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Title of Thesis - Motion sickness in Virtual Reality games

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Abstract:

This thesis tests if the motion sickness in gamers playing a VR game can be reduced through the use of restraints such as being seated. Players played a short physical locomotion VR demo standing and seated The aim of the thesis was to further look at how players could be introduced to VR games with physical locomotion while avoiding motion sickness.

Keywords : VR, Virtual-Reality, Motion sickness, Video games, Physical locomotion, Postural stability, Locomotion

Problem Statement

How might we use the theory of postural control that suggests restraining freedom, of action and perception, can increase stability and prevent motion sickness to help gamers increase comfort in virtual reality games with physical locomotion systems.

Introduction

Virtual reality (VR) has been having a resurgence in recent years. Since the release of the Oculus Rift in 2016, there have been many developers taking interest in both the hardware and software. Among things like Facebook buying out Oculus and many big companies such as HTC and Sony releasing their own headsets at different price points, VR is becoming more accessible to both consumers and developers (Barnard, 2019). This has led to a sudden explosion of video games being designed for VR. With a new medium comes new and exploratory designs that will eventually develop into common practices for the medium depending on their strengths (Cipresso, 2018).

Motion sickness is a prevalent issue in VR (Statista, 2017) and because of this, design practices that combat against it are also commonplace to use while creating games. A major motion sickness design practice is that of creating games that limit the amount of head/camera related movement needed in game (Oculus, 2021). However this can be limiting game design as camera movement is a common feature of games and developers might feel forced to trade gameplay for comfort (Mailberg, 2016).

As a developer who has made VR games, I found most players would get sick after some amount of play when testing games. Which would force my team to make changes and trade-offs that we might not have wanted to. For example, my undergraduate VR game "TSAFrisky" was originally supposed to have the player move around, however both playtesters as well as most of the team had found movement to be motion sickness inducing, so we changed the game to take place in a static environment.

The traditional view of motion sickness is one called "sensory conflict theory". It states that when two sensory organs give us mismatched signals, we get sick. For example, seeing fast movement out the window of a car but not feeling it in your inner ear (Thomas, 1991).

The theory of posture control however, connects motion sickness to the ability for us to keep stable. Our body uses different perceptive organs to develop strategies that keep us stable. When we are in an environment in which we cannot develop a stable control strategy and our body goes through prolonged instability, we become motion sick. One major way of limiting instability according to the theory is to naturally restrain the body's movement or perception. This will limit the amount of action required to keep stable (Stoffregen, 1991). For example sitting down in a moving vehicle.

Using the theory of postural control we can reduce motion sickness in virtual reality games with physical locomotion systems by creating restraints for the player.

Locomotion in Virtual Reality

Intro to virtual reality

Virtual Reality has been a growing technological field since the early 1980s. From its initial enterprise uses such as virtual workstations and training for astronauts or pilots to today's current focus on the gaming and consumer markets (History of Virtual Reality, 2019). The definition of VR is “a particular collection of technological hardware, including computers, head-mounted displays, Headphones, and motion sensing gloves. The focus of virtual reality is technological rather than experiential.” (Steuer, J, 1992). These technologies have been evolving and it is only recently that VR has been affordable and readily available to general consumers along with simple tools for developers to create VR content (History of Virtual Reality, 2019).

The main technologies of VR presently are, a head mounted display (HMD), motion tracked controllers and headphones/speakers. The HMD is the main element of VR. It is essentially a helmet like device with 2 screens you wear on your face. The screens produce two versions of the same image, mimicking the image your left and right eye would see. Your brain can resolve this into a single image. This produces the effect of seeing 3D space (Strickland, 2017).

Figure-1: Vive pro head mounted display (Vive, 2021).

Motion tracked controllers are hand held devices that simulate the user's hand in game. It lets users see their hands in the virtual world along with providing buttons on the controller for additional interactions. These are similar to common video game controllers such as an "Xbox controller" with the addition of being tracked in 3D space (Strickland, 2017) .

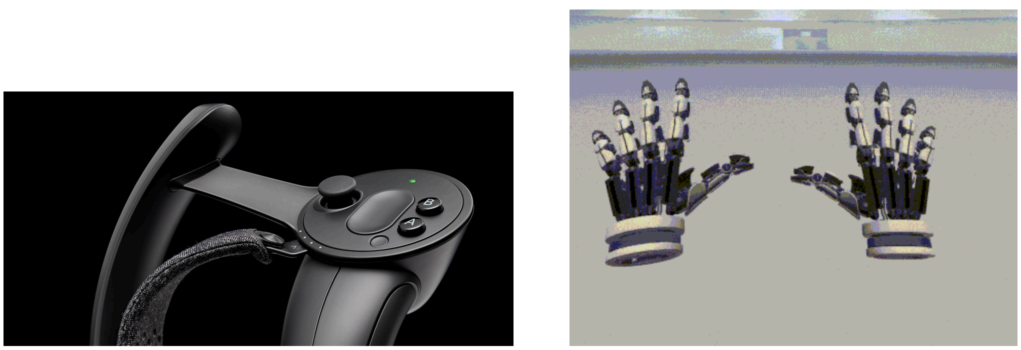


Figure-2: Valve Index motion controllers and Valve Index controllers in game - Knuckles finger test (Valve, 2021)

Finally any kind of headphone or speaker setup is needed for audio. Headphones are recommended as spatial audio is just as important in VR as the 3D effect from the two screens. This helps the player feel more connected to the virtual world regardless of graphical fidelity (Strickland, 2018).

VR comes in at different price points, with more features missing in the budget sets. However a minimum of the HMD, motion tracked controllers and audio solution are required to play most VR games (Iram, 2016).

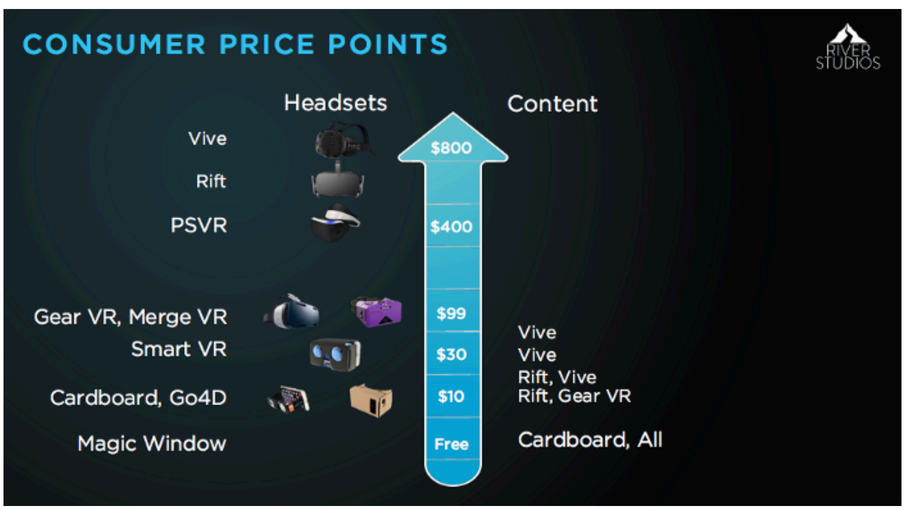


Figure-3: VR headset price points (Iram, 2016).

VR is becoming more accessible year by year with gaming being its biggest market. Most VR games tend to put you in control of a humanoid avatar with in-game “hands” that let you interact with the world. This is a rich presence that lets you perform complex virtual actions like walking around, grabbing an object, and examining it, more natural than the traditional method of using controllers or keyboards (Filmora, 2016).

Figure-4: VR player performing complex actions (Aiming at two targets, leaning body and looking at enemy) (Melnick, 2019).

Locomotion systems.

Locomotion is the act of moving from one location to another. In traditional games, players use controllers to navigate a camera in 3D virtual space. In VR the camera is attached to your head and players use their own body to navigate the 3D space. This gives rise to two distinct ways of moving around in VR, room-space and world-space. World-space movement is the act of moving the in game camera around the virtual world. This is how most games are played.

Room-space movement is the act of walking around in the physical space and having that translated into VR. This is extremely comfortable as the movements between the body and camera are 1:1 and it feels natural (Filmora, 2016). However physical space is a limited resource as players need to dedicate a large zone, free of any obstructions to walk around in. A computer hardware review found that a staggering 81% of players use the smallest available space of 1.5x2m that most VR software will allow. That is not enough to use room-space movement as a primary locomotion method (Hamilton, 2020). There exist hardware solutions to solve the issue of space. Devices like the Omni, which is a multidirectional treadmill with a harness that lets you run and jump in place. This and similar products try to take a small space and let you use that as the primary locomotion method. However these solutions are currently expensive, and require games to be custom tuned for it (Robertson , 2020).

Figure-5: Omni Treadmill (Robertson, 2020).

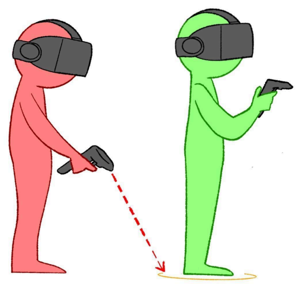
As a result in-game locomotion solutions that use the packed in motion tracked controllers are widely used to allow players to experience game world-spaces larger than their room-space. There are 4 traditionally used design patterns for locomotion, each balancing out gameplay possibilities against comfort and playability (Bond, 2019). The common locomotion design patterns are:

1. Static

   This method involves only letting the player use world space movement to move around. These kinds of games usually have the player interacting in a small environment.

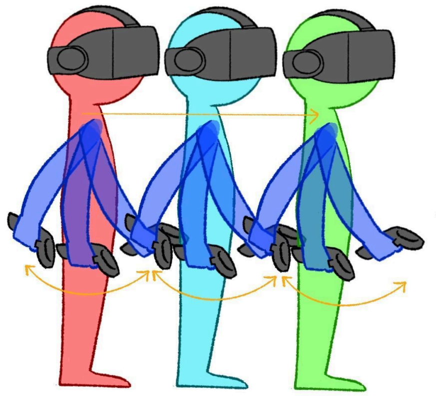
2. Teleportation

   Teleportation has the player pointing to their new destination and pressing a button to be teleported to this new location. This can be seen as moving from static location to static location. It is also the most comfortable and prevalent design pattern (Bond 2019).



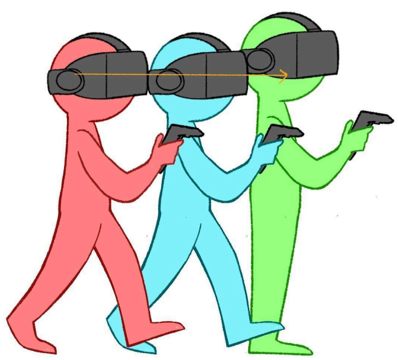
3. Arm Swing - Physical motions are tied to movement speed

   This method translates the player's arm swinging movements into motion. Since we all move our hands while walking this method aims to simulate that aspect of movement and not foot motion. This method can be physically tiring as it requires constant arm motion to keep the player moving. It also affects gameplay as some actions get hindered, for example trying to aim a gun and swing your arms can be hard.



4. Physical Locomotion

   Using a digital input to move an avatar over time in a desired direction. This is a familiar movement system to most traditional flatscreen games where you push a button and watch the camera smoothly move in the desired direction.



Most big budget VR games offer a mix and match of locomotion options in order to maximise the type of users that feel comfortable playing. However as gameplay is affected by locomotion some games do not offer locomotion options instead tying movement closely to their game's core mechanics.

A study on locomotion techniques in VR found Teleportation to have the greatest comfort and was the least overwhelming. Arm swinging or any kind of physical locomotion were surveyed to have low comfort. Most users felt tired and they had a high receptiveness to motion sickness symptoms(Bond 2019). Static locomotion games are where you can only move within world space. As static games have no in-world locomotion they can generally be seen as most comfortable.

Motion Sickness in VR

Most people experience motion sickness after playing some amount of VR with everybody having different limits before they get sick. Motion sickness is generally seen as the discomfort felt from experiencing a sensory mismatch, usually due to events like riding on a moving platform or visual-vestibular conflict such as playing VR(May, 2019). This can manifest in several symptoms that can be recorded and assessed in the form of a survey called the “Simulator Sickness Quiz”. The Simulator sickness quiz weights these different symptoms and produces a single number rating of motion sickness. Some of the symptoms of motion sickness include Dizziness, Fatigue, Lack of appetite and the two most common, nausea and headaches (Sevic, et al, 2020).

In a survey, just under half the respondents said motion sickness was a negative to VR(Statista, 2017). Since the consequences of motion sickness are so high, this makes it a big factor in picking games. Commonly games that do not offer teleportation or other features for alleviating motion sickness are criticized as not being for the “casual” audience. Getting motion sickness can make players not want to pick up VR again for a while, however by subjecting yourself to it longer you can eventually train a resistance to motion sickness (Thompson, 2020).

Physical locomotion rationale

The main difference between teleportation (which is the most comfortable) and the other movement options is that teleportation is a ‘Non-Continuous” kind of movement. When using teleportation it takes a second to regain bearings after each teleport. Movements are characterized by large position changes. This makes it hard to interact while moving (Boletsis,2019). Hand “Interactions” are paused while the teleportation is happening. A physical action such as dragging an object will have it teleporting with you and not actually “dragged”.

Arm swinging offers a much more traditional ‘continuous’ movement system. Here the player moves small increments over time. The speed of the movement is controlled by the players swinging motion while the direction is usually where they are facing. This system makes much more fine grain actions like dragging a chair actually possible. A big downside to this system however is that it requires the player to use physical hand motions to control their character’s walk which can be tiring and also interfere with other actions the hand can perform. Like aiming a gun or swinging a sword.

Physical locomotion with a joystick is similar to arm swinging but the player uses their analog stick to move. Direction is determined either by where the player is looking or the direction their hand is being pointed. This locomotion system is very similar to playing a first person shooter type game on a computer but the mouse/camera controls are attached to the player's head. Physical locomotion is familiar to most gamers as a joystick is how you move characters around in most traditional flatscreen games. It also offers the most immersion in VR as there is a very small barrier between input and in-game action (Bond, 2019). Physical locomotion also offers the affordance for realistic physics interactions of arm swinging while not being as physically fatiguing(Boletsis, 2019).

A survey on different locomotion techniques found that "Controller/joystick provided an overall experience of good quality. The technique scored moderate-to-high values Competence, Immersion, Flow, and Positive Affect; it also got a borderline Excellent in the SUS usability score" (Boletsis, 2019). This means that players found using physical locomotion the most immersive and usable even though it got them motion sick.

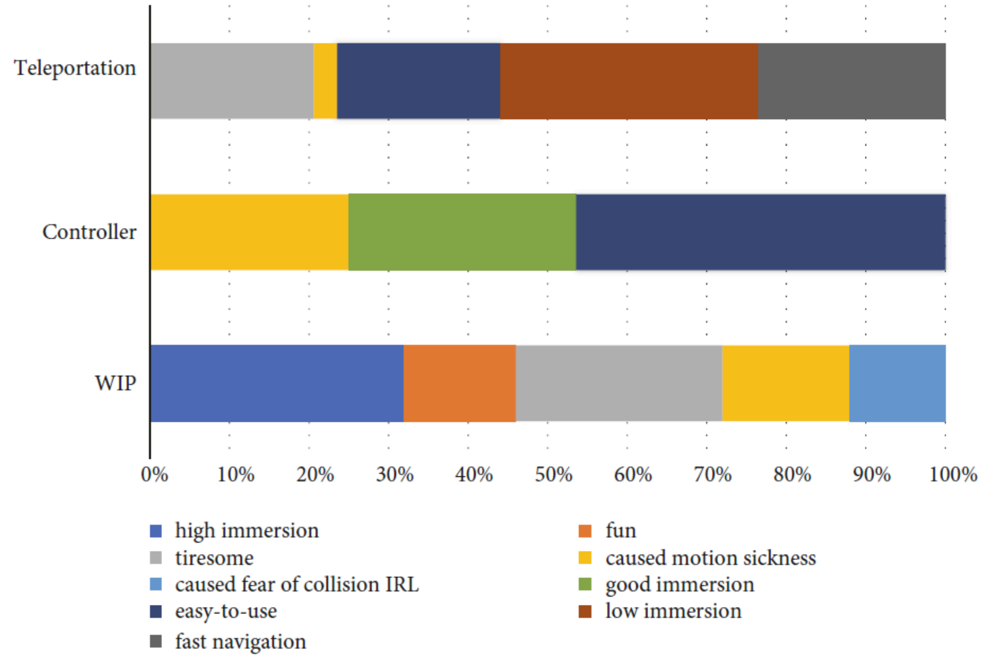


Figure-6: VR Locomotion survey, Controller (physical locomotion) has highest ratings in “good immersion”, “ease of use” and “caused motion sickness” - (Boletsis,2019)

As most players don’t have the physical space to only use room-scale movement, and hardware for physical locomotion does not sell (Statista, 2017). This makes in-game world-space movement the most practical.

And while each locomotion design pattern has its ups and downs, and new ones will be designed and tested as the medium matures, physical locomotion with a joystick is presently a design paradigm that offers a high level of immersion and ease of use (Bond, 2019).

Theoretical Framework

Theory of Posture Control

The theory of postural control, according to Thomas A. Stoffregen states that "..Animals become sick in situations in which they do not possess (or have not yet learned) strategies that are effective for the maintenance of postural stability… In essence a lack of bodily control" (Stoffregen, 1991). This is different to the traditional view of motion sickness that stems from the sensory conflict theory in which it is believed that a mismatch between an expected sensory experience is not matched by the real sensory experience (IE: You are in a car and "see" movement but can't "feel" the movement) (Thomas,1991).

Posture here is defined as "the configuration of your body and its segments" (Stoffregen, 1991) and posture control is the ability for you to stabilize and maintain that posture. In reality we are not staying still at any given time, but are oscillating equally in all axes to create a stable posture. The three key factors of postural controls are perception, action, and the goal at hand.

For example, while standing still on a stationary train you might stiffen the ankles to maintain a stable posture (standing straight), however on a moving train your body uses different senses to perceive the system you are in (movement outside the window, force on your feet, sounds, etc…) and loosens the ankles in order to counter the movement forces and keep to its original goal (standing straight). By stabilizing yourself you further reduce interfering motions that degrade perception and actions (such as swaying around) (Golding, 1991) . The techniques used to gain control in a new dynamic environment is called postural strategy (Stoffregen, 1991).
These are often not explicit but things our body automatically learns and adjusts too.

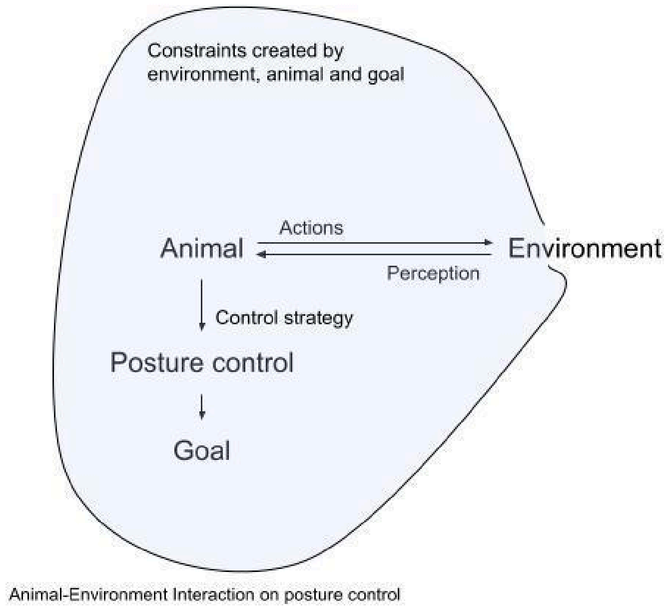


Figure-7 Animal Environment interaction on posture

Stability vs Instability

A stable posture is one in which uncontrolled movements of your perception and action systems are minimized (not swaying much, not exerting too much muscle strength). Maintaining a stable posture requires effort and energy. When we are introduced to new dynamics in the environment we go through instability (uncontrolled movements) which are naturally used as clues about the new environment to help us stabilize. This can lead to one of three outcomes.

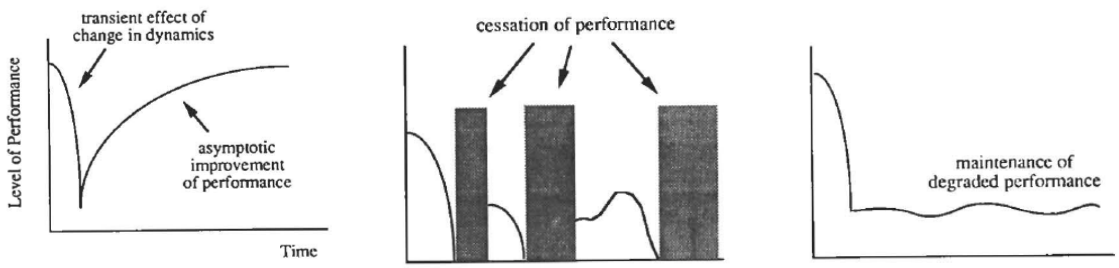


Figure-8 (Outcome A , B , C) (Stoffregen,1991)

A. Performance degrades as a new control strategy is developed and performance asymptotically improves.

B. Performance ends, control is completely lost and then regained in the form of least posture control (Slipping and then falling)

C. Performance degrades, but control is not completely lost. Performance is maintained at a degraded level. This is where motion sickness forms.

In the first case, Our performance will degrade as we learn to develop new strategies and at that point, our performance will begin to improve. This is the most common case and humans are very good at adapting posture stability in dynamic environments. Instability is only correctable so long as we can perceive it. If we cannot then we will cease and lose control (Stoffregen, 1991).

In the second case performance will completely drop and posture control will be completely lost. This can only last a short while and control will be gained at the lowest possible energy usage. In this case, for example, you might slip and fall. Losing posture control and then gaining it back lying down on the floor.

In the final case our body picks up on the clues to stabilize but can't quite create the correct control strategies to stabilize. Here we don't completely lose control but operate at a reduced performance level. The longer we operate at this reduced performance and cannot create control strategies the greater the motion sickness symptoms (Stoffregen, 1991).

Issues with picking up information:

There are two major factors we have when it comes to perceiving and using information in the world. Misperceptions can lead to misactions, which can lead to not discovering an appropriate control strategy in a changing environment. The two major factors are.

1.Detecting and acting on specificity in simulations

Specificity here is our intrinsic understanding of variables and interactions. This is a big issue in simulations and games. You are meant to operate the simulation like its real life (eg: fly the plane like there are actual forces acting on it) but we are also forced to control our own body based on the real world forces we perceive (lack of vestibular movement) and here we are asked to "see through the simulation." (Stoffregen, 1991)

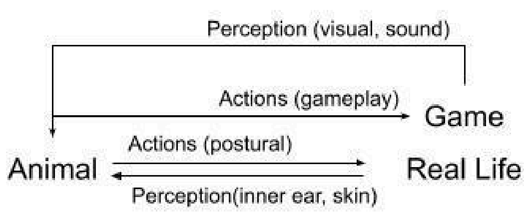


Figure-9: issues with perception in VR

This is something VR will combat overtime with better hardware to stimulate different perceptions in game, like smell and feel. However given the realistic capacity to which regular gamers use VR; affordability and space will keep specialized hardware out of the reach of general consumers.

2.The vestibular system:

The vestibular system is an organ system in your inner ear that is responsible for your sense of balance and coordination. It consists of a small canal that is filled with a fluid called endolymph which aligns with the gravito-inertial force and is picked up by receptors around the canal. It is affected deeply by the movement of any limb. This is sensitive and can be limiting on the type of postural control needed sometimes. It also plays a role in your Proprioception. This is how you can touch your nose with your eyes closed or know the configuration of your fingers without looking. (Neurosci, 2015)

A study from Taylor & Francis co. found that “For instance, labyrinthine-defective people, i.e., without any functioning organs of balance in the inner ears, never get sick from Motion. This is an important part of the motion sickness equation because we cannot get motion sick without realizing that we are under the effects of posture instability. Your vestibular system is an important perceptive organ in this. (Chardonnet, 2017)

Causes of motion sickness

1.**Low Frequency Vibrations.**

Low frequency vibrations can generally be thought about as any slow bobbing motions. Walking is traditionally characterized by a low frequency oscillation of the head and the body (Stoffregen, 1991). This control of the coupling of our head and body motion is the reason we don't get sick from it. However when the environment moves in a low frequency oscillation this can cause a decoupled movement of the head and body which can lead to motion sickness (Stoffregen, 1991). Low frequency Vibrations are believed to be the main cause of motion sickness in Aircrafts and most vehicles.

A study conducted on the effects of motion axis direction on body posture concluded that "Motion direction with respect to the gravity vector (vertical motion) seems a less important factor." They speculate that a reason for this could be that more forced movements of the neck lead to larger stabilizing movements. So when the direction of the bobbing is in line with the gravity vector, there are less sickness symptoms induced(Golding 1995).

2.**Weightlessness.**

Weightlessness is when your body feels no forces acting on it. This happens in space where there are no effects of gravity, during free fall when gravity is equal to the resistance of you falling and during parabolic flight that is used to train astronauts.

On earth every force we make is resisted upon by the surface of support. This makes gravity a very important factor in posture control as we work with its resistances. In space however the simplest motions our body produces are not resisted upon. Head movements in space can cause your body to move uncontrolled with it. The normal control strategies that we are used to will not work and our body must learn new ways to stabilize posture. This could lead to motion sickness if control strategies are not learned (Stoffregen, 1991). To cope with this astronauts might hold onto a wall or stay in a corner to reduce uncontrolled movements by restricting freedom of motion. It is possible to overcome this and learn control strategies to get comfortable in space. The Nasa director for the Gemini missions, William C. Schneider mentioned that "Space sickness relieves itself after about 3 days, although individual astronauts and cosmonauts may have a relapse at any time during their mission"(Nasa, 2001).

3.**Changing relationship between the gravito-inertial force**

Gravito-inertial force is just the sum of gravity and your current inertia. It is what is "felt" by your inner ear. Because acceleration is linear and we only feel the sum of it, gravity is not felt alone and we feel it as a Gravito-inertial force. (Zupan, 2001)

Our bodies can handle a linear change in velocity, like an accelerating car, but cannot handle a constant change in acceleration, like a slowly rotating room or a platform constantly changing direction. Here the acceleration vector is constantly changing in relation to your current gravito inertial force. According to Stoffregen “a slightly different control strategy will be needed for each step in such a walk. Different constraints will also operate on motion in different planes within a single position. It is therefore not surprising that adaptation to movements in such rooms can be ‘direction-specific’.” (Stoffregen, 1991)

4.**Changing Specificity**

Specificity is hard to define. The patterns of our actions are always relevant to the dynamics of the animal-environment system. Over time we build an intuition to these dynamics and the underlying conditions and control strategies we have in order to adapt. The more we are exposed to a certain system’s pattern, the stronger our intuition for these systems grow. When this specificity is altered, our bodies might misinterpret the appropriate control strategies and this could lead to motion sickness. (Stoffregen, 1991)

For example, wearing prescription glasses when you don’t have to, messes with the specificity you have built up between your posture control strategies and what you look at. Doing this could lead to degraded performance and eventually motion sickness. In relation to virtual reality your visual specificity will change while wearing a headset. You are made to perceive a 3D environment on a 2D screen, which is not like real life.

Visually induced motion sickness

Virtual reality adds one more dimension to the causes of motion sickness. Visually induced motion sickness (VIMS) “is a subcategory of motion sickness that specifically relates to nausea, oculomotor strain, and disorientation from the perception of motion while remaining still” (Jasper, 2020). In virtual reality our real bodies exist on a static plane (the real ground is not moving), but in the virtual world what we see and hear is dynamic and moving. Our eyes go through more strain as they are focused on a screen which is close to the face but tries to pick apart 3D distances and separate objects by depth. This can cause oculomotor strain where our eyes move rapidly to try and get oriented. This is why some people can get motion sick in VR even when performing relatively tame actions. (Jasper 2020)

Signatures of instability

Signatures are the general signs of instability. These characteristics can permit the perception of instability without the need for reference for any particular system (Stoffregen, 1991). In essence, they are common body movement signs we make while going through instability. Most times these signatures will come and go as we get unstable and then regain control. If the signatures are prolonged, we can say that they are undergoing motion sickness, which is measured by the severity of its symptoms.

Thomas A. Stoffregen describes 9 different signatures of instability. This has been taken and filtered through Jean-Remy Chardonnet and their colleagues in their paper that tests which of the signatures of postural instability are most relevant to virtual reality and VIMS. They conclude that “We consider body sway as an efficient feature to indicate the occurrence of sickness” and “COG would be a useful index of the level of sickness” (Chardonnet , 2017). The other important note is that recognizing uncontrolled movements vs controlled movements is hard and almost hidden, this they say is another important factor (Chardonnet, 2017).

Body Sway

Body sway is generally equal on all axes, this helps create a motion that is stable and does not require too much effort for us to keep up. While undergoing instability our body will begin to sway more wildy. For ankle sway or constantly changing pressure between feet and ground(Stoffregen, 1991). These changes can all manifest in one common thing and that is destabilization of the head position as our head always has to readjust to minimize perception interference of the eyes, nose and ears (Golding, 1995). In VR we can measure head position by tracking the head mounted display over time.

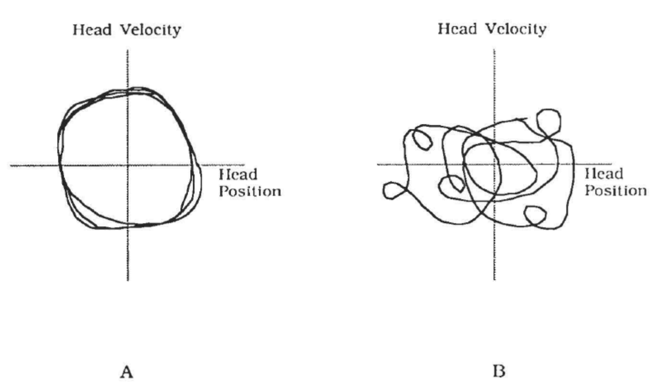


Figure-10: Head position (A) stable vs (B) unstable. (Stoffregen, 1991)

Center of Gravity

Center of gravity (COG) is "the point which is situated in the middle of the object and around which the mass is equally distributed and around which it rotates in space" (Posture, 2021). Our posture is an important factor in balance, good standing posture can reduce the impact of center of gravity as a factor in instability (Chardonnet, 2017). To maintain our center of gravity we are always swaying about it, making sure our body goes through the center of gravity and keeping it as the average location of sway (Stoffregen, 1991)

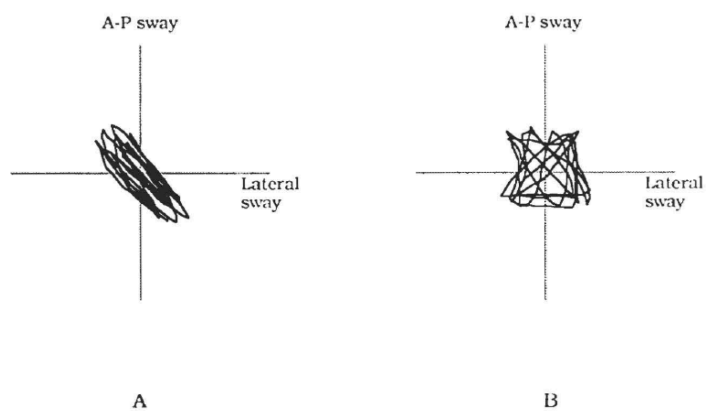


Figure-11: Center of Mass (A) stable posture characterize by going through center vs (B) insatiable posture characterized by more offcentered movements (Stoffregen, 1991)

While undergoing instability our center of gravity can vary wildly and offset from its original position needing to undergo larger stabilizing movements. This will be measured through the use of a "Nintendo Wii balance board".

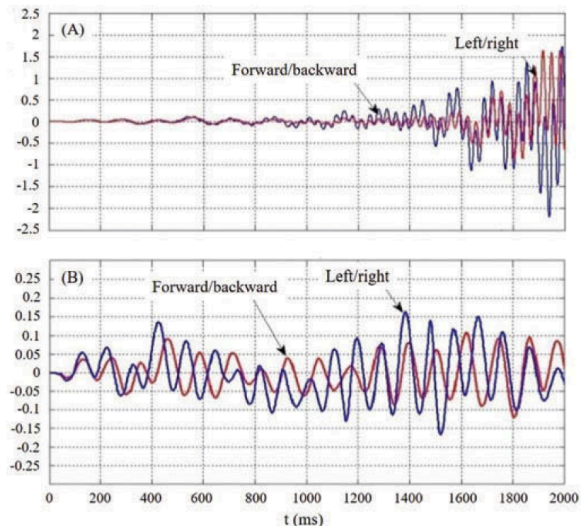


Figure-12: (A) Less stable movement characterized by the irregular patterns vs (B) more stable posture characterized by more equal oscillations (Chardonnet, 2017).

Involuntary control movements.

Involuntary control movements are when your body does “unnatural” motions to try and stabilize. This is the hardest to detect, as what is unnatural movement can vary from person to person. According to Chardonnet involuntary control movements can be seen when the body tries to stabilize but does not quite achieve this and over or under compensates by doing movements that were not planned by the body (Chardonnet, 2017). As an example, a person on a moving platform tries to stabilize but loses control and trips. While falling their arms , head and body will start to make involuntary control movements as they try to gain balance and catch their fall.

Effects of restraint

To reduce motion sickness we can increase stability. One way is to limit motion or perception ability (sit on a chair, seatbelts, ect..). The other is to reduce the effort required to be stable (Lying down, water bath) (Stoffregen, 1991). In general we tend to look for ways to limit destabilizing perceptions or actions in order to combat instability. We might close our eyes after spinning around to combat dizziness at the expense of our sense of sight, or we might hold the rails on a bus to not get jerked around at the expense of movement freedom.

Two restraints we normally practice in life are sitting down and laying down. For example we sit down while in a car to reduce the need for active posture control. We lay down while sleeping as it requires the least amount of effort for posture stability (Stoffregen, 1991). This could be the key to greater comfort in VR games that have physical locomotion as these games tend to have you walking around a lot. By adding restraints to reduce the effort for a stable posture we can increase comfort.

Historical Framework

VR Research was started in the early 80s on stereoscopic lenses that let you see depth on a flat screen. At the time VR was not a consumer product and was something that was exclusive to the research and development community. The birth of consumer VR can be considered to be around 2012 when Oculus rift launched their kickstarter campaign for the first commercially available virtual reality headset (Barnard, 2019). Current consumer VR consists of a headset and two motion tracked controllers. Some headsets require a powerful computer to run games while others have a built-in computer but can only play a limited selection of games. While the initial release of the Oculus rift did not have motion controllers it became widely used and considered necessary shortly after launch, as most games are designed with motion controllers in mind (Tambovtsev, Et al, 2017).

VR hardware and specifications have changed over the years; this paper's historical scope will be limited to looking at modern consumer VR as physical locomotion was not common in the design lexicon before it.

Design principles to combat sickness in VR

While physical locomotion itself can be seen as highly motion sickness inducing and tiring (Boletsis,2019) there are commonly used design principles in games to help increase comfort regardless of locomotion type.

1.**Field of view (FOV)**

One way of reducing motion sickness is to reduce the field of view. The less visual noise in the user's vision the greater the comfort, as there is less visual stimuli to process (Hoffmeier, 2017). Field of view is a tricky trade off as the higher the FOV the greater the immersion but also reduced comfort (Tcha-Tokey, 2017). The reduction of FOV is commonly used in VR games while the player undergoes any movement. VR is a new medium that the user has to develop visual specificity towards, unpredicted/unwanted movements can break that specificity causing unstable posture and an inability to regain composure as the specificity cannot be gauged intuitively (Strofreggen, 1991). By reducing fov and amount of stimuli to process we can reduce the amount of unintuitive information that the user has to perceive (Hoffmeier, 2017).

Eagle Flight is a game developed by Ubisoft Montreal, in which players take control of an eagle. The bird's flight is controlled by the user tilting their head. Normally the user can see the entire FOV of the head set, but when they tilt their heads to turn the FOV dynamically shrinks which makes the turning action more comfortable. This is because a constant change in acceleration (like turning) can cause motion sickness (Hoffmeier, 2017).

Figure-13: Limited FOV while turning in Eagle Flight (Hoffmeier, 2017).

A study from Columbia University, on FOV and comfort found that most players either didn't notice or preferred having FOV restrictors. They conclude that "Users found it more comfortable and did not feel like it intruded on immersion" (Fernandes, 2016).

Figure-14: Full FOV (right) vs Limited FOV (left), (Fernandes, 2016).

This principle of reducing field of view will be the main inspiration for the panic button in my prototype. When players press it, the screen will slowly reduce in FOV until it has gone completely black (similar to closing your eyes). When they feel like they are ready they can let go of the button and the FOV will increase back to normal.

2.**Consistent high frames per second (FPS):**

What is considered a high frame rate is based on the refresh rate of the VR headset display (VR Source, 2016) . Refresh rate is how many times the screen itself refreshes every second. It is essentially the maximum amount of frames that can be displayed a second. The ideal FPS is equal to the display's refresh rate. If the FPS is too low then the images will be choppy and not smooth. If the FPS is too high, too many frames are being received and if a wrong frame is displayed it can lead to an effect called screen tearing where two images are displayed simultaneously. This is a better situation however as a technology called “Vsync” will prevent screen tearing from occuring by capping the FPS to the refresh rate of the display (Ferdov, 2015).

The headset used in this paper’s experiment is a Valve Index. The maximum refresh rate of the headset is 144hz and it can be lowered to 90hz. This means that the prototype can have a high end of 144FPS and still feel noticeably better while having a hard low of 90FPS as that is the display's minimum refresh rate.

3.**No Constant acceleration**

This one is directly related to the theoretical framework’s causes of motion sickness. Specifically that of Changing relationship between the gravito-inertial force. Acceleration is either a change in speed or change in direction. In real life acceleration affects our vestibular system and we “feel” the motion (Day, 2005). According to the theoretical framework, we use all our senses simultaneously to develop control strategies with the connection between the vestibular system and other perception organs being key to gaining posture control (Stoffregen, 1991).

In Virtual reality we can get used to being at a constant velocity. When there is acceleration, we do not get the expected feeling in our vestibular system and this puts us in a situation in which we do not have a good control strategy. A constantly changing velocity will lead to the need for a lot of different little control strategies which could be hard to pick up on and act on and could lead to motion sickness(Stoffregen, 1991).

The Oculus rift developers guide advises against having smooth accelerations in games. They suggest using “Stepped Translations”. This means using a series of small fixed teleportations to simulate movement rather than using a traditional acceleration curve. By doing this you have instant acceleration and deceleration which makes the player feel more in control (Oculus, 2021). I will follow this principle in my game and have the player accelerate and stop instantly.

They also suggest limiting the amount of axes the player can move on, especially on the up-down axis and also not having the environment move the player (Oculus, 2021). This is something I will not follow as it is important to my testing of the player developing control strategies in a changing animal-environment system, where the environment is the virtual space the game is played in.

Games with physical locomotion.

There are many reasons that VR games choose to use physical locomotion. Here are a few different reasons:

1.**Choice**

As discussed earlier, physical locomotion is the most immersive but most motion sick inducing while teleportation is less immersive but also most comfortable (Boletsis,2019). This is why a lot of games offer multiple locomotion options so users can find what is a good fit for them.

Half Life Alyx is a VR shooter game developed by Valve software. The game was developed with one of the highest budgets for a VR game and is one of the highest rated and best selling VR games on PC (Lang, 2020). The game offers both extremely polished teleportation and physical locomotion systems. It was initially developed with just a highly polished teleportation system. While playtesting they found that the more experienced VR players wanted a physical locomotion but newcomers would stick to teleportation. As a result the final game offers both teleportation and physical locomotion (Valve, 2020).

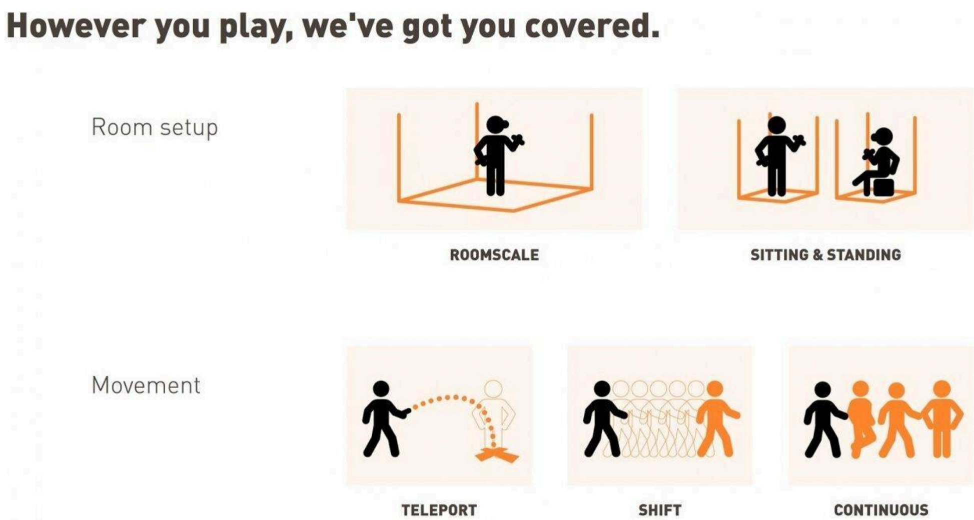


Figure-15: Half-Life Alyx locomotion options (Garreffa , 2020).

Figure-16: Half-Life Alyx gameplay(Left) and Title screen (Right) (Garreffa, 2020).

Another game that offers different locomotion settings is a game called Hotdogs horseshoes and handgrenades (H3VR). H3VR is a gun simulator game where the focus of the game is having the motion controllers interact with guns in a realistic and methodical manner. Each weapon in the game feels unique and requires different physical actions to reload, ready and fire. The sights and recoil are also accurate for each gun. Because the game's focus is more in the player-gun interaction and not the player-environment interaction the game can offer multiple movement methods as movement only serves to take you from one set location to another. Instead of offering three set options, H3VR has many more variations and also lets users set advanced options such as movement speed, acceleration curve and many more little details can be adjusted (Hand,2017). This gives the player much more fine control on how they would like to play but can also be daunting as making wrong adjustments could lead to users getting motion sick. The game offers preset locomotion settings for beginners who do not want to mess around with many options.

Figure-17: H3VR, locomotion options menu (Hand, 2017).

2.**Fairness**

One reason developers might choose to only offer physical locomotion is because of fairness. This is usually common in multiplayer games where players are meant to be without advantages. Offering different locomotion systems here might create unwanted advantages. For example, a teleporting player can clear larger gaps, or could teleport past a doorway preventing others from seeing them. While a physical locomotion player would have to walk past the doorway and expose themself to other players.

PavlovVR is a competitive VR multiplayer shooter. In the game the player is a soldier who has access to many different weapons. Players join multiplayer lobbies of different game modes where they usually kill each other for points. The player or team with the most points at the end of the round wins the game. The game is heavily reminiscent of a classic computer game called "Counter-Strike". With the graphics, maps, weapon handling and movement systems all taking inspiration from it (VR Gaming Reviews, 2020). PavlovVR only offers one kind of locomotion system and that is physical locomotion. You can use a joystick or any kind of feet tracking device like the OmniVR. This is done so that all players share the same movement code and the game is fair for everyone.

Figure-18: PavlovVR aiming a sniper (VR Gaming Reviews, 2020).

Figure-19: PavlovVR buying weapons before the round begins (VR Gaming Reviews, 2020).

An example on the opposite end would be Smashbox Arena. It is a multiplayer shooter similar to Pavlov, with a more cartoony artstyle and a focus on shooting dodgeballs rather than real guns. Smashbox only allows players to teleport and the game's core mechanics are designed around it. When a player chooses to move they launch a big physical disk to the location they will move, this gives other players a visual cue. The actual teleportation also takes a few seconds to occur and has a small cooldown before it can be used again. This prevents players from spamming it (Brant, 2018). In both cases these games force players into a certain locomotion choice for fairness.

Figure-20: Smashbox Arena gameplay. Markers showing where players will teleport (Brown, 2017).

3.**Physical interaction**

Physics based gameplay is another major reason developers might restrict locomotion to continuous joystick locomotion. This is done so that they can simulate the character as a physics body in the world.

Boneworks is a VR game that is unique in that the character is fully physically simulated. Most VR games try to reduce the motion effect the world has on character, as this can cause a lot of unintended movements (such as an enemy pushing you and the camera moving). The storepage for Boneworks has a warning saying the game is for “Experienced VR users” and this is because it offers no locomotion comfort options (Machkovech, 2019). This trade off allows the game to focus more on the physics interactions as they do not have to worry about polishing the game to accommodate multiple methods of movement.

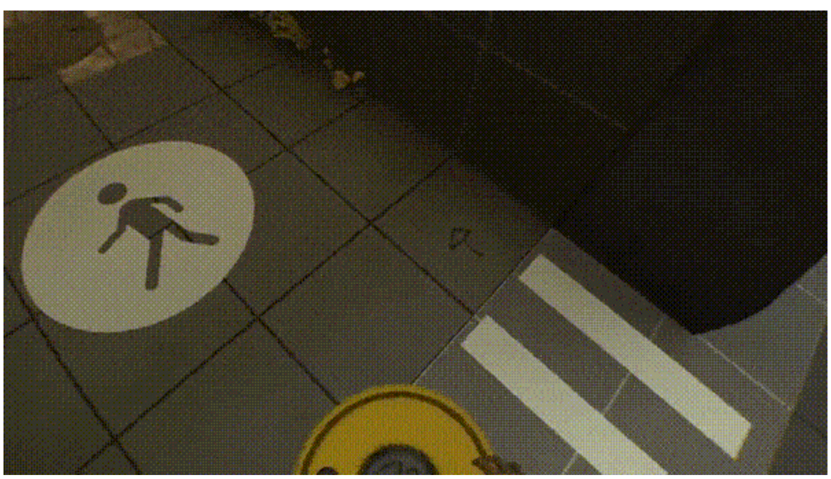

.

Figure-21: Player climbing up a pipe, world is affecting player locomotion (ThisplaceisHell, 2020).

A big part of boneworks is having the world affect the player body, this makes things like climbing up things and using random props as weapons feel natural and more intuitive. Most reviewers for the game seem to agree the game is a unique experience because of the freeform gameplay but it takes a massive strain on the body and is hard to play for long sessions (Machkovech, 2019).

Another VR game that uses only physical locomotion is Blade and Sorcery. In Blade and Sorcery players sword fight against waves of enemies. The game has very intricate melee weapon physics which offers a lot of creativity in gameplay. The game wants the player to act like they are in a real sword fight using large swing arcs for the most powerful swings . A big part of sword fighting is using the body's momentum and your feet to gain an advantage or a powerful hit (Pitchford, 2020). For this reason the game only has physical locomotion as it allows for the incorporation of continuous movement while keeping the hands open to making swinging actions. Even though its fairly large community of players ask for teleporting as a comfort option, the developer and other members have expressed how this would not be possible to incorporate with the physics of the game (Utgaard, 2018).

Figure-22: Player using in-game locomotion to make subtle repositions while knocking out an enemy creatively. (Gfycat, 2019)

Visual Component

Project goals

The goal of the project is to test if the increase in restraints of sitting down can reduce motion sickness in a VR prototype game that features physical locomotion.

Prototype description

The prototype will be a short 5-7min VR demo that will put players in control of an avatar with physical locomotion and in-game hands to grab objects. The goal of the game is to make it to the end of the level and put a key inside a door. The reason for the activity at the end is to see if posture can be maintained when there is a changing goal (Stoffregen,1991). Each level will present a more provocative environment for the player to traverse. The 4 levels are based on the "causes" of motion sickness according to Strofreggen and are arranged based on how they are tied in as game mechanics.

- Changing specificity
    - Changing specificity here is the player getting used to the VR world and developing posture control strategies for their new visual perceptions. there will be no obstacles other than walking to the key and then the goal.
- Changing relationship between gravito-inertial vector and surface
    - This stage will involve the ground plane moving. The key will be at the end of a room in which players will have to ride moving platforms in order to reach the key.
- Low frequency Vibrations
    - This stage will involve something similar to the previous stage but cause movement change in the XZ-plane (forward,backwards,left,right) as well. Here the key will be at the end of a slide with a large jump.
- Weightlessness
    - This final level will have the ground disappear and the avatar suspended in the air. They must use the same locomotion to guide themselves to the end of the level where the key is.

Data to be tracked

Times panic button is pressed - In game panic button

Head position / velocity - HMD

Pressure and center of gravity (body sway) - Wii Balance board

Game recording - OBS

Real life video recording - USB Webcam

Post gauge of overall motion sickness symptoms - Simulator Sickness Questionnaire (SSQ)

Testing process

The testing procedure will be based on a paper from the University of Minnesota called "Control of a Virtual Avatar Influences Postural Activity and Motion Sickness". The paper tests the theory of posture control and motion sickness on traditional flatscreen games. The authors of the paper use the simulator sickness quick and video footage of the players to test the link between posture stability and motion sickness symptoms.(Chen and Dong, 2012).

I will use a similar testing process as I am testing for the same signatures of postural activity but with VR games. The testing process will be.

1. Administer initial SSQ to ensure familiarity and get baseline data.
2. Let users play the VR demo. (they will press the panic button if they feel sick, or stop playing)
3. After playing Administer the SSQ
4. Give the a glass of water and let them rest till we do the next trial
5. Alternate which testers start standing and seated.

According to the theory, signatures of instability arise before motion sickness symptoms occur (Stoffregen, 1991). This means that when we look at the time just before testers push the panic button, we should find their COG and head sway to feature the large changes and unpredictability that characterize instability. This can be contrasted against the baseline data and the severity of the SSQ scores.

Technical component description

Simulator Sickness Quiz (SSQ)

The simulator sickness quiz is a survey that asks users to rate how intensely they are feeling different symptoms of motion sickness. They are broadly broken into 3 categories, Oculomotor which deals with the nerve that allows for focusing the eye and tracking objects. Nausea which is the feeling of sickness and vomiting and finally disorientation which has to do with mental state and loss of direction. Each of these categories are weighted differently and the users' scores can be added up and multiplied by the weights to give an overall score. The weights were determined by the researchers that modeled the questionnaire. The total score for the SSQ is 651 (Walter, et al, 2019).

None = 0
Slight = 1
Moderate = 2
Severe = 3

Symptoms	Weights for Symptoms Nausea	Oculomotor	Disorientation
General discomfort	1	1	
Fatigue		1	
Headache		1	
Eye strain		1	
Difficulty focusing		1	1
Increased salivation	1		
Sweating	1		
Nausea	1		1
Difficulty concentrating	1	1	
Fullness of head			1
Blurred vision		1	1
Dizzy (eyes open)			1
Dizzy (eyes closed)			1
Vertigo			1
Stomach awareness	1		
Burping	1		
Total*	[1]	[2]	[3]

Score
Nausea = [1] × 9.54
Oculomotor = [2] × 7.58
Disorientation = [3] × 13.92
Total Score = ([1] + [2] + [3]) *3.74

Figure-23: SSQ guideline sheet with weights (Walter, et al, 2019).

Measuring body sway with Wii balance board

The Nintendo Wii balance board is a game controller for the Nintendo Wii console. It is a cheap and commercially available force platform. Force platforms are instruments made for measuring balance and distribution of force. They consist of small sensors that measure how much force is being acted on it. This is similar to a weighing scale that measures weight. The difference between a normal weighing scale and a force platform is the number of sensors. By using more sensors you can get higher resolution of data (Hawkin Dynamics, 2021). The Wii balance board has four sensors, one at each corner. This is enough resolution to measure the center of gravity and weight (Jeremy, 2010). This is enough for the scope of this project.

The board is connected to the computer via bluetooth. To help collect data from the balance board I am using a software called "WiiHID". This software is a windows 10 driver that turns the balance board into a generic controller. This allows for the two balance axes of the controller to be converted to a generic "x" and "y" axis controller input (Löhr, 2019).

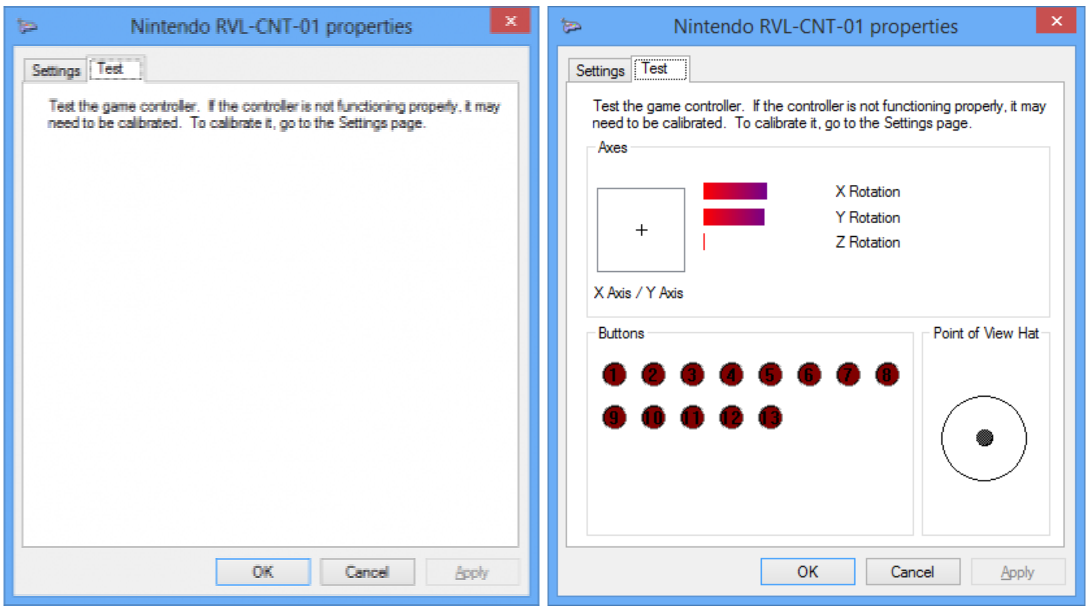


Figure-24: Controller Driver properties Without driver and With driver.

I then use this data in unity and track the axis data over time and create a chart for the users center of gravity. One limitation of this method is that resolution of data is slightly decreased. The balance board outputs floating point data from 0-255 with two decimal places, and the driver maps that number out between 1-0 with one decimal place. However this is still good enough for getting a good measurement, however some edges on the graph might not be smooth.

One important note for installing is that you must set windows 10 to "Test Mode" to turn off driver signature checking. This feature is only available in windows 10 pro or above.

The main parts of the code are in two separate scripts, “DrawTrack.cs” and “BalanceInputTest.cs”. BalanceInputTest finds the balance board when the game starts and then collects its input every frame. DrawTrack draws the graph out on the UI.

```
        foreach (string neme in Input.GetJoystickNames())
        {
            if(neme.StartsWith("Nintendo"))
            {
                Debug.Log("GotController: " + neme);
                balanceBoardID = count+1;
                controllername = neme;
                break;
            }
            count++;
        }
```

Finding the Balance board at the start of the game - BalanceInputTest.cs

```
        if(rT!= null && balanceBoardID <= 4 && balanceBoardID > -1)
        {
            xIn = Input.GetAxisRaw("Horizontal"+balanceBoardID) * w;
            yIn = Input.GetAxisRaw("Vertical"+balanceBoardID) * h;
            rT.localPosition = new Vector3(xIn, yIn, -9);
            lr.AddToPointsList(new Vector2(xIn,yIn));
        }
```

Getting input from the balance board - BalanceTestInput.cs

The graph is drawn through the use of a custom line renderer. The script takes a list of vector2 points and creates 2 vertices per point. It then connects these vertices with each other to make a line. The Vector2 list has a max size of pointsListMaxSize, and will delete and replace old points to keep to the size. This is done to prevent the game from lagging, but it also makes it so that line is deleting itself after a certain point. This point is dependent on the frames per second of the game.

If the game runs at 60FPS at a pointsListMaxSize value 100, then the line will be drawn for the $\frac{100}{60} \approx 1.6$Seconds. This should work for the scope of this project as I am not looking for exact values but rather the large sweeping changes which characterize instability, which should still be derivable from the data.

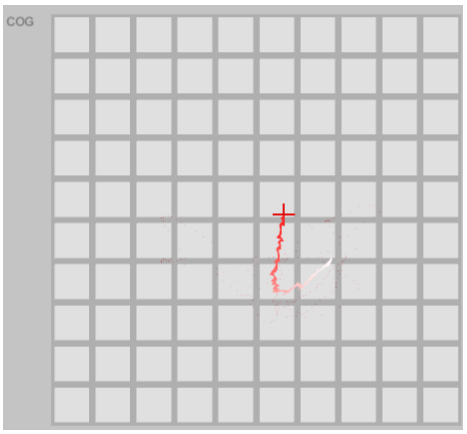


Figure-25: Sample graph of balance in full screen with pointsListMaxSize = 100.

```
    void DrawVerticiesForPoint(Vector2 point, VertexHelper vh, float angle, float index)
    {
        UIVertex vertex = UIVertex.simpleVert;
        vertex.color = new Color(1,1 - index/100,1 -  index/100);

        vertex.position = Quaternion.Euler(0,0,angle) * new Vector3(-thickness / 2, 0); //Half in and out of the point. To keep equal width from the point.
        vertex.position += new Vector3(point.x,point.y);
        vh.AddVert(vertex);

        vertex.position = Quaternion.Euler(0, 0, angle) * new Vector3(thickness / 2, 0);
        vertex.position = new Vector3(point.x,point.y);
        vh.AddVert(vertex);
    }
```

DrawVerticiesForPoint is the main function helping draw the lines. This function takes the point of the lines to be plotted at, the angle between the points and the index of the point. It also needs a reference to the VertexHelper class which lets me use the AddVert function.

```
    public void AddToPointsList(Vector2 pos)
    {
        if(points.Count > pointsListMaxSize)
        {
            // Shift all indexes one value down and add to the end.
            for(int i=0; i < pointsListMaxSize; i++)
            {
                points[i] = points[i + 1];
            }
            points[pointsListMaxSize] = pos;
        }
        else
        {
            points.Add(pos);   // add new points to the list
        }
        SetVerticesDirty();
    }
```

The AddToPointsList is a function that can be called from other classes. It adds the given point to the list making it render the next frame. If the list reaches its maximum length then all values are shifted one down and the new value is inserted at the end. This has the effect of deleting the first point in the chain. This function is hooked up directly to my balance board input and VR HMD position.

Measuring head sway with the HMD

Measuring the head sway uses the same UI and line rendering as measuring body sway. The only major difference here is the source of the input. The input is the position of the HMD in virtual space over time. All that was done was to get the position and remap it into the bounds of the UI.

```
            xIn = playerCam.localPosition.x * sensitivity;
            yIn = playerCam.localPosition.z * sensitivity;

            imgRt.localPosition = new Vector3(xIn, yIn, -9);
            mappedX = Map(imgRt.localPosition.x, -2, 2, 0,
mySprite.bounds.size.x);
            mappedY = Map(imgRt.localPosition.y, -2, 2, 0,
mySprite.bounds.size.y);

            lR.AddToPointsList(new Vector2(mappedX,mappedY)); //Send
value to line renderer
```

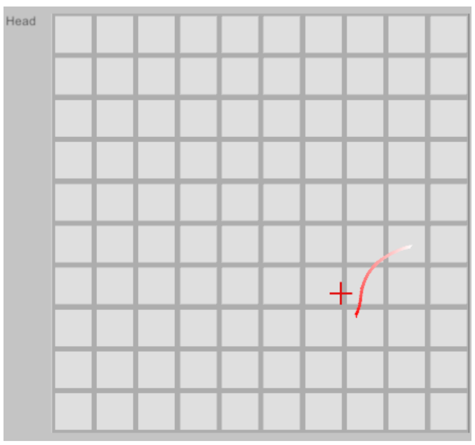


Figure-26: Example of the head tracking UI.

Panic Button Implementation

The panic button creates an effect that simulates the eyes closing. The screen fades to black from both top and bottom like eyelids closing. This is what testers will be told to press when they feel any symptoms and need a second to gain composure.

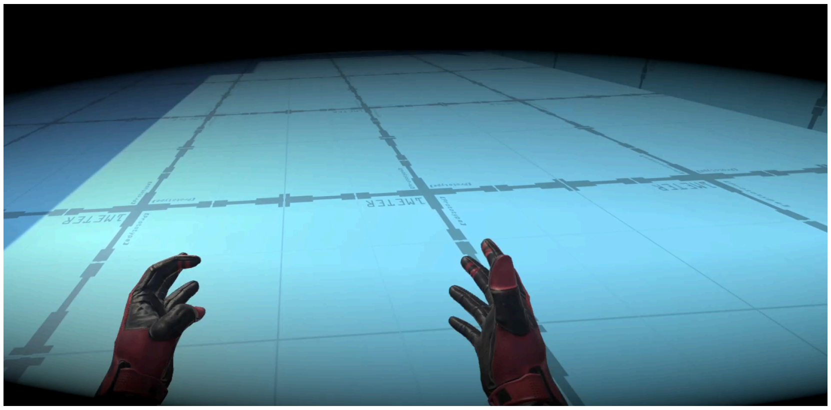


Figure-27: In the middle of closing eyes animation.

Timeline Implementation

The timeline was implemented as a simple stopwatch that begins when I start recording. When the user closes their eyes the time they press the button and when they release it are both recorded and then displayed on the UI.

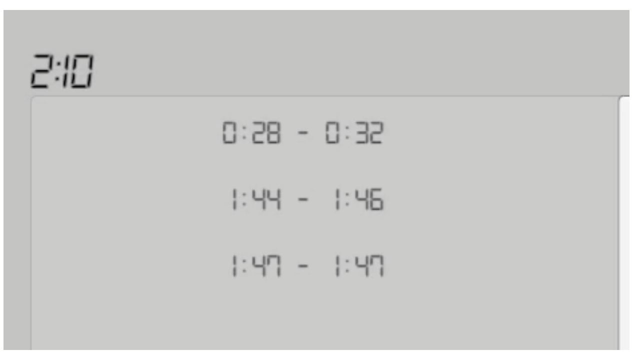


Figure-28: UI displaying when the user had hit the panic button.

Physical Locomotion System

For movement I went with a physics based solution as this is similar to what popular games such as Boneworks and PavolVR have. This solution treats the player's collider the same as any other physics object in the world. The player will slide, stick and bounce off walls based on the physics engine. This made it easy to add features like jumping, sliding and crouching as they are treated as forces on an object. The basic algorithm for every frame is

1. Get the movement input (Left stick, jump button, crouch button)
2. Get look input (HMD rotation)
3. Get relative movement direction (Stick + HMD rotation)
4. Check what the player collider is touching (Slopes, ground, walls, ect..)
5. Use appropriate friction values
6. Add appropriate forces to the player body, which in turn moves the camera.

Unlike traditional flatscreen games which only have the player controlling a camera. In VR the player controls the camera as well as two motion tracked controllers that follow them. On top of that the player avatar must follow the player when they either move using the joystick or walk around their physical space.

To have the motion controllers follow the player It was just a simple solution of making a root gameObject that did all the movements. This way the parent object moves in the world and the hands and head can move relative to it.

Figure-29: Player character hierarchy. [CameraRig] is the parent moving object and the controllers and camera are children of it.

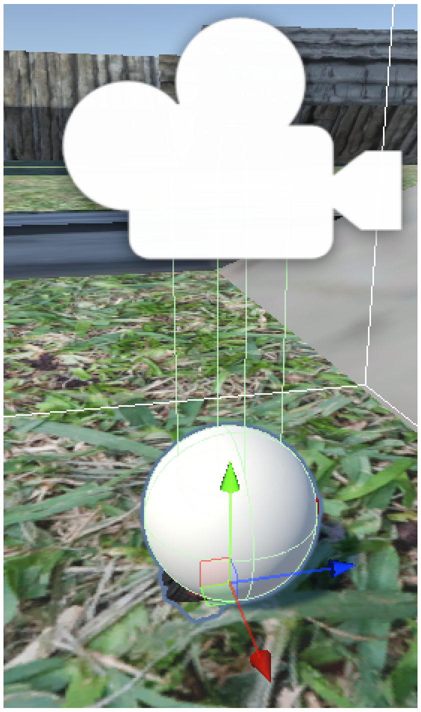


Figure-30: Player hierarchy in viewport

The final player character has a sphere to represent their feet, a camera for their head and a single torso collider that scales depending on the distance between the feet and head. The sphere is used for all movement collisions and the torso collider is more for gameplay purposes such as detecting if the player is entering any special areas.

Since the main body is driven by physics, it makes sense that the hands are also done the same way. The player's hand models follow the controller's location through the use of physics forces. They can get stuck behind walls and if they get too far from the real controller they are teleported to it.

Level design

- Changing specificity

  Goal: Go through a short set of hallways to get to the end room and put the key in the door

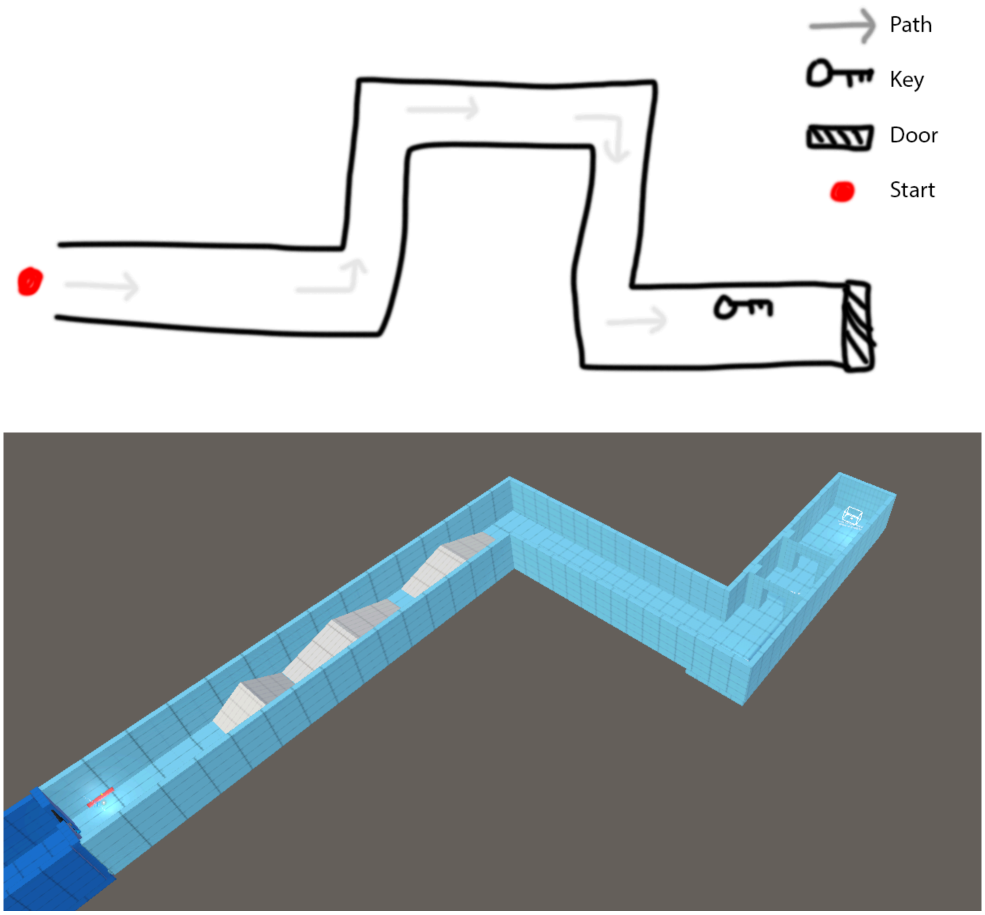
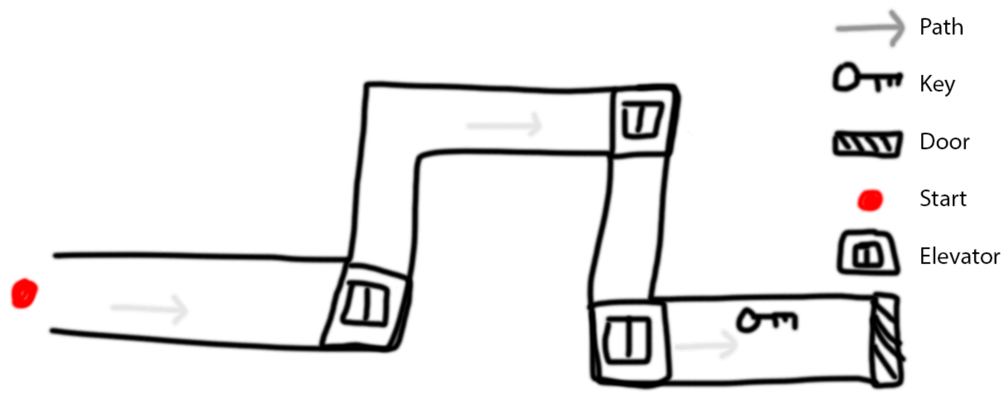


Figure-31: Level 1 screens

- Changing relationship between gravito-inertial vector and surface

  Goal: Navigate a set of hallways that are connected by moving elevators. At the end there will be a key and door.



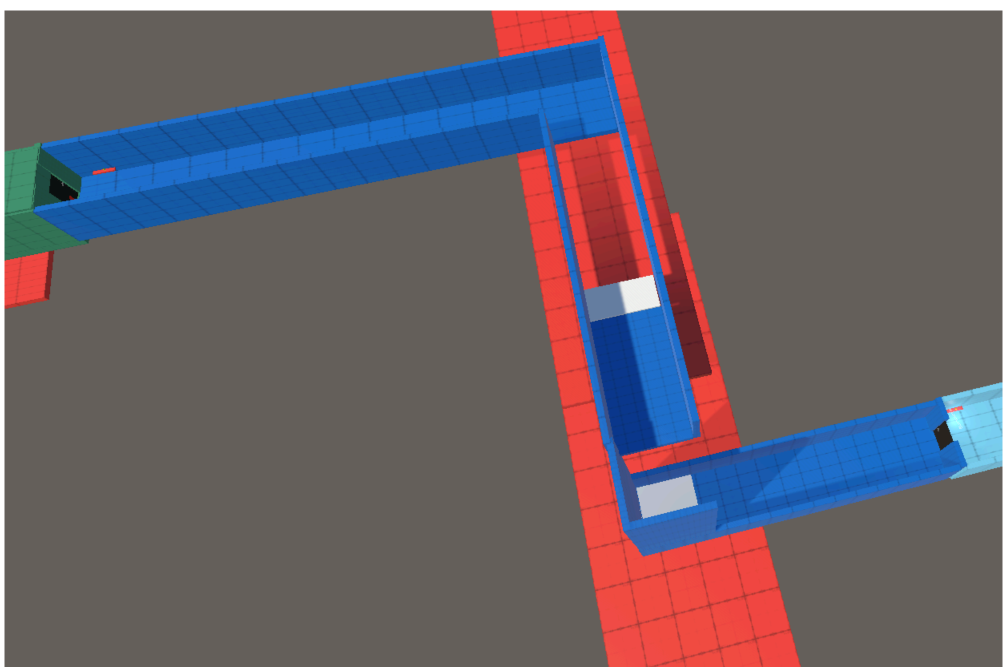


Figure-32: Level 2 screens

- Low frequency Vibrations

Goal: Navigate hallways that feature gaps that need to be jumped over. The last gap will be wall-jumping upwards.

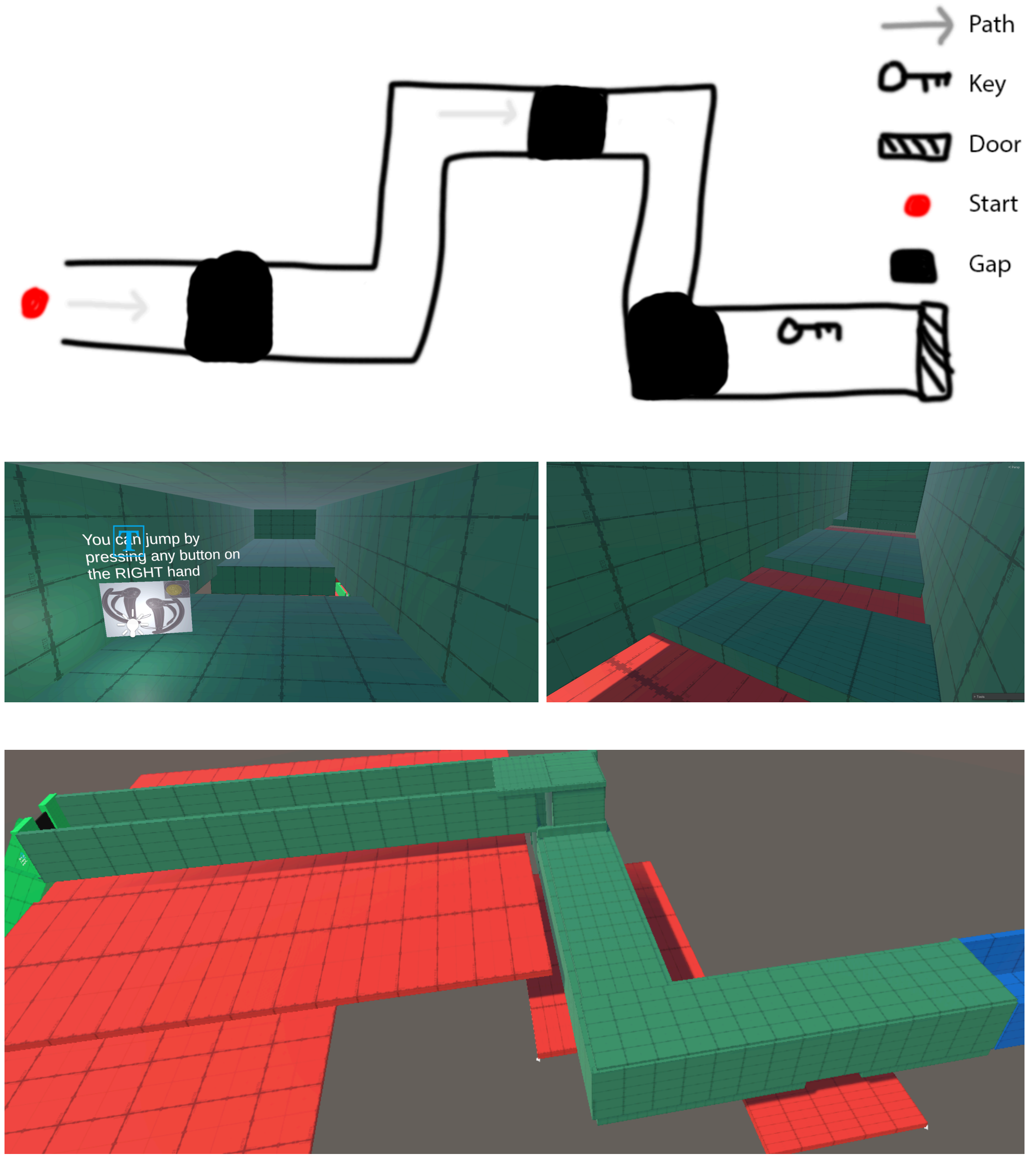


Figure-33: Level 3 screens

- Weightlessness

Goal: Slide down a large slide, then get launched really far with a catapult.

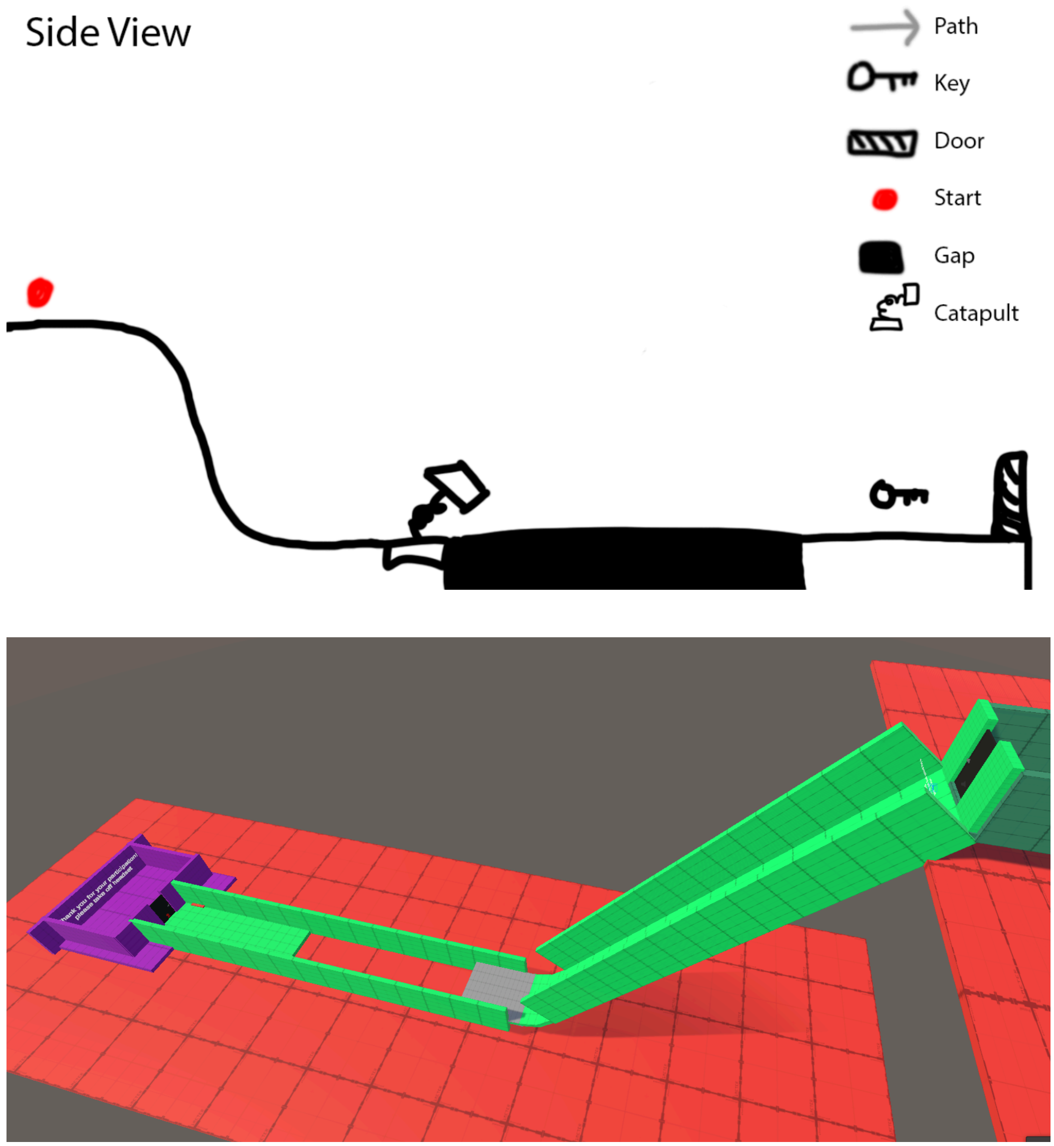
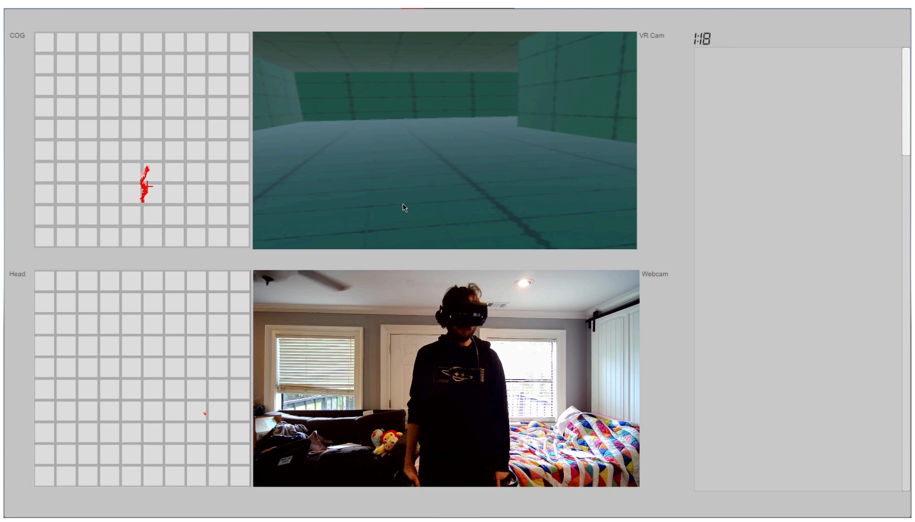
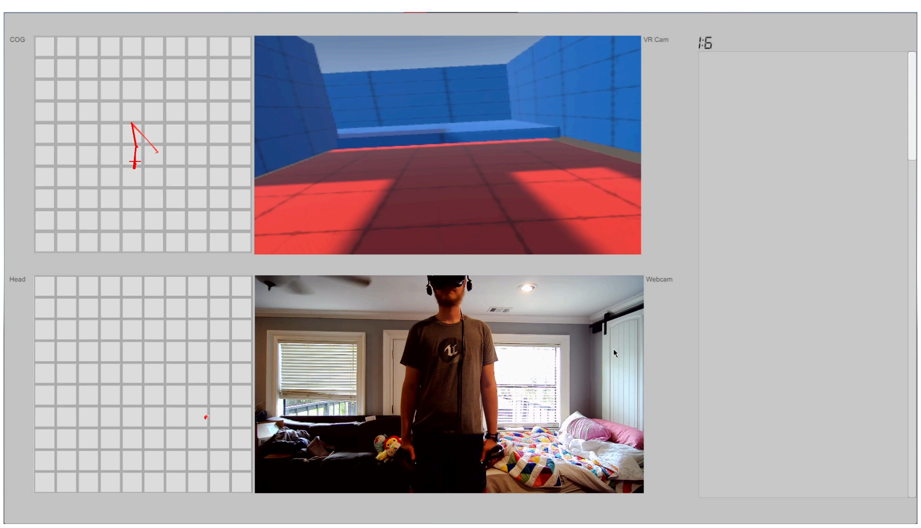


Figure-34: Level 4 screens





Figures-35,36,37: Images from testing video capture. (Full runthrough : https://youtu.be/IOq23TT_-cQ)

Data collection and analysis

Data was collected from four testers. Two were familiar with VR and said they tend not to get motion sick easily. The other two testers were not so familiar, while they had tried VR they said they do get motion sick pretty quickly. All trials were done in one day in the span of 3 hours. Each tester got about ten to fifteen minutes of rest and a glass of water before their next trial. Here are the insights based on the data collected.

Panic button was not used

The first and most obvious critique would be that testers did not really use the panic button naturally. No tester used it on their first play through. When they were explicitly instructed about it before their second trial. The two experienced players still did not press it and the two newer players pressed it but noted afterwards that they closed their eyes first then pressed the button only because they were instructed to.

The possible reason for this could have been because when undergoing motion sickness our body looks for ways to limit perception easily (Stoffregen, 1991), and closing our own eyes is quicker and more natural than pressing a button on a controller.

Effects of restraint on motion sickness

When we look at the SSQ scores we can see that testers reported a higher level of sickness after playing while standing rather than seated.

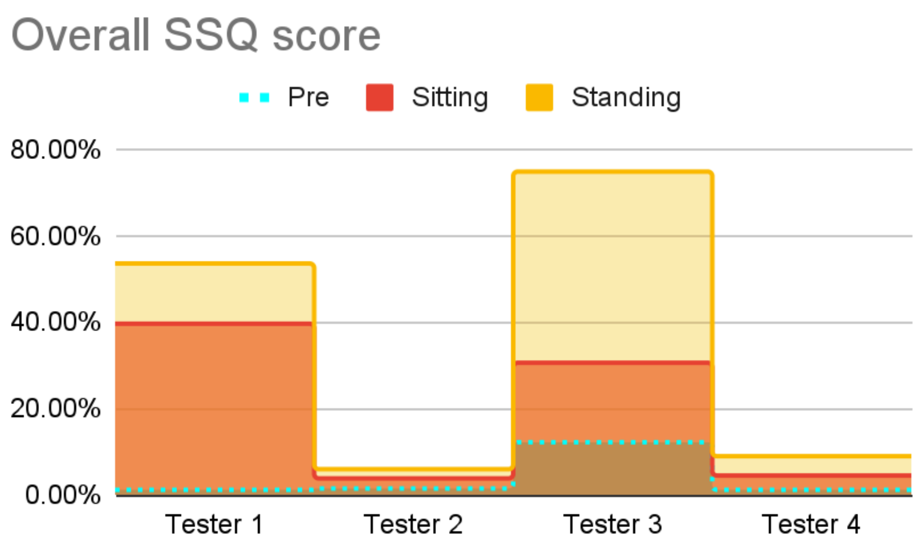


Figure-38: Stepped-Area graph showing testers SSQ scores in percentages.

From the graph above we can see that testers 2 and 4 are more experienced with VR as their overall scores are very low, but even they reported more sickness after playing standing over sitting. Tester 3 was the only one who did not finish the entire experience while standing and had opted out during level three due to feeling too sick. They reported a 75% on the SSQ while standing. Looking at the video footage we can see that the COG and unrelated head-arm movement signatures match up with what is said in the theory (Stoffregen ,1991).

Players had a mostly stable COG while seated but while standing it would swing wildly, usually when turning, grabbing the key or landing after jumping. The more experienced testers (2,4) would stabilize much faster after COG instability than testers 1 and 3.

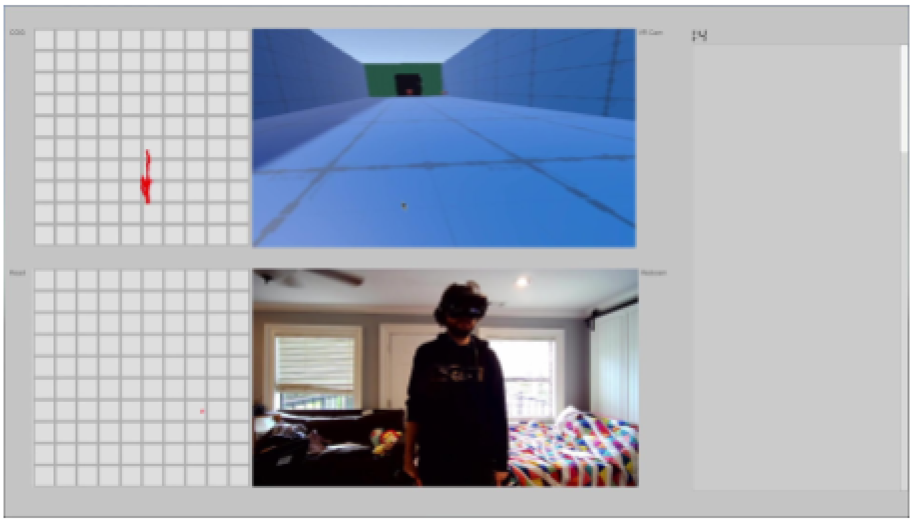


Figure-39: Tester 4 (experienced) after turning. A short destabilizing of COG before it became relatively stable quickly.

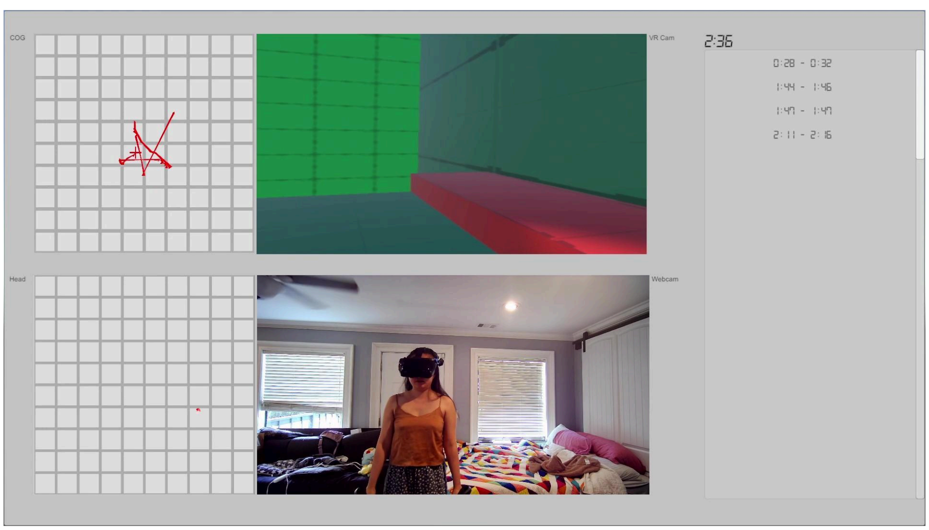


Figure-40: Tester 1 (Inexperienced) after turning. Larger destabilizing COG movements which took a while to stabilize.

This was common through all the playtests for standing and is a sign that players were learning to stabilize in their environment (Stoffregen, 1991).

Unrelated head-arm movements were another signature that matched up from the theory. Since people can train resistance to getting motion sickness in VR (Thompson, 2020), the more experienced testers (2,3) did not show many signs of unrelated head-arm movement as they were familiar with the medium and how it operates. The two inexperienced testers however would make clear movements that were not related to the goal at hand and instead aided in comfort by minimizing perception or action (Stoffregen, 1991).

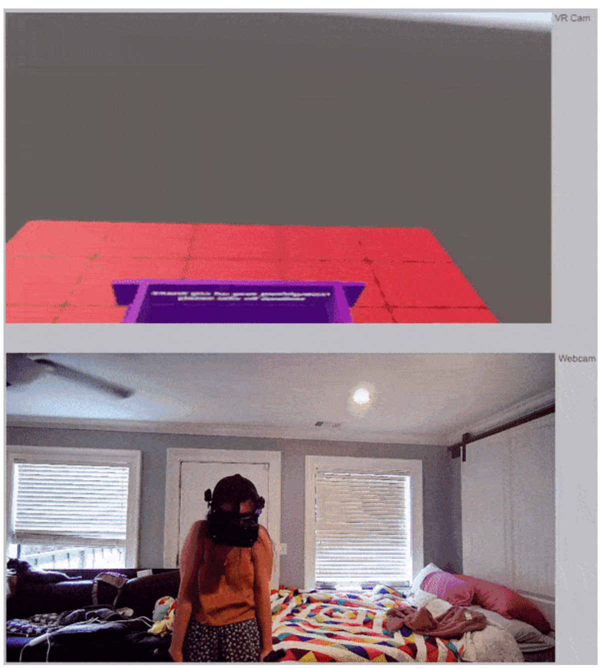


Figure-41: Tester 1 wild arm and head movements while on the last level jump.

Figure-42: Tester 3 turning while wincing and tensing up the body.

Uncontrolled head sway was the only data point that was not consistent with the theory. The theory of posture control states that “the path of head motion could sway more and be different… during instability” (stoffregen, 1991). All the testers during all the trails had perfectly normal headway. The tester's headsway normally would pivot in a circle around a point. The radius of this circle is so small that the graph on screen looks like a dot.

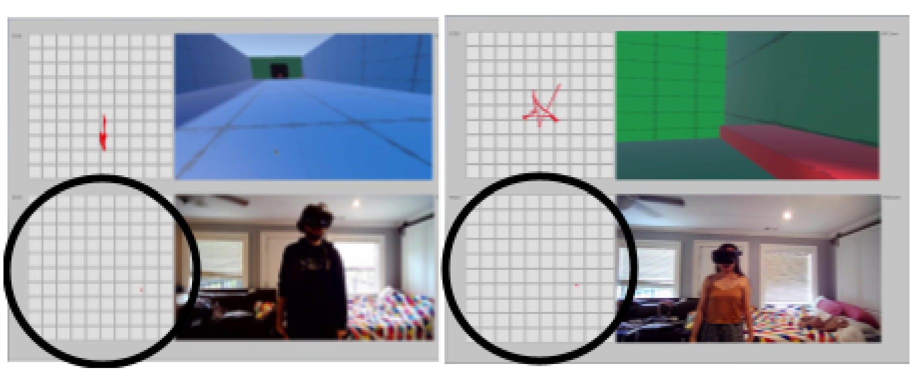


Figure-43: Tester 1 and 3 going through COG instability but headway is non-existent.

In the above image, the small red dots inside the black circles are the testers head position just after a turn. This is different to their COG which does swing wildly and in accordance to the theory. Going through the video footage, head movement did not ever swing wildly. Large head movements only happened when players looked up/down or leaned forward to read the text, however these motions were immediately stabilized. A big reason for this could be that a fundamental goal of VR is to focus on the screen (Brennan, 2019) and our body prioritizes keeping stable enough to achieve this goal (Stoffregen, 1991). In this case head stability leads to eye stability. This can be seen in the head sway of the participants and how it was very still. Even though their COG would sway.

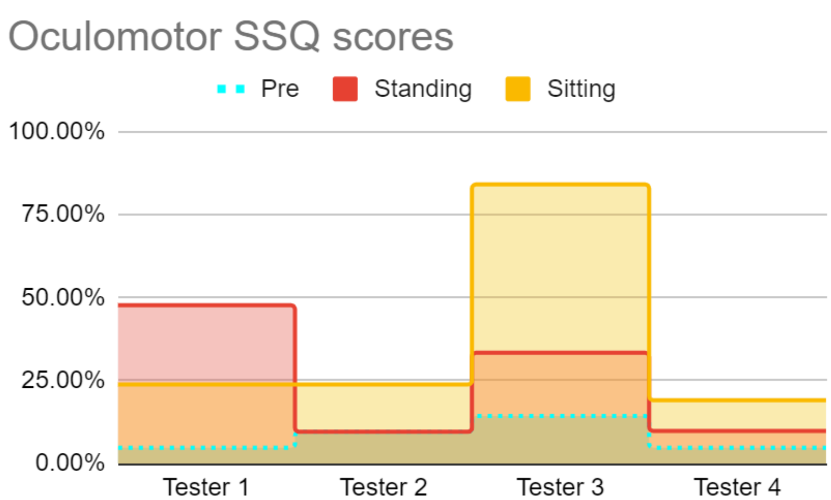


Figure-44: Oculomotor SSQ scores

The testers alternated which method they did first (standing or sitting), and their overall SSQ scores were higher standing. Their oculomotor SSQ score however would always increase from one trail to another and level of restraint did not matter. This could be another sign that the goal of focusing your eyes in VR is mandatory and losing eye focus is not an option while in VR. So we try to keep our head stable above all else.

Limitations and constraints

Balance board accuracy

The Nintendo Wii balance board is a cheap alternative to a commercial force platform. It does not have the same level of accuracy as a commercial platform nor does it process input at the same speed. The balance board is also small, only allowing for users to stand on it. Larger commercial platforms would have allowed the player to walk around more naturally in VR while still allowing for the collection of COG data.

Lack of testers

Due to Covid-19 and due to the proximal nature of the testing it was hard to find testers. More testing would have led to a much greater accuracy in the analysis. The experienced VR users did not provide as substantial of data points as motion sickness is something you can train yourself out of. More newer to intermediate testers would have been good.

Better Audio

Since we use all our perceptions to help keep us stable, good spatial audio might have aided in better postural control and less sickness. However that is out of the scope of this paper.

Testing Time

Since users will eventually get sick in VR (Thompson, 2020), better data could have been collected through a longer play session, especially with experienced players as they did not really feel the effects of motion sickness in the short playtime given.

Conclusion

While the features of postural control do present themselves in VR for users undergoing motion sickness, and having the added restraints of sitting led to a lower SSQ score. The effect of VIMS is one that is central to VR as a main goal is to focus the eyes on the screen which can cause oculomotor strain. This strain cannot be reduced through restraints other than closing one's eyes (Brennan, 2019).

Therefore, restraining motion is helpful in making users feel less motion sick while playing and could be a good way to ease newer players into games with physical locomotion. However motion sickness in VR will happen over time due to the uncontrollable nature of the oculomotor strain from focusing on the screen.

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Appendix/Raw data.

All raw video files and questionnaire data link - https://drive.google.com/drive/folders/1wLUPUuodrOYP5DYZSxzpEDDNBws3t-JJ?usp=sharing