.

5.1.3. Time on task and task success: touch controllers vs ODP

Forty-five participants successfully completed all the tasks using the ODP and touch controllers. The average time on task for these 45 participants was very similar (touch controllers = 205.3 seconds; ODP = 217.7 seconds), with the average time when using the ODP being 12.4 seconds more than that of the touch controllers. The data for the two participants that did not complete the tasks (one for the touch controllers and one for the ODP) were still taken into consideration for the rest of the results, seeing that they were still exposed to both the navigation techniques and completed all the questionnaires accordingly.

5.2. Expectation measure

The Expectation Measure [32] was used to compare the participants' expected ease of use to the actual ease of use with both navigation techniques. The participants had to read the tasks and indicate their expected ease of use in completing the task with the specific navigation technique. Once they completed the tasks, they again had to rate the ease of use, this time based on their actual experience. The two values for the actual vs the expected ease of use was then compared to obtain the expectation measure. Note that higher ratings (on a scale of one to seven) indicated higher ease of use. For the expectation measure, the standard deviation is not applicable towards the comparisons of the quadrants and is therefore not showcased.

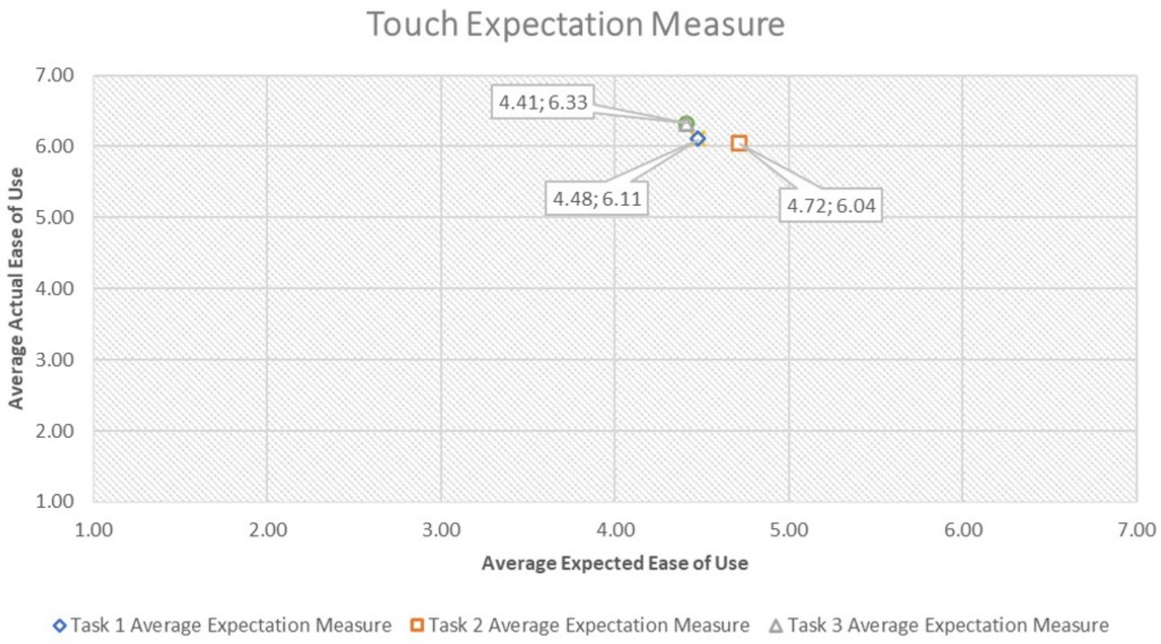

Figure 3: Touch controllers' expectation measure (noted as expected ease of use, actual ease of use)

5.2.1. Expectation measure: touch controllers

The touch controllers' average expected and actual ease of use ratings per task were between 4 and 5, which indicated that participants expected the tasks to be somewhat easy to perform using the touch controllers. The actual ease of use ratings was higher than the expectations, all being above six (very easy), which indicated that the tasks were not difficult to perform at all. The expected ease of use compared to the actual ease of use for the touch controllers indicated that participants did not expect the tasks to be very difficult to perform, and in the end, experienced that these tasks were, in fact, very easy. This phenomenon is referred to as the "leave alone" category, indicating that these tasks were handled well on the touch controllers and did not need changing or improving [43], as can be seen in Figure. 3.

5.2.2. Expectation measure: ODP

The expected ease of use was average (the ratings varied from three to five), which indicated that participants expected the tasks on the ODP to be 'somewhat difficult to somewhat easy' to perform. The actual ease of use ratings were much higher than those expected for the ODP. Task 1's rating was a little below five (somewhat easy), task 2's rating was well above five (easy), while task 3 was above six (very easy), which indicated that the tasks were not as difficult to perform as expected.

When comparing the expected ease of use with the actual ease of use (see Figure. 4), one can see that only one of the tasks fell into the category "promote it", which meant that this task on the ODP was handled so well that similar tasks should be handled in the same way. The other two tasks fell into the category "leave alone", as they were perceived as being relatively easy to perform and were in fact easy to perform.

5.2.3. Expectation measure: touch controllers vs ODP

When averaging all the task scores per navigation technique (Figure. 5), there is not a major difference between them.

Both techniques fell into the category labelled as "leave alone", which indicated that, overall, the tasks were perceived and experienced as easy to use. It is, however, important to note that the ODP did

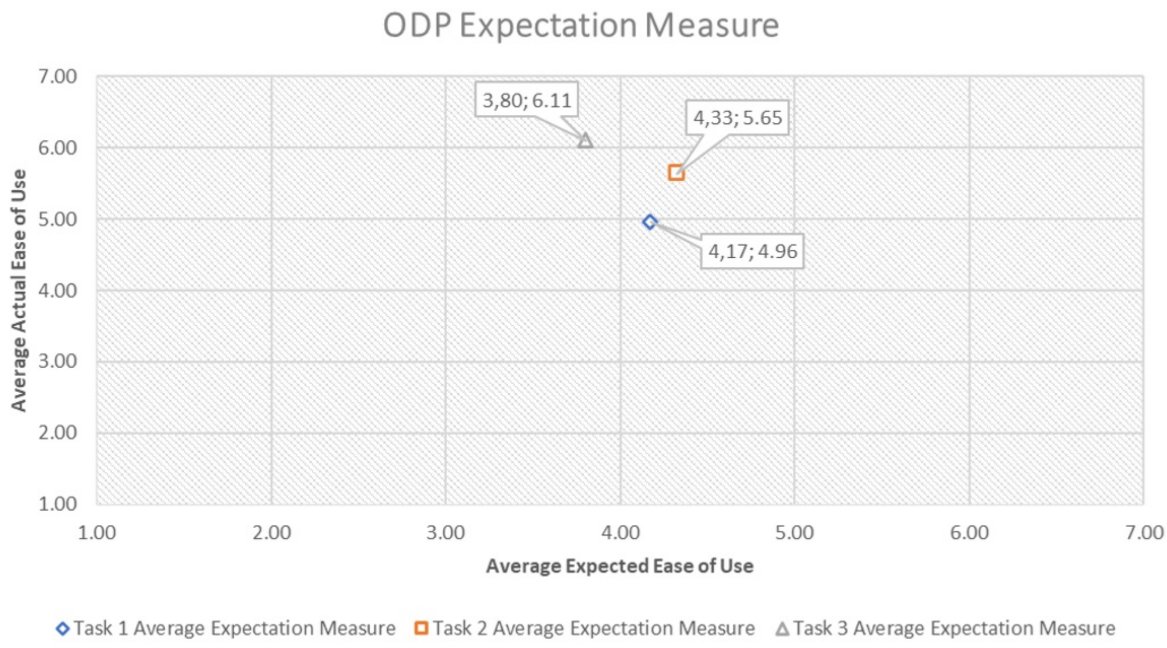

Figure 4: ODP expectation Measure (noted as expected ease of use, actual ease of use)

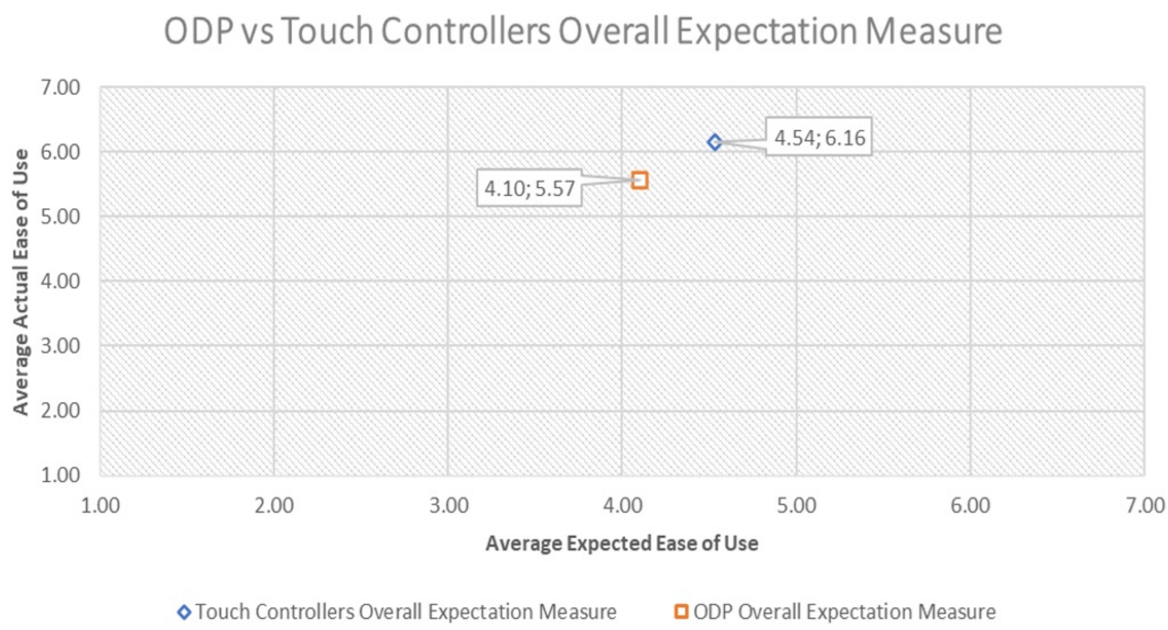

Figure 5: Touch controllers vs ODP overall expectation measure (noted as expected ease of use, actual ease of use)

have a lower Expectation Measure with the first task. While the reason is not clear, it might be due to the learning curve of the ODP. However, this needs to be investigated further to draw a definitive conclusion.

5.3. After-scenario questionnaire (ASQ)

The ASQ uses three statements to which the participants had to rate their level of agreement. The three statements each measures a different aspect of usability, namely effectiveness, efficiency, and satisfaction. The first ASQ results to be discussed are those for the touch controllers.

5.3.1. After-scenario questionnaire (ASQ): touch controllers vs ODP

The touch controllers' ASQ results indicated that the participants were overall more than adequately satisfied (more than or equal to six) with the navigation technique. The ASQ results for the ODP indicated that the participants were overall adequately (greater than or equal to five, but lower than six), or more than adequately satisfied (more than or equal to six) with the ODP as a navigation technique. The results for both the ODP and touch controllers, along with the STDEVs, are listed per ASQ question: I am satisfied with the ease of completing the task in this scenario (effectiveness).

- Touch controllers (AVG=6.49; STDEV=0.90).
- ODP (AVG=5.90; STDEV=1.31).

I am satisfied with the amount of time it took to complete the tasks in this scenario (efficiency).

- Touch controllers (AVG=6.48; STDEV=1.03).
- ODP (AVG=5.99; STDEV=1.03).

I am satisfied with the support information (online help or messages and documentation) when completing the task (satisfaction).

- Touch controllers (AVG=6.76; STDEV=1.00).
- ODP (AVG=6.54; STDEV=0.56).

In comparing the ASQ results for the touch controllers and the ODP, the averages for both techniques were adequately satisfying (five or higher). A possible reason for the slightly lower ODP score could be related to it being a newer and unfamiliar technology, while the touch controllers represented a more familiar model of interaction, even on other types of platforms, like PlayStation or Xbox.

5.4. System usability scale (SUS)

The SUS was used to determine a single usability score for the navigation techniques used in the VE. For the navigation techniques to be considered as truly usable, a SUS score between 70 and 100 was required. A score below 70 was deemed inadequate.

5.4.1. SUS: touch controllers

The touch controllers provided an overall truly usable score, namely 75.27% (with 15 of the 45 scores falling below the truly usable threshold). The STDEV was 14.64. This indicated that touch controllers are a highly usable navigation technique, possibly due to their design, as they mimic modern console controllers, for example, PlayStation and Xbox.

5.4.2. SUS: ODP

The SUS score for the ODP was 64.46%, with an STDEV of 20.08. This score was not adequate and indicated that improvements were required to the ODP as a navigation technique. It is, however, useful to note that the value was not that far below the 70% required. The large STDEV, along with the fact that 21 out of the 46 participants did find the ODP to be truly usable, could indicate that the ODP has the potential to become a usable navigation technique for VCS. Improvements and advanced training may be required to achieve this.

5.4.3. SUS: touch controllers vs ODP

When considering the average SUS scores for the touch controllers (75.27; STDEV: 14.64) compared to that of the ODP (64.46; STDEV: 20.08), the touch controllers were superior and the most usable method of navigating VCS. The gap between the levels of usability of the two navigation techniques, according to the SUS, could be due to the touch controllers being an older and more acceptable model of interacting with a VCS. The ODP is newer and less known and might need more training to get used to it being effective.

5.5. Satisfaction ratings

The satisfaction ratings consisted of three statements with a seven-point Likert scale to which the participants had to indicate their level of agreement. The satisfaction ratings for all the questions related to the touch controllers were more than adequate (six or higher). The average score for all three questions was also above six. This indicated that the touch controllers were more than adequately satisfying. The satisfaction ratings for the ODP's first question were more than adequate (six or higher), while the last two questions were rated between five and six (which is considered an adequate satisfaction rating).

5.5.1. Satisfaction ratings: touch controllers vs ODP

The comparison between the average satisfaction of the touch controllers (AVG=6.38; STDEV=1.29) and ODP (AVG=6.00; STDEV=1.37) indicated that the ODP fell a little short of the touch controllers. The three statements with the values are listed below. I found the method of navigation visually appealing.

- Touch controllers (AVG=6.39; STDEV=1.20).
- ODP (AVG=6.28; STDEV=1.00).

I enjoyed using the method of navigation.

- Touch controllers (AVG=6.41; STDEV=1.34).
- ODP (AVG=5.87; STDEV=1.61).

The method of navigation was fast and responsive.

- Touch controllers (AVG=6.33; STDEV=1.33).
- ODP (AVG=5.85; STDEV=1.37).

However, both navigation techniques provided a more than adequately satisfying experience.

5.6. Evaluation of the navigation elements

Two statements (accompanied by a seven-point Likert scale) were presented to the participants relating to the ease of use of the navigation techniques to complement those of the Expectation Measure.

5.6.1. Evaluation of the navigation elements: touch controllers vs ODP

When comparing the overall averages for the touch controllers and the ODP, there was a difference between their ease of use. The ODP (AVG=5.23) was adequately easy to use (greater than or equal to five, but lower than six), while the touch controllers (AVG=6.09) were more than adequately easy to use (six or higher). The touch controllers' navigation elements for both statements were more than adequately (six or higher) scored. This indicated that the participants found the touch controllers very easy to use and very easy to maneuver. For both statements regarding the ODP, the overall ease of use and ease of maneuverability were adequate. This indicated that the participants found the ODP easy to use and easy to maneuver. The two statements are listed below. I found the selected method of navigation easy to use for walking in the VE.

- Touch controllers (AVG=6.09; STDEV=1.31).
- ODP (AVG=5.13; STDEV=1.78).

I found it easy to maneuver using the selected navigation technique.

- Touch controllers (AVG=6.09; STDEV=1.30).
- ODP (AVG=5.33; STDEV=1.66).

Even though the ODP was adequately easy to use, the participants found it to be a more difficult navigation technique and harder to get used to.

5.7. Net promotor score (NPS)

As mentioned, NPS was used to determine the likelihood of a participant recommending the respective navigation technique. A ten-point Likert scale was used for this purpose. The touch controllers' NPS indicated a total of 38 promoters (a score of nine to ten on the Likert scale), 4 detractors (a score of zero to six), and 4 passive participants (a score of seven to eight). The calculated NPS for the touch controllers of 73.91% turned out to be an excellent score, falling between 50 and 75. This indicated that the participants were more than willing to recommend the touch controllers as navigation techniques.

The NPS results for the ODP presented a total of 29 promoters (nine to ten), 10 detractors (zero to six), and 7 passive participants (seven to eight). The calculated NPS was not very high, with a 41.30% likelihood that the ODP would be recommended. However, it is still considered to be a good NPS, as it is between the zero to 50 range [32].

The NPS values for the touch controllers (73.91%) and ODP (41.30%) were very far apart, which indicated that the participants were much more likely to recommend the touch controllers than the ODP. The reasons for these results could be due to the issues that were experienced by most of the participants. Examples include issues in controlling the avatar, the increased learning curve of using the ODP, and the unnatural feeling of walking on the ODP. However, when considering the analyzed data results, it could be attributed to the ODP being more difficult to use than the touch controllers.

5.8. Virtual reality sickness questionnaire (VRSQ)

The VRSQ used two categories of symptoms to determine the level of CS while navigating the VE with the two respective navigation techniques. The resultant value for the touch controllers was 17.37 (with a STDEV of 22.71), while the VRSQ for the ODP was 15.36 (with a STDEV of 20.25). The data was not normally distributed and required applying a signed rank test to compare the VRSQ values, using the differences between the values of the participants.

The results indicated that the ODP was somewhat superior to the touch controllers in reducing CS. However, when conducting a signed rank test, the p-value of 0.5739 showed that the difference was not statistically significant. Some participants, however, found that the ODP reduced their CS levels quite a bit, while others indicated that the ODP increased these levels.

While the VRSQ did not show a significant difference in CS between the touch controllers and the ODP, it did indicate that the ODP had much more potential as an immersive VCS navigation technique, especially when compared to the overall usability and UX metrics in the previous sections. Even though the CS scores for the ODP were not significantly lower, it could indicate that should the lack of adequate usability be addressed, the ODP could reduce CS even more.

5.9. Combined usability and UX metrics

To determine an overall usability score based on the metrics discussed so far in this chapter, the values for each metric (that were not yet in this format) were converted to a percentage value, as described below:

- Task success: Number of participants who successfully completed the tasks (I) divided by the total number of participants (N), then multiplied by 100: $(I \div N) \times 100$,

- Expected Ease of Use: Average expected ease of use (X), divided by the maximum number on the Likert scale (7), and multiplied by 100: $(X \div 7) \times 100$
- Actual Ease of Use: Average actual ease of use (Y), divided by the maximum number on the Likert scale (7), and multiplied by 100: $(Y \div 7) \times 100$
- ASQ Combined: Average combined ASQ scores (T), divided by the maximum number on the Likert scale (7), and multiplied by 100: $(T \div 7) \times 100$
- SUS: The SUS values were used as is, as it was already out of 100.
- Satisfaction rating: Average satisfaction rating (Q), divided by the maximum number on the Likert scale (7), and multiplied by 100: $(Q \div 7) \times 100$
- Navigation Elements: Average navigation elements rating (V), divided by the maximum number on the Likert scale (7), and multiplied by 100: $(V \div 7) \times 100$
- NPS: The net promoter scores were used as is, as it was already out of 100.
- VRSQ: The VRSQ average (S) was subtracted from 100 to obtain the positive value, seeing that the values were percentage of CS symptoms experienced: $100 - S$
- Time on Task: For time on task, the best value (A) and worst value (B) were taken as benchmarks [39].

The percentages for the time on task were calculated by dividing the difference (C) between the worst value (B) and the observed time (D) by the distance (E) between the longest (B) and shortest times (A). The time on task percentage values (F) were then averaged across the participants who completed all tasks over both methods successfully (I). As seen in the steps below.

- Step 1: $B–A = E$
- Step 2: $B–D = C$
- Step 3: $(C \div E) \times 100 = F$
- Step 4: $(\sum I) \div X$

To substantiate the separate data, an overall usability score was calculated for each navigation technique by combining and averaging all the individual metrics for each. The usability score for the touch controllers was 82.42%, while the score for the ODP was 72.24%. The aforementioned combined usability and UX score consisted of the task success (touch controllers = 97.83% vs ODP = 97.83%), expected ease of use (touch controllers = 64.86% vs ODP = 58.57%), actual ease of use (touch controllers = 88.00% vs ODP = 79.57%), ASQ combined (touch controllers = 93.95% vs ODP = 87.76%), SUS (touch controllers = 75.27% vs ODP = 64.46%), satisfaction rating (touch controllers = 91.14% vs ODP = 85.71%), navigational elements (touch controllers = 87.00% vs ODP = 74.71%), VRSQ (touch controllers = 82.63% vs ODP = 84.64%), and time on task (touch controllers = 69.63% vs ODP = 47.80%).

Fig. 6 showcases a radar chart with an overall comparison of the usability and UX metrics previously discussed. Except in the case of task success and the VRSQ score, the touch controllers were seen as the superior navigation technique, also being more usable and user-friendly.

The VRSQ rating indicated that the ODP did provide an immersive experience with a little less CS than the touch controllers, since the VRSQ score was slightly better for the ODP. However, the difference was not statistically significant ($p= 0.57$). It is necessary to note that the VRSQ scores were inverted by subtracting the actual score from 100, meaning that a higher score in this case indicated a better score. Regarding task success, the touch controllers and ODP were on par with each other. However, for the rest of the scores, the touch controllers were superior.

More insight is, however, needed to determine the reasons for the lower usability and UX metrics for the ODP compared to the touch controller.

6. Conclusion

After measuring the usability and UX of the ODP and the touch controllers, and when considering practical insights, application, and lessons learned [44], as well as the radar chart presented in Figure. 6,

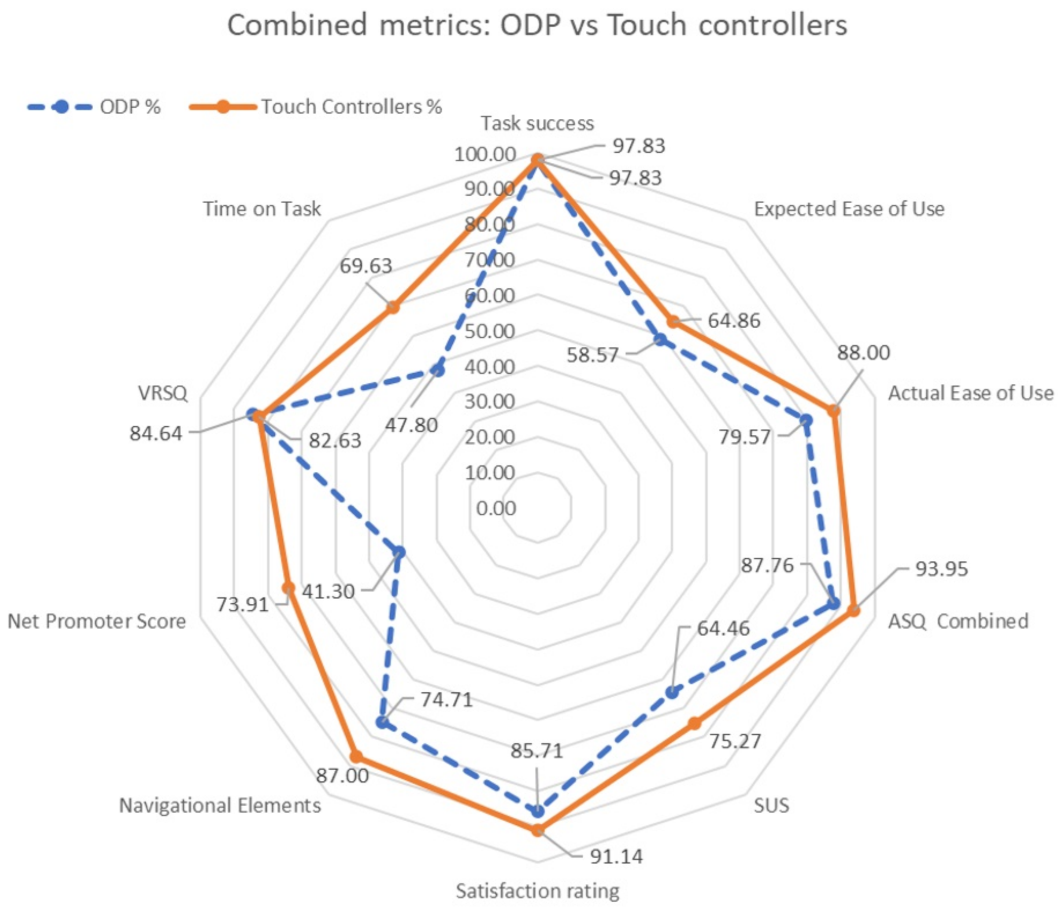

Figure 6: Combined usability and UX metrics: touch controllers vs ODP

it became apparent that the touch controllers were evaluated as being the superior navigation technique to the ODP. Although the difference between the VRSQ scores (touch controllers = 82.63 vs ODT = 84.64) were not statistically significant, the ODT showed that it has the potential to become a valid model of interacting in VCS. It did have a lower CS score, even though it was not evaluated as being as usable as the touch controllers.

A larger and more inclusive sample size might provide additional insights (although the number of students sampled was more than the statistically calculated minimum of 42). The study only focused on nursing students, of which most had little to no gaming experience with either consoles or PC gaming. A possible consideration for future research could be to determine the effects of CS on avid gamers vs non-gamers. Other medical-related professions (other than Nursing) could also be included in future testing.

The fact that the ODP did not appear to be as usable as the touch controllers, but still provided a lower CS score, could be investigated in future research, as well as how the ODP can be improved as a model of interaction for immersive VCS.

Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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7. Online Resources

The data related to this study can be downloaded at:

- UFS Online Repository