UNIVERSITY OF CAPE TOWN

DEPARTMENT OF COMPUTER SCIENCE

CS/IT Honours
Final Paper 2021

Title:

Author:

Project Abbreviation:

Supervisor(s):

Category	*Min*	*Max*	Chosen
Requirement Analysis and Design	*0*	*5*	
Theoretical Analysis	*0*	*0*	
Experiment Design and Execution	*0*	*20*	
System Development and Implementation	*0*	*10*	
Results, Findings and Conclusions	*10*	*15*	
Aim Formulation and Background Work	*10*	*10*	
Quality of Paper Writing and Presentation	*10*		10
Quality of Deliverables	*10*		10
Overall General Project Evaluation (*this section allowed only with motivation letter from supervisor*)	*0*	*0*	
Total marks		**80**	

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Theoretical Analysis	*0*	*25*	
Experiment Design and Execution	*0*	*20*	
System Development and Implementation	*0*	*20*	
Results, Findings and Conclusions	*10*	*20*	
Aim Formulation and Background Work	*10*	*15*	
Quality of Paper Writing and Presentation	*10*		10
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Total marks		**80**	

Comparative Simulator Sickness Investigation of Locomotion Methods in Virtual Reality

Ryan Acton
University of Cape Town
Cape Town, South Africa
ACTRYA001@myuct.ac.za

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1. Abstract

Simulator Sickness is a motion sickness-like effect that negatively effects Virtual Reality users. It manifests as dizziness, nausea and other debilitating effects, that hamper user enjoyment and further research. The aim of this investigation was to combat this effect, using haptic feedback from a novel designed locomotion method. The degree to which participants were affected by Simulator Sickness, using three locomotion methods (the designed method, teleportation and arm swinging) was calculated and compared, using the standardised Simulator Sickness Questionaire, to determine if the designed method sufficiently mitigated the effects. Participants were evaluated using the Game Enjoyment Questionnaire (GEQ) to determine their level of immersion with the experience and they were assigned their own accuracy scores, that would be compared. It was found that the Cradle system induced less but not significantly less Simulator Sickness in the participants as the standardised methods, with more investigation being necessary to determine the degree to which haptic measures combat Simulator Sickness.

2. Introduction

Virtual Reality (VR) is technology that is regarded as a natural extension to 3D Computer Graphics [15], that permits a user to occupy and immerse themselves in a real or simulated environment. The area was initially seldom explored by the public and the majority of intrigue and discussion surrounding the elusive technology was driven by academic researchers and companies that sought specific purposes from it. However, massive advances in the industry have seen the technology not only branch into new research and practical areas, but also become accessible for personal use. This consumer-grade re-invention was driven initially by the introduction of the Oculus Rift, a powerful but expensive user experience. Since then, various VR devices have been released, at varying price points and barrier to entry, to cater for all levels of user interest and financial commitment.

With the lowered barrier to entry, it is no longer a niche and foreign technology and not limited to the development of wireframes or 3D modelling. This wide accessibility is additionally aided by the lowering cost and increasing power of general personal computer components, as an increase in computing power ensures a better VR experience. The technology has been employed in various practical areas, such as introducing a helpful moderatable benchmark in phobia therapy [11] and helping people with developmental disorders - such as autism spectrum disorder [5][18]. VR is useful in any area in which a simulated reality is beneficial, either for practice - such as in driving or flying simulators [4], or for introducing something that is not possible to be introduced to people in reality. It is not only a incredible hardware accomplishment, but the ability to challenge what human beings understand as reality and a massive leap forward in philosophy and human psychology.

However such a phenomenon is significantly hindered by Simulator Sickness (SS), an effect, akin to motion sickness, that manifests as: nausea, dizziness and other shared symptoms [20]. It is classified as a subset of motion sickness, according to work done by Hyun et al. [19] and even further classified as a visually induced motion sickness in 1995, by Eugenia and Kolasinski [21]. This effect occurs is many people and because of its debilitating results, hinders users' enjoyment of VR and their participation in further research and in their own capacity. The causes of simulator are not wholly known, however there two three dominant theories: the postural instability theory and the sensory conflict theory. For the purposes of this research I will only be using the sensory conflict theory to explore the SS results, as it is the most commonly accepted theory governing the

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interpretation of motion sickness[7].

Simulator sickness by this definition, requires a difference in a user's visual and sensory system experiences. A compulsory inclusion in VR titles, associated with generating this sensory mismatch, is locomotion. Locomotion can be implemented in numerous ways and for this paper, three techniques were considered. Arm Swinging is a technique, in which a user swings their arms back and forth to move in the direction they are facing. In this respect it is static and does not require the user to move from their location to travel in VR. Teleportation is the industry standard for locomotion in VR and like Arm Swinging, it is static, not requiring the user to move from their starting position. A user will point to a location where they wish to travel to and use their hand-held VR controller to travel there. The final method is the designed method, named the Cradle. It involves a user physically walking into a plastic ring, suspended above the ground by tense elastic cables.

This experience provides the user with physical haptic feedback for their walking action, which, relying on sensory conflict theory and cross modality, is predicted to reduce Simulator Sickness in the experiment participants. Cross modality refers to the utilisation of multiple senses simultaneously, in this case: sight, provided by the HTC Vive Pro Head Mounted Display and touch, from the Cradle itself. This combination should aid in further reducing the effects of Simulator Sickness.

For the simulation, the game took place in a hilly, forested environment, designed in such a way as to induce Simulator Sickness in the participants. This was so that an effective base line can be compared to the three locomotion methods and a comparison between them would be clear.

3. Background & Related Work

3.1 Locomotion

Travel techniques in Virtual Reality are varied in their implementations and user practices. While attempts have been made to quantify them in an appropriate way, Boletsis, was able to create a typology to represent the various used methods in a readable and effective way [8]. Figure 1 shows the various subcategories of waling methods.

Notably, these factor in environment variables, such as room scale and whether a user has to physically walk in order to travel in the virtual environment. They are primarily separated into Physical and Artificial Interaction types.

3.1.1 *Physical*

This refers to locomotion in which a user must carry out significant physical action to travel in the virtual environment. This includes more literal implementations such as the Real-Walking and Moving-Where-Looking classifications, discussed by researchers from the University of North Carolina [3]. Real-Walking is further categorised in Figure 1 as room scale-based, as physically walking is mapped to the virtual environment accordingly, however Walking-In-Place, allows non-limited motion. This type of motion in which the direction is solely driven by the head position, further includes the Arm Swinging Method.

3.1.2 *Artificial*

In contrast to the physical, this does not require physical user involvement. It typically relies on some hardware, for instance a joystick or accompanying controller to perform some kind of continuous or non-continuous motion. The most common type of artificial locomotion is teleportation, as it is recognised as the industry standard for travelling in virtual reality, because of its non-limited movement and lack of effort requirement. Point-and-Teleport is commonly used [10], as handheld devices or gestures can be appropriately mapped to teleport to a specific location in the virtual environment.

3.2 Simulator Sickness

Significant research has been conducted to determine the severity of effects of Simulator Sickness in users, however the causes of this phenomenon are not concretely understood. There are thus a number of theories that explain the causes of this effect, however the two most significant, governing theories are: The Postural Instability Theory and The Sensory Conflict Theory, otherwise known as Cue-Conflict Theory.

3.2.1 *Postural Instability Theory*

The postural instability theory was introduced in 1991 and maintains that an animal will not suffer motion sickness if it maintains its postural stability, which is necessary to perform physical tasks [26]. It suggests that an animal that is not forced to maintain postural stability will not do so and will experience motion sickness. In this case, in a virtual environment, the user will not be physically carrying out any activities and will therefore feel the symptoms of motion sickness. According to the work of La Viola, postural instability is likely to occur when the body makes use of a different muscle control to move, due to the virtual environment altering the visual perception of motion [22].

3.2.2 *Sensory Conflict Theory*

Sensory Conflict Theory refers to the mismatch of experienced sensory inputs and expected inputs [24]. This is clearly illustrated in a virtual environment, employing a teleportation travel method. A user would expect a physical resistance on their legs when walking, as they are used to in real life, however in VR they simply point to a location to teleport to it. They have not experienced any of the expected sensory inputs, however they have traversed a distance in the virtual

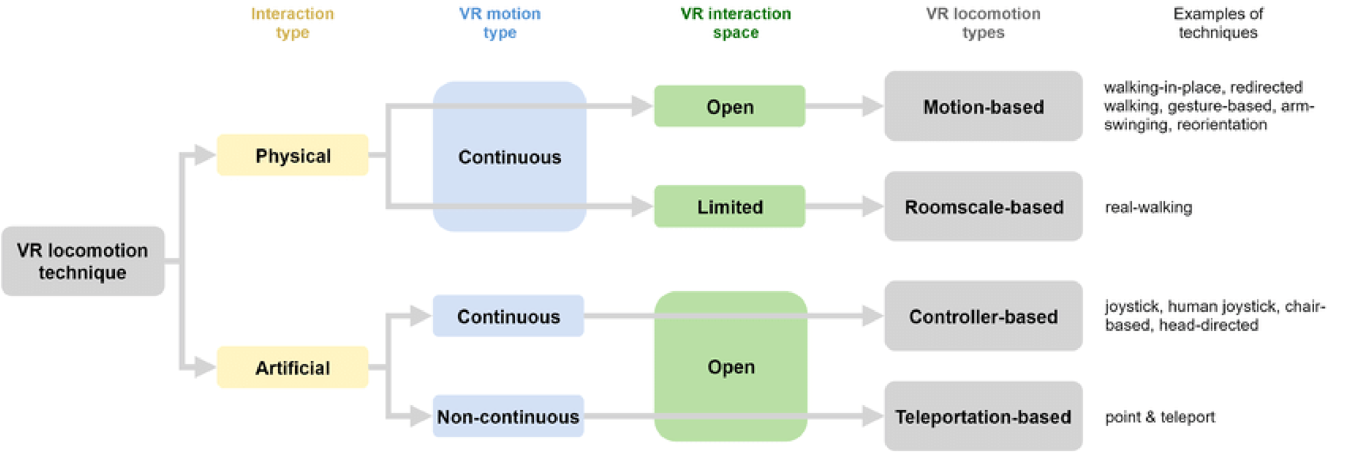


Figure 1. Boletsis Typology

space.

It is impossible to quantify the causes of Simulator Sickness at this time, however numerous experiments have been conducted, using separate metrics based off of the dominating theories. Vection refers to a sensation of illusory self-motion, which is induced by viewing optical flow patterns. It is said to enhance the user's presence within the virtual environment [9] and if a changing vection is sensed, Hettinger et al. found that the it increases the effects of Simulator Sickness [13], which supports the Sensory Conflict Theory.

Additionally, it was found that the frame rate that the virtual environment was running at and the Field of View that the user experiences, affect the Simulator Sickness felt. A changing frame rate, results in more jitter, an unrealistic effect, that created more Simulator Sickness in research conducted by Jerald in 2015 [16]. A wider Field of View (FOV) introduced more stimuli in users' peripheral vision. This meant that the users were more sensitive to vection, resulting in increased levels of Simulator Sickness [23].

3.3 Diagnosing Simulator Sickness

Quantifying Simulator Sickness is a difficult process, because of the various experienced symptoms and the postulated causes. While many causes have been illustrated, the list is non-exhaustive and it is likely that more will be discovered. Thus the practice of quantifying is done by a self-assessment of the symptoms.

This is done with the Simulator Sickness Questionnaire (SSQ), which was divised by Kennedy et al. [6] and compartmentalises the users feelings in various physiological areas.

Alternatively, as of 2005, with work done by Kim [20] building on the work of Harm in 2002 [12]: heart rate, skin conductance and other physiological attributes can be tracked to understand the effects of Simulator Sickness.

3.4 Haptic Feedback

Haptics are a form of physical feedback, typically provided by some device or apparatus, designed to simulate a familiar physical feeling. While not a significant amount of research has been done regarding Simulator Sickness mitigation, haptic measures have been shown to increase user presence in the environment [27]. This is reinforced by research done on HapticSnakes, a collaborative university research project [1] that was able to effectively emulate: gripping, tapping and brushing. Additionally, force-feedback haptic methods have been investigated, such as a controller that simulates grasping objects [29] to further increase levels of user presence. Noting this current research, a strong relationship between user presence and Simulator Sickness is identifiable [17][2] and this provides reasonable grounds to investigate the relationship by testing a haptic device in comparison to other industry standard locomotion techniques.

4. Design & Implementation

This investigation was carried out by two people, with varying areas of focus. The environment and game was jointly designed and implemented. This paper focused primarily on the design and implementation of the cradle method and the project partner focused on the design and implementation of the arm swinging and teleportation methods.

4.1 Environment Design

The chosen environment was designed to induce a small amount of Simulator Sickness in the experiment participants. This was important, because it is impossible to test if a method improves Simulator Sickness that the participants experience, if they are not found to experience any. The environment was designed using the Unity Game Engine, a powerful, industry standard platform that allows for fast

Figure 2. RHE Forest Environment

Figure 3. All placed targets with renderers enabled

Figure 4. Arrow pointing at Nearest Target

rendering and development speeds. Any scripting was done using C# and Unity's scripting tools.

With the need to induce Simulator Sickness, a forested environment was chosen - using and altering demo assets from the Forest Environment-Dynamic Nature Unity Asset Pack. For this reason hilly terrain was selected, to provide participants with vection in the y plane, as well as the x and z planes. This is in accordance with Sensory Conflict Theory, as the up and down sensation from traversing the hills will only be experienced in the game and the participant in real-life will not need to change their elevation. Additionally, considering the participants would be firing arrows into the trees, the environment has been named: the Robin Hood Environment (RHE). It was made, in order to provide enough landscape, to occupy the participants for 10 minute experiment duration, and an unrealistically large number of targets were placed in the scene to satisfy this same condition. The RHE was densely populated with trees, bushes and grass, to induce more Simulator Sickness in participants, because of the increased likelihood of vection. In accordance with the discussed FOV indicator of Simulator Sickness, the environment has been designed to showcase a lot of scenery in a wide FOV. This peripheral involvement with further aid in inducing Simulator Sickness.

4.2 Game Design

The game aspect of this project was necessary, because it motivated participants to travel around the environment in order to find and shoot at the targets, as they were spread out amongst the dense foliage. Participants, therefore, had to learn the various methods to play the game. The game involved shooting as many spawned targets as possible, within the allotted 10 minute time frame. Participants were rated on their accuracy and how many targets they were able to shoot. The 10 minute limit was borne out of both concern about inducing too much Simulator Sickness in the participants and practicality, as three methods were being tested and with the added data capture it was necessary to keep the total experiment time under 1 hour.

The targets were always present in the environment, however their renderers were disabled. When a participant shot the starting target and onwards, the game would locate a target within a specific range, from the participant's position and activate its renderer. The range had a minimum distance limit, as there was initially concern that the targets would have always spawned physically close to the participant and this would lead to skewed results, as the participant would not have to move from their starting position. An additional mitigation strategy, was the introduction of a nearest target pointer in the form of a floating arrow. This arrow, sat in the participant's vision and pointed to the next target, to ensure that the participant kept moving and was able to progress in the game. The environment was vast and this helped the participant to find targets in the dense foliage.

4.3 Teleportation & Arm Swinging

Teleportation and Arm Swinging are pre-existing locomotion methods that were appropriate to compare in this investigation.

They both exist and are used in industry, with teleportation seeing use in most modern game titles, like Half-Life Alyx. Teleportation is borne out of convenience, as it allows for limitless travel and the controls are fairly intuitive. Arm swinging offers an alternative, that although more physically involved also enables limitless motion, as a user is not required to move from their starting position to travel.

4.4 Cradle Development

The Cradle would need to be an effective mode of locomotion within the environment and be intuitive to use and learn. It would also need to provide physical force feedback to the participant, to align with the haptic device proposition for alleviating Simulator Sickness.

4.4.1 *Design Process*

When initially proposed, the Cradle was to be an elastic resistance band, supported by no less than 11 vertical support structs, that were attached by springs to a metal base. However, upon further investigation, it was found that the cost of this would exceed the research budget and it would need to be re-designed. The new design featured: a reinforced plastic ring, 1.2 meters in diameter, that was suspended in the middle of the experiment area by 6 taught elastic bungee cords.

The participant would then be able to walk into the plastic, as it is not uncomfortable, and the resistance offered by the 6 bungee cords, would act as the haptic trigger for the user. Figure 6 shows the final product, with the HTC Vive Tracker attached. This would be used to interface with the software to allow for movement within the virtual environment. The initial design would move the user in the direction their head was pointing - in particular the direction of the HTC Vive Pro HMD. While this was convenient for testing, the action did not map as naturally to real-life walking as the final solution did and was overwritten for this reason.

4.4.2 *Device Implementation*

The user would stand in the center of the cradle and move into the plastic ring, displacing the HTC Vive Tracker in the process. The software would have originially established the location of the tracker as its origin, before being displaced. This tracker has its own xyz-coordinate system and when it detected displacement in the xz plane, the software would register this as the user moving in the direction of the displacement. The y axis was not necessary for displacement for this investigation.

The device would register the origin as (0,0,0), using a three dimensional system. The research disregarded the middle value, however it utilised the value and sign of the x and z coordinates, with positive x meaning a shift to the right, negative x, to the left, positive z in front of the tracker and negative z behind the tracker. This was multiplied by a factor to create an exponential effect, that meant that the user could achieve variable speed based on how hard they forced the tracker and thus the cradle in one way or another.

There was initial concern about this movement being jarring, so an adaptation was made to alter the user speed by the extent to which they displaced the hoop and thus the tracker. This provided a useful learning factor and comfort control system for the participants during the experiment. The result of this implementation was a haptic device, which

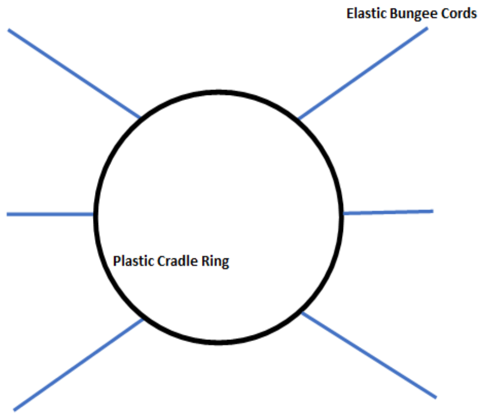


Figure 5. Cradle Design

Figure 6. Cradle Device

Figure 7. User using Cradle Device

enabled user-movement in a sensible walking action translation between the real and virtual worlds. Figure 7 shows the use of the Cradle, which allows for free use of the HTC Vive controllers, to fire arrows at targets in the RHE.

5. Experiment Design

5.1 Research Objectives

The aim of this investigation is to quantify and fairly compare the effects of Simulator Sickness experienced, using three different types of locomotion techniques in virtual reality. Additionally, this experiment aims to investigate the effect that the techniques have on user performance within the designed game.

With this in mind the three research objectives to be investigated are:

1. Will the Cradle solution, a novel walking method, result in lower levels of Simulator Sickness in participants than the industry-tested: arm-swinging and teleportation techniques?
2. Will the Cradle solution, a novel walking method, result in higher scores on the Game Experience Questionnaire (GEQ) than the industry-tested: arm-swinging and teleportation techniques?
3. Will the Cradle solution, a novel walking method, result in greater performance scores after executing tasks in the RHE in comparison to arm swinging and teleportation methods?

5.2 Participant Categorisation

Simulator Sickness can vary hugely in experiment participants so it is important to minimise variables that might impede the investigation by skewing the data. Age has historically been found to significantly vary Simulator Sickness [25] [14] and for this reason an age-group of 18-30 years old was used for the experiment. Additionally, the assumption was made that introducing technology to people that may be less familiar with it would impact the time taken to understand the motion techniques, which would have also affected the data.

Neurotypicality also impacts the degree of Simulator Sickness effects that users' experience. Participants were screened for: autism spectrum disorder, other learning disabilities and atypical neurological patterns. There is some research to suggest that people that suffer from autism spectrum disorder are effected in the same way as people that do not, when it comes to Simulator Sickness [28], however this is not significant evidence to discount the original theories. Additionally, participants were screened for epilepsy, as partaking in the experiment could have proved a risk to their health.

The Covid-19 pandemic meant that is was important to ensure both the safety of the participants and the safety of the testers. Thus participants were additionally screened for any co-morbidities that would make them more susceptible to contracting the virus. It was vital that the participants were made aware of the full experiment procedure and the risks involved. For this reason, they must have been be fluent in English.

5.3 Apparatus

For all the tests, the participants used the HTC Vive Pro Head Mounted Display (HMD) and accompanying controllers. Even if these controllers were not necessary for movement, they were necessary for the actions of drawing and firing the bow.

These components were connected to the desktop PC, powered by an i7 processor and GPU, capable of the necessary rendering speeds. Additionally, the Cradle itself was required as a piece of apparatus, to investigate it as a walking method.

5.4 Measurements

The SSQ was used as the primary quantifier for Simulator Sickness and was used initially, before the participants performed the test, as a baseline and after each successive walking method.

Additionally, the participants had to complete a shortened GEQ, after each walking method to quantify how the method in question affected their experience of the game. Finally, the participants were evaluated with a hit ratio calculation that was done, post experiment, after the number of succesful hits and misses was tracked by the program, using a C/ script.

5.5 Experiment Procedure

Human trials were run to answer the Research Questions, with participants who pass the screening process. Each experiment was conducted, following a set 4-phase protocol.

Phase 1 involved the preparation of the hardware between participants. This included ensuring all components were correctly connected and sanitising the apparatus that would be used by the next participant.

Phase 2 involved providing the participant with all the relevant information about the experiment process and the risks involved. The participant must have been informed that they could withdraw from the experiment at any time and that there anonymity would be respected in the experiment findings. They must have confirmed that they completed the UCT Health Check to confirm their lack of Covid-19 symptoms. Finally, once all the information had been provided, the participant must sign a form indicating that they give their informed consent to participate in the research.

Phase 3 referred to the experiment execution as illustrated below:

1. The participant carried out a baseline Simulator Sickness Questionnaire (SSQ). The order of the three experiments A, B and C was then randomised.
2. The participant then began the first of the randomised experiments, all of which incorporated a brief tutorial to introduce the mode of locomotion for the experiment.
3. Once the participant has completed the first test, they filled out another shortened SSQ and Game Enjoyment Questionnaire (GEQ). The game retained certain data to assess the participant's performance, in particular with respect to the distance travelled and their accuracy.
4. The participant repeated the process for the other two methods, filling out the SSQ and GEQ for both.

Finally Phase 4 involved prompting the participant to provide any feedback they might have, thanking them for participating and paying them a sum of R50 for their assistance.

6. Results & Discussion

Once the data had been collected, it was grouped into appropriate tables and then various tests were carried out. For all the tests concerned, an

$$\alpha = 0.05 \tag{1}$$

was used. Initially, a Shapiro-Wilk test was carried out to determine the normality of the data. When conducted on the full SSQ data set this test returned a probability (p) value of 9.82e-08, which is significantly lower than the selected alpha. This illustrates that the data does not have a normal distribution and thus is not normal. This is likely due to the lower sample size of participants (n=22) and the fact that within this low data set there are outliers.

For each of the testing categories the following tests were carried out: The Friedman test for non-parametric data to evaluate all the given data sets at once, the Wilcoxon test with Bonferetti adjustment, to determine similarities in the data medians, between pairs of data sets and make the data easier to read and finally, the Pearson Correlation Test, to determine the extent that two walking methods relate to each other in the investigated area.

6.1 Simulator Sickness

In the Simulator Sickness Questionnaire (SSQ), Simulator Sickness is grouped into three categories, namely: Disorientation, Nausea and Oculomotor. Each of the questions on the SSQ is grouped into one or more of these categories and the severity of the participants symptoms was assigned a numerical value to indicate its significance. The totals of which will be given a weighting to generate a Simulator Sickness quantify each of the three categories and the total amount of experienced Simulator Sickness.

In order to create a metric from measurements can be taken, the participants completed a baseline SSQ, before attempting any of the tests. For the SSQ data, considering that the data was not normal, both a Friedman Test and a Wilcox Test were performed, to understand the contrasting Simulator Sickness values between the various SSQ sections and the tested walking methods.

6.1.1 *Disorientation*

In terms of disorientation, Teleportation had the highest Mean value, followed by Arm Swinging and finally the Cradle. As for the Medians, the Arm Swinging was significantly higher than both the Cradle and the Teleportation methods, as shown in Table 1. The Friedman Test returned a p value of 1.38e-05, which is lower than the alpha value. This means that the null hypothesis can be discounted and it can be assumed that the medians of the three data sets are not the same and that the levels of Simulator Sickness differs. This is further illustrated in Figure 8, which illustrates the SSQ Disorientation component of the three walking methods.

The Wilcox Test better explored the relationship between all the possible pairings between the walking methods. Three of the pairings: the arm swinging and teleportation, the arm swinging and cradle and teleportation and cradle methods. The p values for these cases were: 0.94, 1 and 0.59 respectively. Applying a Bonferetti adjustment, rounded all of these values up to 1, indicating a strong similarity in the data set

Method:	Mean:	SDev:	Median:
Baseline	1.90	4.89	0
Arm Swing	48.72	48.55	41.76
Teleport	51.25	53.03	27.84
Cradle	47.45	54.11	27.84

Table 1. Disorientation SSQ Results

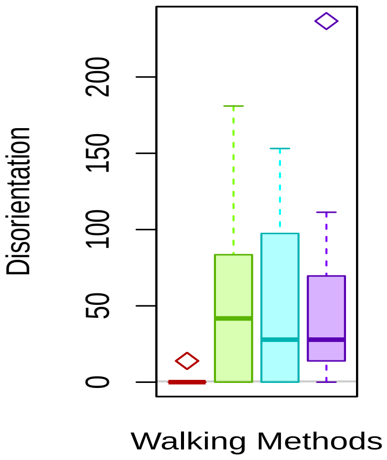


Figure 8. Disorientation

medians. This is shown in the Table 1 Medians and reinforced by the median line and clustering in Figure 8.

Finally, the Pearson Correlation Test was able to identify the relationship of the data between the pairs of walking methods. The arm swinging and cradle relationship yielded the strongest positive correlation of 0.82, whereas a strong correlation of 0.59 and 0.54, was shown by the relationships of the arm swinging and teleportation and the teleportation and cradle methods, respectively.

6.1.2 *Nausea*

For nausea, the medians for all the walking methods were the same, however there was slight change in the means, illustrating that the Cradle was causing the most Nausea-related effects. The Friedman Test returned a p value of 5.14e-06, which is also lower than the alpha value. The null hypothesis can once again be discounted, however there is greater similarity in this category than what was shown for disorientation. This is portrayed in Figure 9, which illustrates the tight groupings of the data and how similar the mean levels are.

The Wilcox test highlighted a similar result to that of disorientation, with the same three relationships being rounded up to 1, after applying the Bonferetti adjustment. Once again showing a strong similarity in the data set medians, as shown in Figure 9 and Table 2.

Method:	Mean:	SDev:	Median:
Baseline	3.90	5.63	0
Arm Swing	22.12	21.71	19.08
Teleport	23.42	24.41	19.08
Cradle	26.45	29.87	19.08

Table 2. Nausea SSQ Results

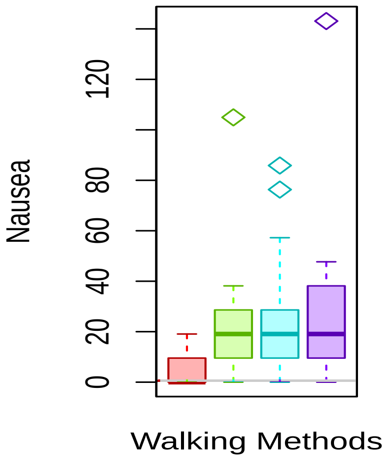


Figure 9. Nausea

The Pearson Correlation Test found two negative correlations, between the baseline and arm swinging tests and the baseline and cradle tests, with the former of the two being the strongest. Values for this were: -0.21 and -0.13. The strongest positive correlation was shown between the arm swinging and cradle methods, which had a value of 0.78.

6.1.3 *Oculomotor*

For oculomotion there was a difference in all the mean and median values. The Friedman tested yielded a p value of 7.77e-05, once again allowing for the dismissal of the null hypothesis and illustrating the difference in the medians. This relationship is shown in Figure 10 and in Table 3.

A combination of the Wilcox Test and Bonferetti adjustment returned a familiar array of partnerships that had their values rounded up to 1, showing similarity. Once again: the arm swinging and teleportation, the arm swinging and cradle and teleportation and cradle methods were shown to be strongly related. This can be seen in Figure 10.

Finally. the Pearson Correlation Test found two negative correlations, once again between the baseline and arm swinging tests and the baseline and cradle tests, with the former of the two being the strongest. Values for this were: -0.15

Method:	Mean:	SDev:	Median:
Baseline	7.24	9.50	3.79
Arm Swing	28.94	22.02	22.74
Teleport	30.66	30.36	18.95
Cradle	29.29	23.89	26.53

Table 3. Oculomotor SSQ Results

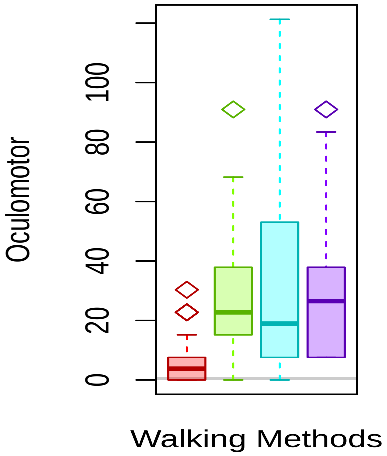


Figure 10. Oculomotor

and -0.03. The strongest positive correlation was once again shown between the arm swinging and cradle methods, which had a value of 0.88.

6.1.4 *Total Simulator Sickness*

The weighted sum was calculated and a total value for Simulator Sickness was calculated for each walking method, encompassing all the SSQ areas. Interestingly, as shown in Table 4. Teleportation had the lowest median, but it also had the highest mean. This is indicative of the data being more top-heavy, or more outliers. This is shown in the Box-And-Whisker plot (Figure 11). Arm swinging showed the highest median, but the lowest mean, possibly also due to outliers.

The Friedman test returned a p value of 8.78e-06, when comparing all the movement techniques' totals. This permits the rejection of the null hypothesis, as the medians are not equal, as is shown in Figure 7.

The Wilcox Test found three combinations that were greater than the selected alpha. These were: the arm swinging and teleportation, the arm swinging and cradle and teleportation and cradle combinations. The results of which were: 0.93, 0.42 and 0.97. All of which were rounded up to 1 after accounting for Bonferetti adjustment. The medians on Figure 11 accurately identify these close relationships.

Method:	Mean:	SDev:	Median:
Baseline	5.61	6.90	3.74
Arm Swing	36.04	29.64	29.92
Teleport	38.08	36.56	24.31
Cradle	37.57	35.21	28.05

Table 4. Total SSQ Results

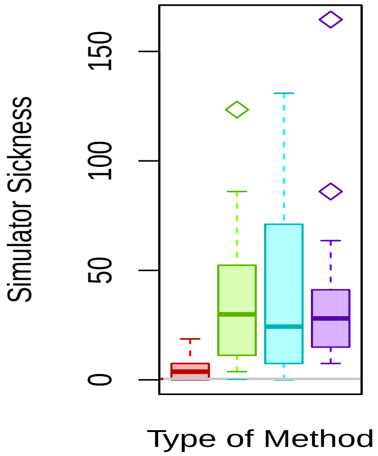


Figure 11. Total SS

When the Pearson Correlation test was applied, the strongest positive correlation, involved the arm swinging and cradle methods and the value for this was 0.84. The baseline and arm swinging and the baseline and cradle relationships exhibited negative correlations: -0.24 and -0.03, the former of which being the strongest.

The total information can be seen grouped together with the SSQ components in Table 6.

6.2 Game Performance

Considering that the game was a time trial in which participants needed to shoot as many targets as possible, an interesting metric to evaluate was hit accuracy. The various methods could be additionally differentiated by this factor. A Shapiro-Wilk test was conducted to determine data normality. Maintaining the alpha, used in the SSQ evaluation. The p value returned from this was 0.03. While closer to the set alpha, the data has proven to not have a normal distribution.

A Friedman Test returned a p of 0.0016, which is less than the alpha and thus the medians for all the methods are not equal when it comes to target accuracy. A Wilcox Test further investigated the relationship between the 2-component subsets and found that the arm swinging and teleportation methods p value was greater than the alpha (0.30), meaning that the medians in this case were similar. This was still the case after Bonferetti adjustment, with the lowest adjusted

Method:	Mean:	SDev:
Arm Swing	0.52	0.20
Teleport	0.57	0.18
Cradle	0.39	0.16

Table 5. Hit Ratio Data

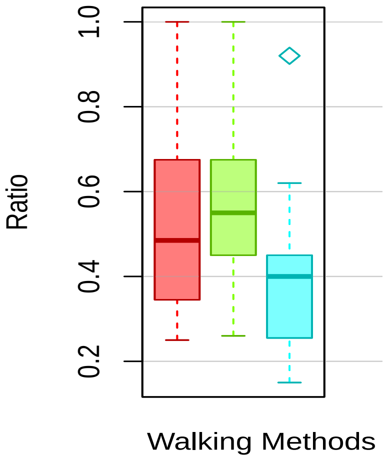


Figure 12. Hit Ratio

p value (0.0015) belonging to the relationship between the teleportation and the cradle methods.

The Pearson Correlation Test returned three positive correlations for the data set, however they were not very strong with the greatest of which being 0.66, belonging to the relationship between arm swinging and cradle.

Considering Table 5, the cradle exhibits the lowest mean value for accuracy of 0.39, with arm swinging and teleportation showing similar results. However the standard deviation for cradle is less, indicating that the values more commonly fell close to the mean. What this shows, that is reinforced in Figure 12 on the Box-And-Whisker diagram is that the Cradle exhibited the lowest percentage in firing accuracy.

6.3 Game Experience Questionnaire

As with the SSQ, the items in the GEQ are divided into one or more sections. These include: positive effect, negative effect, flow, sensory, tension and challenge.

As can be seen in Figure 13, the Cradle exhibited the highest value for GEQ positive effect (3.02). It also showed the most consistent range in this area, as it had the smallest standard deviation (0.64). However the cradle also had the highest mean for the Negative Effect category, however due to the high standard deviation, this is likely due to the small data set that has been mildly compromised by outliers.

When calculating the p values for the Positive and Negative Effects, it was found that in both cases, the alpha of 0.05 was less than the calculated values (0.27 and 0.64). Thus in both cases, the null hypothesis can not be rejected as the median values are similar.

The combination of Wilcox test and Bonferetti adjustment, resulted in a value of 1 for the relationship between the arm swinging and teleportation methods for the Positive Effect category. The Negative Effect category when undergoing this same test combination, returned values of 1 to indicate a relationship in the medians between the arm swinging and teleportation and the arm swinging and cradle methods.

The Pearson Correlation test did not find any particularly strong positive or negative correlations in the data for the Positive Effect and Negative Effect sections.

For the flow, sensory and competence values, after the Friedman test, values of: 0.91, 0.35 and 0.82 were found, respectively. This illustrates that for all the cases the null hypothesis can not be rejected and that there is median similarity.

The Wilcox test and Bonferetti adjustment found that for flow, sensory and competence cases, all the relationship combinations were adjusted to a value of 1, indicating that there was a lot of similarity in the data.

Finally, the Pearson Correlation test found no strong relationship between the data combinations for the flow set. The strongest value returned was 0.56, and belonged to the arm swinging and cradle relationship. Sensory and competence categories showed the same results as flow, once again reinforcing the similarity in the data.

7. Conclusions & Future Work

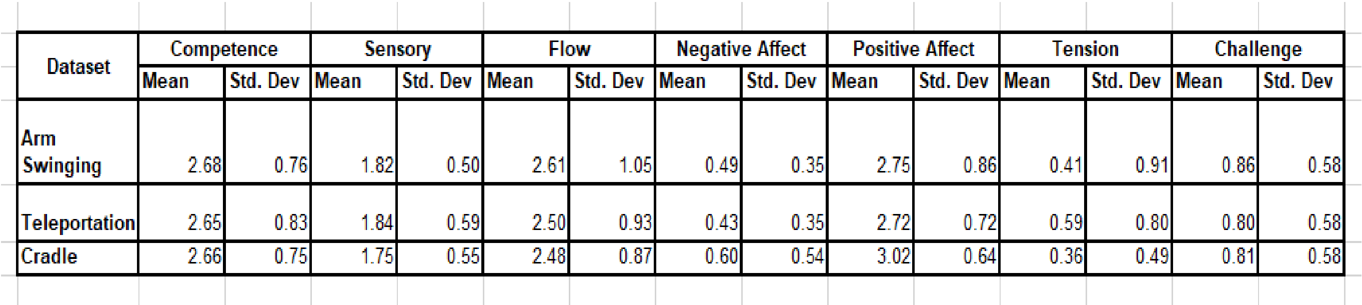
The aim of this investigation was to gain a better understanding of Simulator Sickness through the assessment of various locomotion technologies.

7.0.1 *Simulator Sickness*

The cradle solution did prove to induce less Simulator Sickness in the participants than the arm swinging and teleportation methods, however it did not significantly reduce the effects to warrant proving the hypothesis. Considering the sample size for the data, while sufficient to compare the methods, is not enough to justify that haptics mitigate Simulator Sickness. The prototype haptic device managed to compete with industry standard methods and while the effects are not wholly clear, it warrants further investigation.

Dataset	N		O		D		T	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Arm Swinging	22.12	21.72	28.94	22.02	48.72	48.55	36.04	29.64
Teleportation	23.42	24.41	30.67	30.36	51.25	53.03	38.08	36.56
Cradle	26.45	29.87	29.29	23.89	47.45	54.11	37.57	35.21

Table 6. All SSQ Results



Dataset	Competence		Sensory		Flow		Negative Affect		Positive Affect		Tension		Challenge	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Arm Swinging	2.68	0.76	1.82	0.50	2.61	1.05	0.49	0.35	2.75	0.86	0.41	0.91	0.86	0.58
Teleportation	2.65	0.83	1.84	0.59	2.50	0.93	0.43	0.35	2.72	0.72	0.59	0.80	0.80	0.58
Cradle	2.66	0.75	1.75	0.55	2.48	0.87	0.60	0.54	3.02	0.64	0.36	0.49	0.81	0.58

Figure 13. GEQ Components Data

7.0.2 *Game Experience*

The Cradle Solution did not result in high enough scores, compared to the other sections to prove the hypothesis. However, considering the positive Game Experience Feedback, a more appropriate hypothesis might have investigated whether the Cradle would result in a worse Game Experience. There was very little distinction between the GEQ scores for the items and considering the other two are implemented in industry, the Cradle can be viewed a success in this right.

7.0.3 *Performance*

The Cradle interestingly resulted in the lowest performance scores. This is possibly due to the ability to move and shoot simultaneously being used by the participants, which is not a feature in the other locomotion methods. Alternatively this could be because the Cradle method involved slower movement, and the participants were trying to move less using it to maximise the scores in the game.

While the sample size of 22 participants was not ideal, the data is enough to warrant further investigation. It suggests that haptic props do aid with Simulator Sickness reduction to some extent and this is not a cost of user enjoyment, as it was not for the Cradle Method. The design implemented was just a prototype, but potentially a more effective design that forces the cradle to be used more: such as a smaller ring, or the inclusion of more tension bearing supports in a bigger area might yield better results.

The cradle design itself was a prototype and can be improved. It was noted by many of the participants that the there was a lot of space to move around without making contact with the cradle and a smaller sized hoop might work more effectively. This might improve participant accuracy, as the they would be able to more quickly get in front of targets and would not resort to firing at them from a far distance.

While the aim of this investigation was to compare the designed method to methods in practice, it is unable to compare many methods across the Boletsis Typology. Possibly considering a Walking-In-Place technique, as an additional continuous motion, which is likely to yield different results to the teleportation and arm swinging methods.

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