ISSN 2409-2665
Journal of Logistics, Informatics and Service Science
Vol. 9 (2022) No.4, pp.1-14
DOI:10.33168/LISS.2022.0401

Wheeling Through: Locomotion Based Virtual Reality Game

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Abstract. Locomotion in Virtual Reality (VR) is a challenging system to implement due to the complications of how the human brain and vestibular system works. In an attempt to further explore traditional continuous movement locomotion within VR games while attempting keeping motion sickness levels low, leaning gestures in order to stimulate the vestibular system while moving in virtual reality were looked into. As a result, a game that utilizes a head-directed locomotion interface with hoverboard-like movement in which the head's displacement determines the player character's acceleration in-game is designed and developed. There are 3 game modes developed alongside this locomotion gameplay as a way to explore the possibilities of this control style in VR. Preliminary testing was conducted with 6 testers using Game Experience Questionnaire (GEQ) and Simulation Sickness Questionnaire (SSQ). As result, overall GEQ scores above average in the areas of competence, immersion, flow and positive affect. As for SSQ, overall scores are low. This concludes our VR game which not only allows the user to move around freely and rather immersively within a virtual environment but also with minimal motion sickness.

Keywords: virtual reality, locomotion, motion sickness, video game

1. Introduction

Virtual Reality (VR) is an interactive and immersive (with the feeling of presence) experience in a simulated (autonomous) world, and is multi-sensory in most cases (Mazuryk & Gervautz, 1999). It is a developing technology for various purposes such as education, training, telecommunication, engineering and most relevantly, entertainment. With its ever rising popularity today (Lang, 2022) along with increasingly good hardware sales (Gurwin, 2022), VR as an entertainment for the masses is beginning to rival even gaming consoles.

As it stands now however, there are a few issues that lie within VR that it still needs to overcome before it becomes truly mainstream within the video game industry: its network externalities value which is its installed base and access to complementary goods (Laurell et al., 2019). This means that to further improve its relevance, there has to be more games on the platform in order to encourage more VR headset purchases. The type of games available may also very well be a contributing factor to increasing the perceived variety of VR games. The most prevalent VR locomotion techniques can be summarized into 2 forms of movement in a virtual environment: teleportation and joystick controls. Typically, teleportation controls are the most common and joystick controls are the easiest to implement and use (Bond & Nyblom, 2019). Hence, this project aims to broaden the VR installed base by introducing an alternative way of moving in VR.

2. Literature review and Related works

Virtual reality locomotion enables the user to move in a virtual-world. It can be defined as self-propelled movements in the virtual environment while staying confined in a room-scale real-world environment (Cherni et al., 2020). To develop a game mostly around locomotion, one must also understand the challenges as most developers stray away from implementing linear locomotion in VR games, that being Motion Sickness.

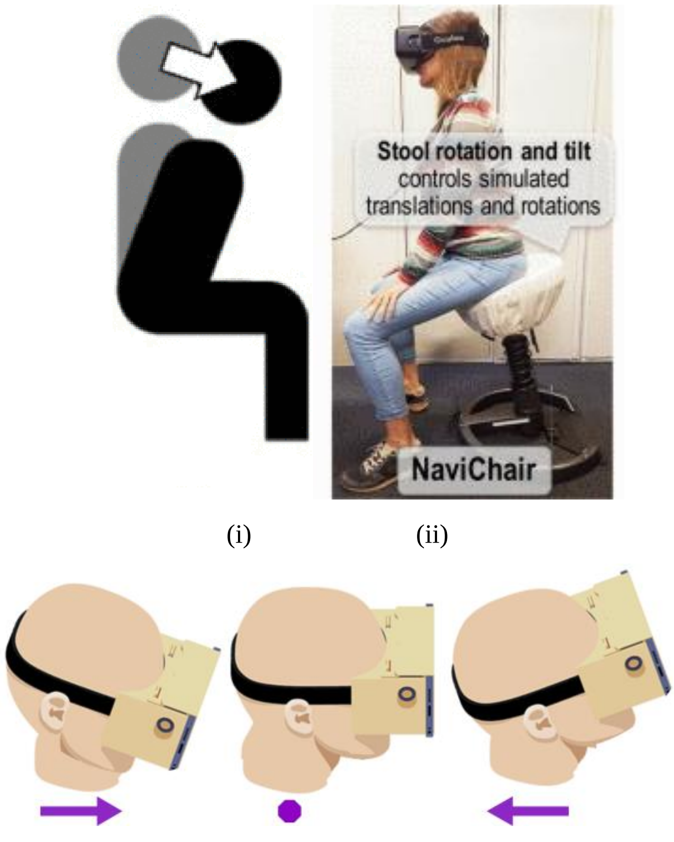
2.1. Motion sickness theory

Motion Sickness is a condition characterized by pallor, nausea, vomiting and fatigue, which is caused by exposure to real or apparent and unfamiliar motion that people have not adapted to (Cao et. al., 2018). One of the main theories that explain motion sickness is Sensory Conflict Theory. Sensory Conflict Theory explains that the key to motion sickness is the incongruence between the motion signals transmitted by the vestibular system and the non-vestibular receptors and the comparison between present and past patterns of spatial stimulation. It also states that incongruence between the vestibular system and the non-vestibular receptors alone does not cause motion sickness (Cao et. al., 2018).

2.2. Leaning locomotion interfaces

There have been several attempts of testing other methods of controls in terms of reducing motion sickness in virtual environments. One of such attempts include the use of leaning the body above the torso to move the player character in a virtual environment (Buttussi & Chittaro, 2021).

Leaning locomotion interfaces usually involve users doing gestures or cueing strategies utilizing body parts above the torso to perform locomotion in a virtual environment (Cherni et al., 2020). Methods that are considered as such can include head directed interfaces that translate input in the form of either the VR head mounted display's positional displacement (Buttussi & Chittaro, 2021) or orientation (Tregillus et al., 2017), and trunk motion interfaces that use the seat to detect the user's leaning (Kitson et al., 2017) into movement in VR. These methods aim to solve motion sickness by stimulating the vestibular systems through displacing and orienting the head in order to address Sensory Conflict Theory.



(i) (ii)

(iii)

Fig. 1: Head displacement (Buttussi & Chittaro, 2021) (i), Trunk motion (Kitson et al., 2017) (ii) and Head tilt (Tregillus et al., 2017) (iii) leaning locomotion interfaces

However, in terms of reducing motion sickness, most of these studies have concluded that leaning interfaces do not perform significantly better than joystick controls do. Even the most optimistic studies detailing leaning interfaces only increase user precision (Buttussi & Chittaro, 2021) or speed of performing task (Tregillus et al., 2017). One of the researchers suggests that even though the head was displaced, the head remained still for the rest of the period the user moves in the same direction (Buttussi & Chittaro, 2021).

With that in mind, improvements on this method could potentially be made in the way speed is calculated such that the perceived motion matches the leaning motion more. Previous studies that utilized leaning locomotion implemented movement speed in a way that velocity change is almost immediate, with the input directly affecting velocity values (Buttussi & Chittaro, 2021) rather than acceleration values. Hence, we could approach the utilization of leaning interfaces in a different manner via simulating balancing one's body in response to acceleration. Such motion is similar to that of performing actions such as skateboarding or ice skating in which leaning affects gradual velocity change in the form of acceleration.

3. Game and Locomotion system design

The game's main focus will be centered around its locomotion system and will be built for the Oculus Quest 2 for its 6-DOF properties. There will be multiple types of game modes the player can choose from. Within each of them, players will be given objectives that require them to utilize movement in order to complete tasks and earn a high score. Depending on the game mode, they will also be given tools in order to complete the game mode's specific objectives.

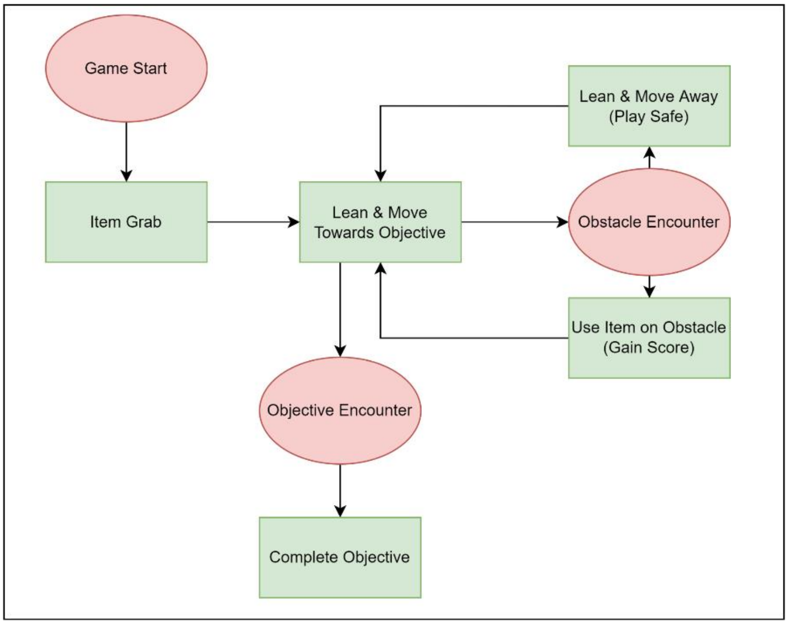


Fig. 2: Core Game Loop

Fig 2 shows the core game loop of the game. On starting the game, the player will grab the given item in preparation to commence the game mode they are in. During the game mode, players will utilize their movement to complete the objective while also making decisions around it based on their competence with the system. For example, while the player is making their way to an objective, an obstacle might appear and the player has to decide whether to take a risk confront it directly while moving towards the obstacle directly, earning more points in the process, or to avoid the obstacle and steer away from it entirely to be safe, conserving points they might potentially lose in the encounter.

3.1. Leaning locomotion interfaces

The leaning interface to be used will be the head directed movement interface. After calibration to determine a center point, the headset's position will be tracked relative to the center point set in order to determine movement. Such movement is independent of the player's looking direction, hence the player will be able to move around in the direction they lean towards while being able to look in a completely different direction.

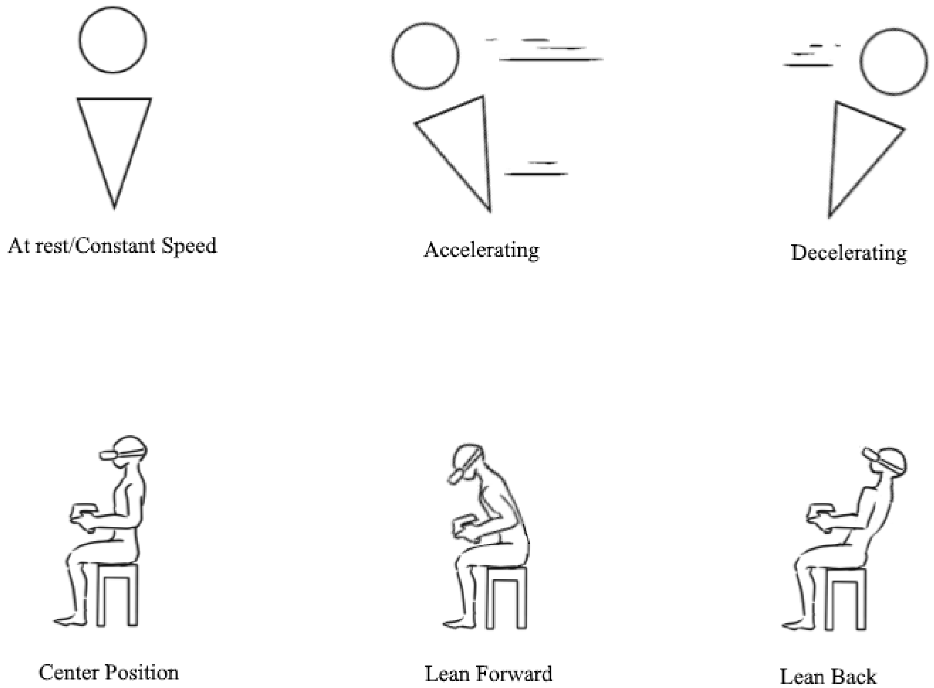


Fig. 3: Illustration of locomotion system

Movement properties within the game will be similar to that of controlling a hoverboard. Lean towards a direction to accelerate and staying in a neutral position keeps the speed. Lean in the opposite direction against where the player's speed is to decelerate and leaning left or right will redirect the player to the respective direction, Fig 3.

3.2. Game design constraint

In order to further minimize motion sickness, verticality within levels and vertical movement should be restricted. In other words, levels with flat terrain only should be the most ideal way of reducing motion sickness. Levels should also be designed with more leaning forwards and turning in mind. Strafing and backpedaling within the game's systems should be minimized (Oculus, 2017). Outside forces such as knockback that pushes the player a certain way will be completely omitted as well and whenever the player needs to be moved, the player's view will fade to black before teleporting them to the appropriate location. Play sessions should also be kept relatively short to allow players to be able to breathe in case of low tolerance to motion sickness.

4. Implementation

4.1. Submitting

Most of the functions necessary to achieve this locomotion system through the help of Unity's XR Interaction Toolkit package. It already comes with pre-made scripts and setups of XR rigs that support head mounted display (HMD) tracking, hand positioning and even some of the movement code. However the movement scripts need to be rewritten.

```
Input = ReadHMDPositionInput()

Input.Z = 0

If InputLength > InputDeadzone
  CurrentAcceleration = Input * PlayerAcceleration

if CurrentVelocityLength < MaxPlayerSpeed
  CurrentVelocity += CurrentAcceleration

else
  CurrentVelocity +=            DotProduct(CurrentVelocityUnitVector,
CurrentAccelerationUnitVector) * CurrentAcceleration

CurrentVelocity -= CurrentVelocityUnitVector * GroundFriction

PlayerPosition += CurrentVelocity
```

Fig. 4: Pseudocode for Locomotion System

The locomotion system (Fig 4) runs for every frame of the game. Since this is an acceleration based movement system instead of a flat speed change, the head's horizontal position will be taken as input to calculate its acceleration which will be added onto the player's velocity. There is also a configurable input deadzone variable to make sure that the player's head position does not cause unwanted movement out of even the slightest tilt. A max speed is introduced as well to ensure that the player does not go too fast to prevent the player character going out of control. To make deceleration easier, ground friction is also applied to the player character.

4.2. Game modes

There is a supplementary hub world (Fig 5) for the player to test the game's mechanics in a safe environment. Depending on the game mode, the player will be given a tool to help them out in completing the objective. The player can defeat obstacles or complete a particular task to earn scores within a game mode and when an objective is finished early, time scores will be further rewarded to the player.

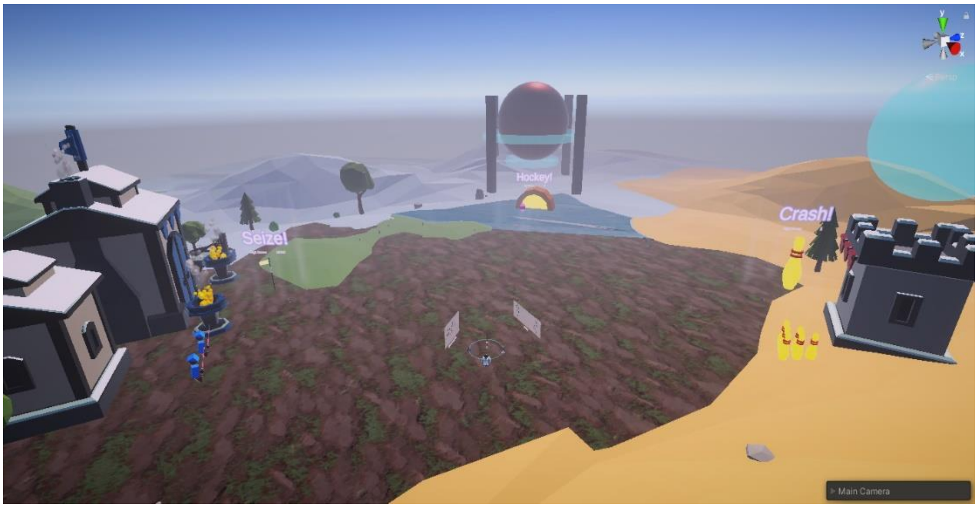


Fig. 5: Screenshot of hub world

For the “Seize!” game mode (Fig 6), the player wields a weapon and the objective of the game mode is to to seize the enemy’s tower. As the player’s obstruction, there will be multiple soldiers and projectiles aiming to damage and stop the player from reaching their objective. The player will need to charge towards an opposing army to defeat enemies and deflect projectiles coming their way. More scores will be earned if the player defeats more enemies and reaches the flag as fast as possible. Any damage taken will deduct the player's score.

In the “Hockey!” game mode (Fig 7), the player will challenge an enemy AI in a hockey match. The player will have to direct a puck using two hockey sticks to the enemy goal and prevent the enemy from doing the same to the player's own goal. The first to achieve 3 goals will win the game, and the player can earn more points by winning the game as quickly as possible without letting the opponent score their goal.

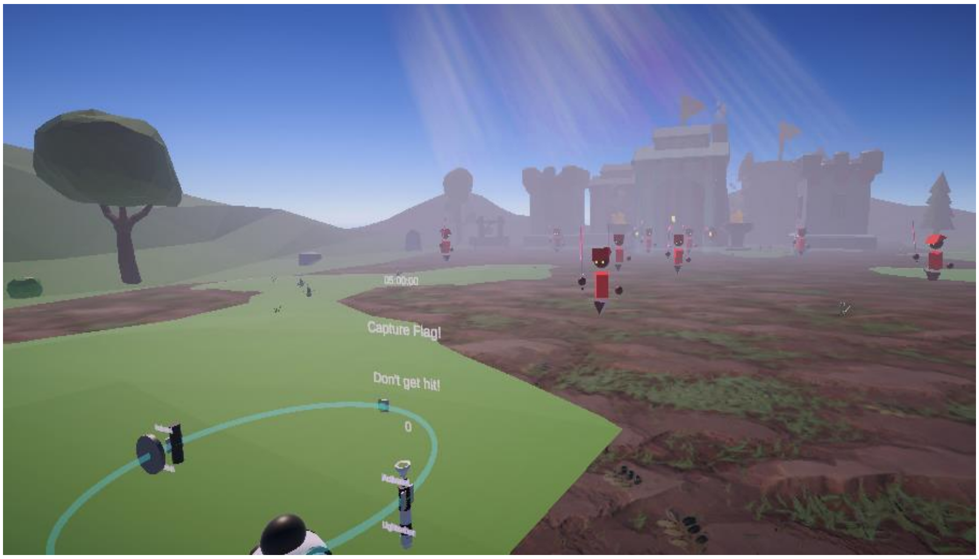


Fig. 6: Screenshot of the "Seize!" game mode

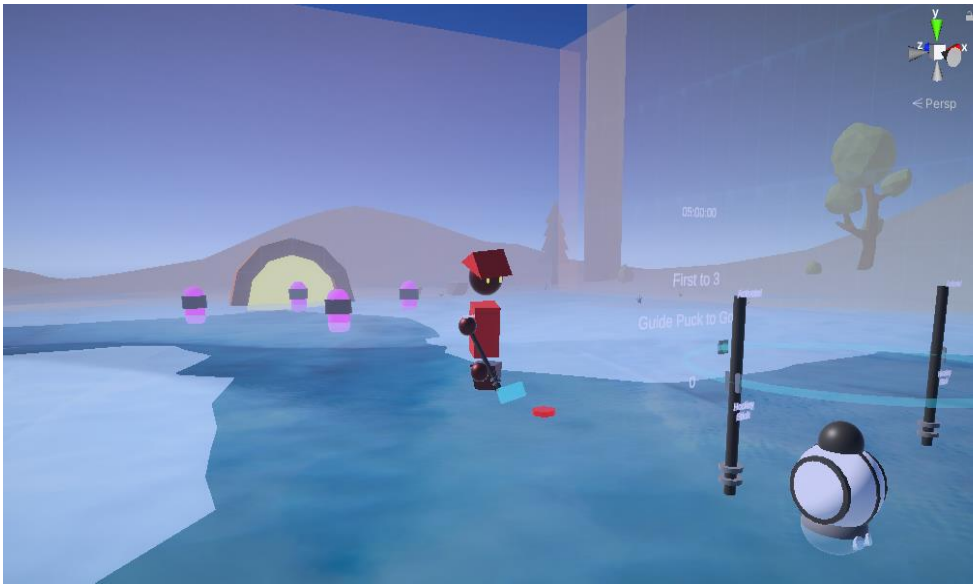


Fig. 7: Screenshot of the "Hockey!" game mode

In the "Crash!" game mode (Fig 8) the player will be put in an arena with randomly spawning bowling pins to knock over. The objective is to knock each of these pins down and the more pins the player topples, the more points they earn. However, there will be occasionally bombs that spawn randomly and when they explode, it will harm the player and deduct their score. The goal of the game is to crash into as many pins as possible and earn a high score.

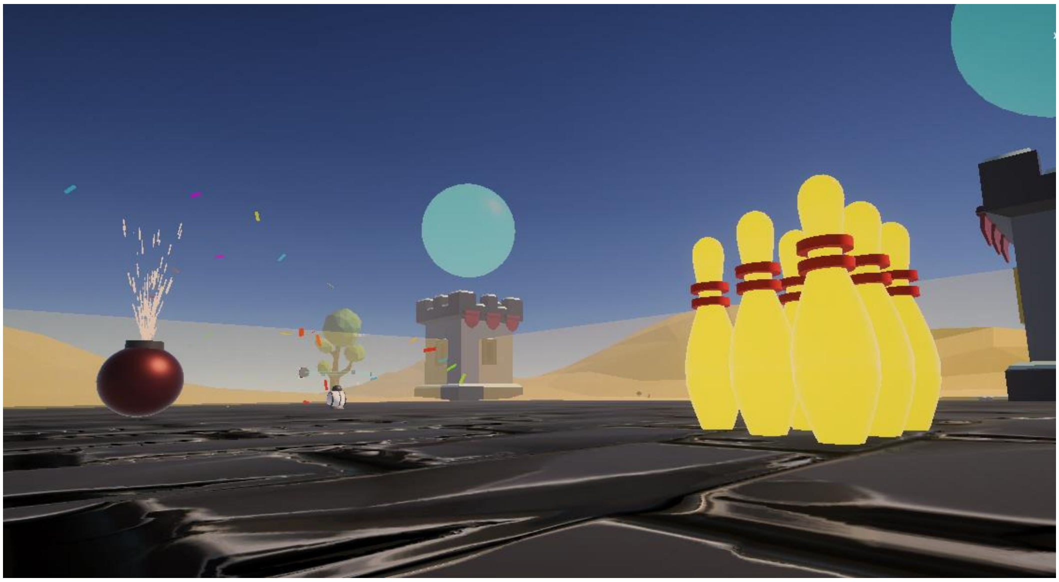


Fig. 8: Screenshot of the “Crash!” game mode

5. Preliminary testing

5.1. Test plan

The preliminary testing aims to evaluate the VR game in 2 aspects: the playing experience and resulting motion sickness after playing. To test these aspects, two form questionnaires are used. The Game Experience Questionnaire (GEQ) and its core questionnaire module (IJsselsteijn et. al., 2013) is used for evaluating the playing experience of the VR game. The Simulation Sickness Questionnaire (SSQ) (Kennedy et al., 1993) is used to evaluate motion sickness after playing the game. There are also some added questions outside of the established forms used such as time taken to finish the game, learning curve and uniqueness of the game to evaluate the game on aspects other than the conventional variables.

In the beginning testers were given the SSQ before playing the game categorized as a pre-test. After the testers finished the game, they were given the SSQ once again as a post-test evaluation and the results were compared with the initial pre-test values by deducting post-test values with pre-test values. Testers were also given the GEQ after filling the post-test SSQ.

After compiling the SSQ and GEQ test results, we averaged the results and it was interpreted based on the questionnaire’s assessments. For the GEQ, the answers will be averaged and each item will be assessed into one of the 7 components: immersion, flow, competence, tension, challenge, positive affect and negative affect (IJsselsteijn et. al., 2013). As for the SSQ, each item will simply be averaged and any noteworthy effects any item has will be noted. Any comments or miscellaneous feedback will also be taken into account for the evaluation of the game.

5.2. Test Results

The preliminary testing was conducted from 8th of April to 10th of April with a total of 6 testers. The testing had some hiccups while providing instructions due to some users testing the game only with online supervision, otherwise it went rather successfully.

Fig. 9: Testers testing the game

Of the 6 testers 2 of them have also played VR games before and are familiar with movements in VR. The average time it took for all testers to complete the game was 20 minutes on average, the longest time being 30 minutes and the quickest time being 15 minutes.

The GEQ scores (Fig 10) were above average, as the competence, immersion, flow and positive affect components received a score above 2 and the tension and negative affect components scored below 1. As far as criticisms go, many have pointed out that the objective of the game is quite unclear and they oftentimes can get lost easily during gameplay. Another fairly common critique is on how quickly the player character moves and how hard it is to stop moving due to the nature of hoverboard-like movement.

This is especially prevalent when the tester is playing a game mode where precise movement is required like the “Hockey!” game mode. This critique is also a suspected reason why most testers prefer the “Seize!” game mode the most as the level adheres to the moving forward guideline the most (Oculus, 2017).

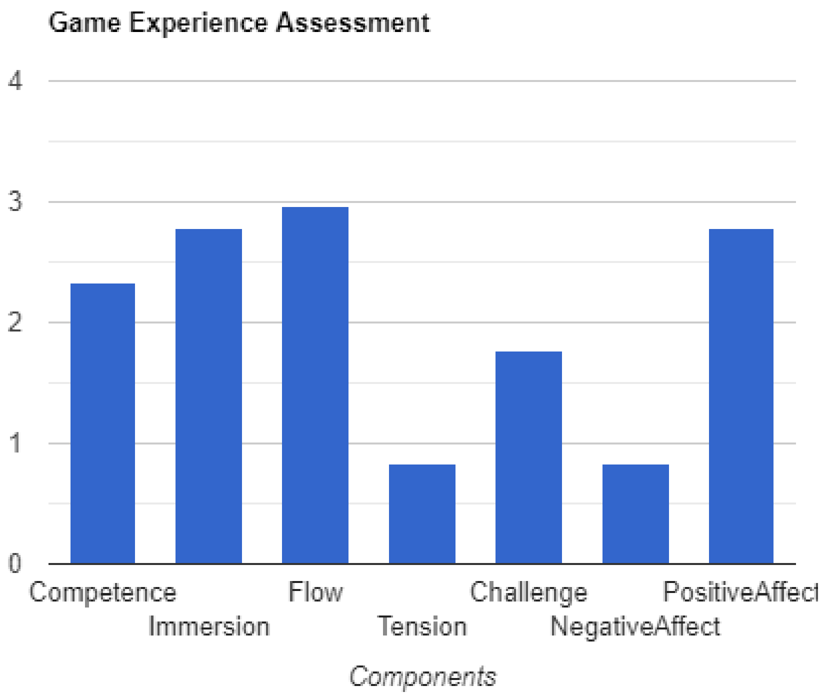


Fig. 10: Game Experience Questionnaire Scores

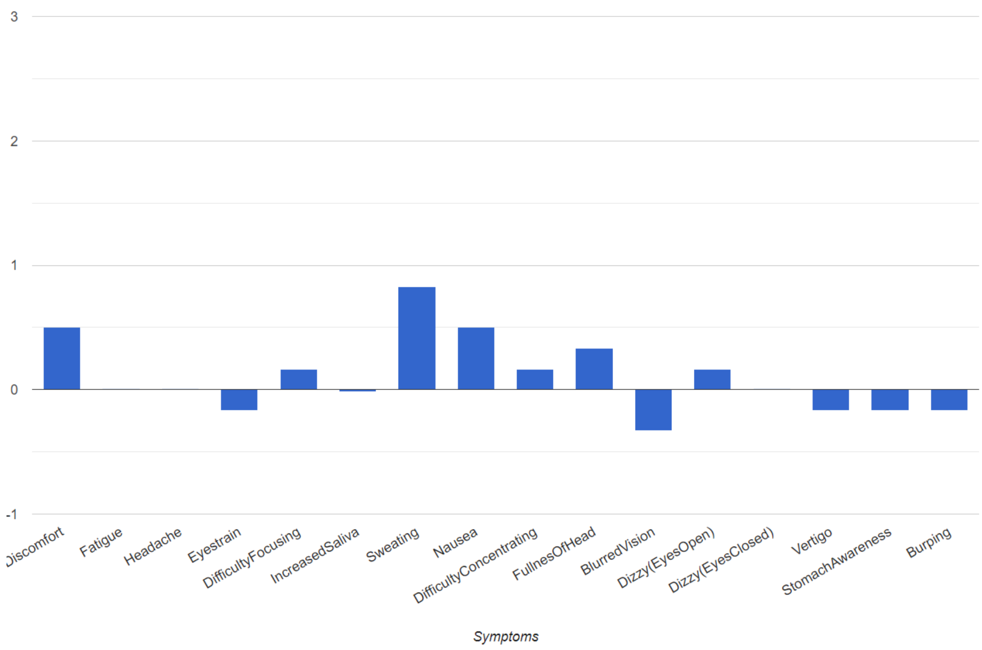


Fig. 11: Simulator Sickness Questionnaire Scores

For the SSQ evaluation (Fig 11), the average score for all items is low. Note that the highest scored item, sweating, might have been influenced by the relatively warm room for the testers that are supervised physically, and also influenced by the game requiring some form of physical exertion. Of all the other items, other than sweating due to reasons stated above, nausea is the symptom that has the most amount of occurrence. This most likely also contributed to the general discomfort score and gave an average score of 0.5 out of 4.

Interestingly, the 2 testers with VR gaming experience provided some negative and 0 scores across the board. Therefore the game does not cause more motion sickness than other VR games. However, one of the testers that played VR games also expressed their preference of using a joystick over the head directed method due to its precision.

Another interesting note on the results from one particular tester which has the most severe symptoms of simulator sickness with a score of 2 in dizziness while eyes open, 2 in vertigo and 1 in nausea. Their play style contributed to the sickness where it involved turning around and leaning the opposite direction of their movement in order to decelerate with more control. It is also observed that this particular tester is the most competent among the testers in terms of understanding the locomotion system. This sort of playstyle unfortunately also lines up well with Oculus' recommendation of discouraging unfamiliar movement such as strafing or backpedaling (Oculus, 2017). One of the testers also noted that the "Hockey!" game mode in particular was the worst offender for them in terms of contributing to nausea, as the game mode requires the player to move back and forth between the map.

6. Conclusion

In conclusion, the usage of head directed motion combined with hoverboard like movements made for VR games to utilize and such a concept has generated some positive reception that is worth trying to incorporate into more VR games in the future. The results of preliminary testing seem to hint that the issue of motion sickness that occurs in the game is relatively minor, however more testing is needed in future studies as the number of testers were fairly limited. As for future improvements, we would include a better tutorial and instructions system to improve on the familiarity of the in-game movements. Another improvement would be the handling of deceleration as it is one of the most commonly criticized parts of the game for being hard to control. Potential fixes for this would be to increase the acceleration while leaning in the opposite direction of the player's velocity.

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