Reducing Simulator Sickness for Travel in Virtual Reality

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ABSTRACT

We review the literature on simulator sickness with a focus on travel or locomotion in virtual environments. We evaluate the causes of sickness and also how the issues surrounding sickness are currently addressed. We also look at how we may further experiment and build on these solutions.

KEYWORDS

virtual reality, motion sickness, simulator sickness, travel in virtual reality

1 INTRODUCTION

Sickness in VR is often referred to as motion sickness, cybersickness or simulator sickness. Often used interchangeably, the terms have similar symptoms but are not the same.

[Jerald 2015] provides a description of each:

- Motion sickness: Adverse symptoms resulting from real or apparent motion.
- Cybersickness: Visually induced motion sickness resulting from immersion in a computer-generated virtual world. That is, symptoms from real or apparent motion while being immersed in a computer-generated, virtual world.
- Simulator sickness: Adverse symptoms resulting from shortcomings of the simulation, unrelated to the activity being simulated. The comparison between flying a plane in reality and flying a plane in virtual reality is often used to illustrate this: in reality the pilot does not get sick while flying the plane but when performing simulated flight they do. This is therefore as a result of the simulator.

To clarify on the above, while these three terms have different meaning, cybersickness defines specific parameters within which motion sickness occurs and is therefore a specialized term for motion sickness. Simulator sickness may occur as a result of cybersickness. That is, a person experiencing cybersickness while using a simulator can be said to be experiencing simulator sickness, but it is not always the case the other way around. A person said to be experiencing simulator sickness may be experiencing it as a result of something other than cybersickness (i.e. may be experiencing eyestrain which has nothing to do with motion sickness or cybersickness).

As previously mentioned, motion sickness and simulator sickness share similarities but are still unique conditions. The similarities they share lie in the symptoms induced by the condition. The following symptoms are commonly experienced: headaches, nausea, eyestrain, as well as any other feelings of general malaise. Since its inception, persons undergoing travel and movement in Virtual Reality has been plagued by these symptoms. When an individual experiences these symptoms while engaging movement in these virtual environments or realities it greatly degrades the experience. Furthermore, it could result in further complications depending on the individual, the infrastructure or equipment and the task being performed. [Kolasinski 1995]

2 MOTIVATION

Virtual Reality and Virtual Environments are an up and coming technology that has the potential to impact a multitude of industries and facets of everyday life. From entertainment to skills training, the utilization of a virtual environment provides possibilities for the creation circumstances that *seem* real but are virtual. It does so in a way that is feasible, scalable and furthermore, comfortable. Or at least it should be. Simulator sickness, aside from making the virtual experience unpleasant, can be seen to leave lasting effects even after exposure to the virtual environment [Kellogg and Gillingham 1986]. This is both a usability and safety concern in that people will not be interested in engaging with VR and also, depending on the severity of the symptoms, might leave people temporarily incapacitated. Movement or travel in VR is one of the main causes of simulator sickness and is still largely an unsolved problem. As movement or travel in VR is such an integral component to our interaction and experience we must investigate into the strides made in the reduction of simulator sickness and aim to provide a meaningful contribution to a solution to this problem.

3 SIMULATOR SICKNESS AND PRESENCE

Presence is defined by The International Society for Presence Research as follows: “Presence (a shortened version of the term “telepresence”) is a psychological state or subjective perception in which even though part or all of an individual’s current experience is generated by and/or filtered through human-made technology, part or all of the individual’s perception fails to accurately acknowledge the role of the technology in the experience.“ It is commonly referred to as a sense of ‘being there’ in a virtual environment. [for Presence Research 2000]

The experience of sickness breaks the ’presence’ of the user, especially when it is due to flaws in the simulation or hardware.

4 CAUSES OF SIMULATOR SICKNESS

As there is a domain of causes and effects shared by each of motion sickness, cybersickness (cybersickness, being motion sickness in a specific environment, will have the same physiological causes as motion sickness) and simulator sickness we will look at the most prominent hypotheses regarding the cause of each of the sicknesses. This is in order to have complete coverage of potential causes for symptoms while traveling in VR.

4.1 Response to poison

[Treisman 1977] proposes that motion sickness is as a result of evolution of the human body to detect and rid itself of toxins. This theory suggests that suggests ill symptoms are a defensive mechanism as part of the bodies response to poisoning.

Treisman's hypothesis has three core points:

- Inorder to carry out their function, eye-head and head-body systems involved in controlling movement must be extremely sensitive
- Neurotoxins in the body can affect motion control
- Neurotoxins, when ingested, usually result in emesis (vomiting)

Triesman thus argues that together, these facts suggest that if the body detects alterations in the way the eye-head and head-body systems function then this may signal as early warning signs for neurotoxins in the body and therefore the body responds by forcibly removing it from the system by vomiting.

This theory does not cover all symptoms of motion sickness as it only discusses nausea and malaise. Therefore there must be some other reason for other symptoms.

4.2 Sensory Conflict

Sensory conflict proposed first by [Reason and Brand 1975] occurs when there is a lack of corresponding input from all senses that expect to receive input. For example, stimulation of the vestibular system is usually accompanied by visual information corresponding to such stimulation. This lack may occur in VR when visual and auditory cues for motion are provided by the simulation. The brain then expects corresponding vestibular and proprioceptive (relating to body position and movement) stimuli originating from the movement of the body. When input from these senses do not correspond as expected then motion sickness may occur.

4.3 Postural Instability

The postural instability theory by [Riccio and Stoffregen 1991] suggests that stable posture is a primary goal in animals and as such also in humans. This postural stability is dependent on the environment and humans adapt their physical positioning to ensure this stability. When no such adaptation is possible for long periods of time the body begins to show symptoms of motion sickness. [LaViola 2000] states that the body is constantly moving and maintaining bone position to ensure stable posture. When the wrong muscle control is applied due to perceiving visual motion inconsistent with the physicality of the body, postural instability occurs. This is backed up by the experiments done by [Stoffregen and Smart 1998] in which participants were exposed to different visual patterns via a head mounted display. Postural sways were observed to precede motion sickness in participants which is a strong point in favor of the postural instability theory. They also report on several experiments where sensory conflict should have occurred but no motion sickness ensued in participants.

5 SYMPTOMS

It can be seen by literature that it is common for simulator sickness to occur when either one or more of eyestrain, vection and disorientation is experienced. [Biocca 1992] states that symptoms often fall into one of three general cases: 1. Nausea 2. visual-motor disturbances 3. user disorientation. This is likely based on the grouping of the SSQ discussed in section 6.1 [Kennedy et al. 1988] Here follows a discussion of each of these factors.

5.1 Oculomotor disturbances

Oculomotor disturbances are often triggered by eyestrain (Asthenopia). [Donders and Moore 1864] proved that eye movement and focus is involuntary. This means that if a VR environment is observed to be grainy or blurry the eye and brain will struggle to resolve the details. Clearly this is a futile process but the brain does not know this and will continue until an active effort is exerted to change focus onto something else. This experience results in asthenopia, more commonly known as eyestrain or eye fatigue. A common symptom of asthenopia is the onset of a headache.

5.2 Nausea

Nausea is often triggered by vection. Vection is the illusion of self-motion while being stationary. It is experienced when the brain receives visual information from the ocular senses that motion is being experienced but no other supporting information from other senses. This mismatch between input from the balance and visual organs induce nausea such as that experienced from motion sickness. This is as per the sensory conflict theory [Reason and Brand 1975]. A study done by [Kennedy et al. 1987] shows that repeated exposure to vection leads to reduced symptoms, as the brain learns to accommodate the mismatch. The study was carried out 10 participants who repeatedly experienced a visual/vestibular conflict over trials and days. These participants were shown to have reduced symptoms of dizziness and ataxia. It is estimated that 95% of people are able to adapt [Tyler and Bard 1949]. The remaining people, regardless of the amount of exposure, do not adapt or experience reduced symptoms.

5.3 Disorientation

Movement in an unknown environment or in a unknown or unpredictable manner may result in the brain losing its sense of location. If the brain loses its sense of location the brain attempts to reconstruct a mental model of the space. If it is unable to it will not know to stop and thus may lead to the brain being overwhelmed with this task and motion sickness symptoms such as headache or malaise may ensue. [Jerald 2015].

6 FACTORS THAT MAY INCREASE SIMULATOR SICKNESS

There are multiple factors that increase the chance of sickness occurring. Here we discuss factors specific to both the VR system and the individual using the system.

6.1 Factors relating to the VR system

6.1.1 Latency. Latency is the delay between the user input and the observed output. In most VR systems, latency is the largest source of error [Holloway 1997] and often is the main reason behind motion sickness.

6.1.2 Calibration. Calibration is the correct mapping between actual user input and system input. If calibration is not accurate, it may be a major cause of simulator sickness. In the worst case, bad calibration may result in unstable, shaky scenes and scene motion when the user moves their head [Holloway 1995].

6.1.3 Field-of-view (FOV). A wider FOV will result in more sickness due to higher sensitivity to vection which in turn is due to more stimuli to peripheral vision [Lin et al. 2002].

6.1.4 Judder. Jerky, glitchy or coarse motion observed when using VR is known as judder. [Jerald 2015]

6.1.5 Refresh rate. The higher the display refresh rate, the lower the latency, judder and flicker. [Jerald 2015]

6.1.6 Flicker. Higher luminance results in more flicker. In the best case flicker is a distraction and results in eyestrain. In the worst case it can cause seizures. [Jerald 2015]

6.1.7 Conflict between vergence and accommodation. Conventionally, accommodation remains constant but vergence does not. Therefore when visuals are placed close to the eye it may induce eyestrain. Therefore it is advised to either avoid it or only do for short periods of time to reduce strain on the eyes. [Donders and Moore 1864]

6.1.8 Binocular Images. Either monocular or binocular imaging may be used. Monocular uses the same one image for each eye while binocular imagine uses two slightly different images to provide the illusion of depth. Incoherent binocular images can lead to double images and eye strain. [Donders and Moore 1864]

6.2 Factors relating to the individual using the system

6.2.1 History of motion sickness. [Johnson 2007] states that a prior history of motion sickness has a positive correlation with simulator sickness.

6.2.2 Health. [Kolasinski 1995] reports that health factors such as sleep, hunger or malnutrition or the intake of drugs may affect the individuals susceptibility to sickness.

6.2.3 VR experience. As mentioned in section 4.2, the majority of people are able to adapt to vection which is a main cause of sickness.

6.2.4 Thinking about sickness. When participants think about getting sick, or dwell on the possibility of experiencing negative symptoms, they become predisposed to feeling these effects [Young et al. 2007].

6.2.5 Gender. Due to differences in field-of-view, and hormonal differences it is hypothesised that females are more susceptible to sickness [Hale et al. 2014].

6.2.6 Age. Motion sickness susceptibility is greatest between 2-12, diminishes drastically between 12-21 and is almost non-existent after 50 [Reason and Brand 1975].

7 MEASURING SICKNESS

Due to the various symptoms and causes, more than one variable must be used to measure sickness. This, along with the fact that the experience of sickness in VR varies greatly from person to person makes it difficult to measure sickness. The most common means of measurement is to make use of questionnaires or surveys. This is, however, a subjective measure and depends on the individuals ability to report and gauge feelings of sickness due to the simulation. Postural stability tests and other psycho-physical measures are sometimes used as a more objective means of measurement.

7.1 The Simulator Sickness Questionnaire

The Simulator Sickness Questionnaire (SSQ) was designed by [Kennedy et al. 1988]. It uses a 4 step Lickert scale ranging over "none," "slight," "moderate," or "severe" to measure symptoms across three categories: nausea, oculomotor and disorientation.

Nausea symptoms relate to stomach awareness, burping and increased salivation. Oculomotor symptoms relate to eye strain, difficulty focusing, blurred vision, and headache. Disorientation symptoms relate to dizziness and vertigo.

While the SSQ is usually given before and after an experiment so as to provide a baseline [Young et al. 2007] found that when the SSQ is given prior to the experiment then the amount of sickness those users report after the VR experience increases. Therefore, in order to remove bias, it has become standard practice to only have the participant complete the SSQ after the experiment and not before [Jerald 2015]. This, however, means that there is no baseline to compare to and leaves the experiment with confounding factors that were not a problem when the baseline was used.

7.2 Postural stability

Postural stability can be used as a behavioral measure for motion sickness. Either dynamic or static postural stability may be tested. The Sharpened Romberg Stance is a common static test.

The stance is performed as follows: one foot in front of the other, heel touching toe, weight evenly distributed between the legs, arms folded across the chest, chin up. The postural instability measure makes use of the number of times a subject breaks the stance [Prothero and Parker 2003]. Several commercial systems currently exist to measure postural stability.

7.3 Physiological measures

The use of physiological measures provide an objective, unbiased measurement of sickness over a VR experience.

Physiological data that changes as sickness occurs include the following [Harm 2002; Kim et al. 2005]:

- Heart rate
- Blink rate
- Electroencephalography (electrical activity of the brain)
- Stomach upsetness
- Pallor
- Cold sweating

This data can be measured with a variety of sensors such as those measuring skin conductance levels and heart rate monitors.

8 CURRENT BEST PRACTICE AND GUIDELINES FOR REDUCING SIMULATOR SICKNESS

The following guidelines are given by [Jerald 2015].

8.1 Hardware

The head mounted display (HMD) should be light, comfortable on the head, and have high refresh rates and low judder. It should also have precise and accurate position tracking.

8.2 System calibration

Ensure proper calibration of the system, as well as a match between the virtual environment field of view and the field of view of the HMD.

8.3 General design

Minimize imagery close to the eyes so as to avoid conflict between vergence and accommodation. Overlays and text in 3D should be positioned at some distance from the user. 2D heads-up displays should be transformed to, or replaced with, a 3D version that has a distance from the viewpoint so that occlusion depicted correctly. This is so that users do not get confused when the heads-up display appears at a distance but is not occluded by closer objects. If this is not done it may lead to asthenopia. Scenes should be made darker (within reason) inorder to avoid eyestrain.

8.4 Motion design

Do not move the viewpoint in any way that deviates from actual head motion of the user. If high latency is present, avoid inducing rapid movements to reduce judder. A real-world stabilized rest frame may be used to provide visual input that matches vestibular cues. This may reduce sickness but is likely only an option for scenes where a large portion of the background is visible and realism is not required. Other recommendations include avoidance of head bobbing, attempting to only make slower orientation changes and to provide visual indicators when motion is about to occur.

9 WAYS TO MOVE IN VR

We look at the various ways movement with minimal sickness is currently implemented.

9.1 World In Miniature (WIM)

World in Miniature [Stoakley et al. 1970] allows the user of the virtual environment to move through the world by manipulating a miniature world. This allows the user to indirectly move through the world and therefore is less susceptible to producing effects pertaining to motion sickness.

9.2 Jumper Metaphor

The jumper metaphor is a form of teleportation whereby the user points to a position in the virtual environment and is then teleported to that position, maintaining the original orientation. [Bolte et al. 2011]

9.3 Physical or pseudo physical movement

[Usoh et al. 1999] carried out an experiment investigating whether participants experience a higher sense of presence when they by by walking-in-place (virtual walking) than when they use hand-held controllers to 'fly' in a virtual environment, this was compared to real walking as a third condition. Their findings were that presence is highest for real walking, then virtual walking, and lastly flying.

The following graph of user responses reiterates that walking is the most natural.

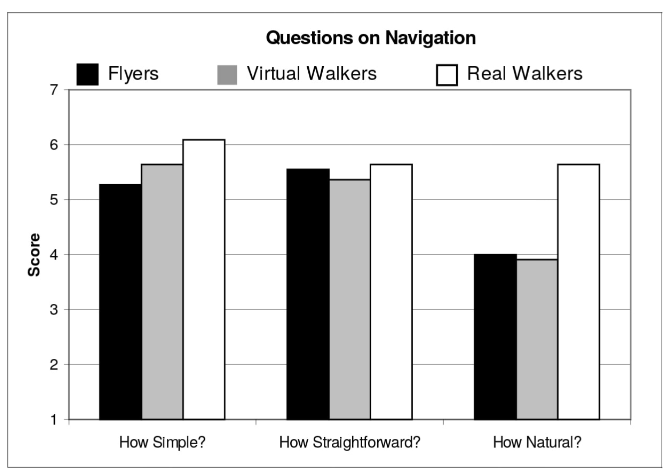

Figure 1: Ease of locomotion across groups[Usoh et al. 1999]

10 DISCUSSION

10.1 Evaluation of potential causes

When looking at the causes behind sickness, particularly motion sickness, we saw that sensory conflict was proposed as a theory. According to [Kolasinski 1995] it is the most widely accepted theory. It suggests that the lack of redundant, expected sensory information prompts the brain to reason about it and figure out why there is a discrepancy between what it expects and what it experiences. This likely results in ill-symptoms due to cross-talk over neurons. More succinctly: all pathways between sensory organs and the brain are crossed (except the nose). This means most pathways run parallel in the center of the brain, including the vagus nerve to the entric system (controlling the gut). If there is mismatch between the optic and balance systems then cross-talk on the vagus nerve may be triggered which could lead to nausea. We then looked at the postural instability theory which says that it is a primary human function to maintain postural stability and when this is thrown into question the body takes corrective steps. When we receive visual stimuli that we are turning or our orientation is changing our body attempts to move and adapt. This can be likened to the scenario of racing games where one tilts the body in the direction of the way the car is turning. The Postural instability theory by [Stoffregen and Smart 1998] opposes the sensory conflict theory, arguing that the lack of redundant sensory information is commonplace in our everyday environments and thus should not cause sickness. Furthermore, while the sensory conflict theory states that sickness will occur where there is a mismatch between expected and experienced stimuli it does not predict which situations will result in this mismatch and how severe the sickness will be while the postural instability theory is able to predict potential sickness. Finally, the postural instability theory is backed by several experiments and can be measured while the sensory conflict theory and in some experiments better explains sickness than the sensory conflict theory. This suggests that perhaps sensory conflict is simply the more popular choice as opposed to the true reason behind motion sickness. It is of course entirely possible for both theories to hold and motion sickness be caused by a combination of the two.

10.2 Evaluation of existing solutions

In order to minimize simulator sickness during locomotion we evaluate each of the different solutions for travel in virtual environments. Various issues can be identified that make some modes better than others, depending on the environment in which it is to be used. In the case of the fixed visual cues, there is still the possibility that the user is unable to remain focused on the fixed frame and they may experience vection. If they are able to remain focused it may take effort for them to do this which may result in eyestrain. Furthermore, the fact an active effort must be made to remain somewhat focused on the fixed frame which may detract from the user experience. The WIM approach has limited uses in that it is only applicable in situations where the user moves with discrete, fixed and well defined motions. It would not work in a racing game or RPG (role-playing game). The jumper metaphor suffers from disorientation as the user may not know what environment they teleport into and what they will be facing. Furthermore orientation and rotation is also a complicating factor. Lastly, physical movement requires either large empty space to move around in while pseudo physical movement does not reach the same levels of presence. It is also not applicable to all scenarios, such as that of a racing or flying simulation. Therefore the fixed visual cue approach may be the one that may be most generally applied with the most consistent experience and could therefore be the better of the approaches. Walking in place on the other hand may be the best for continuous movement and navigation, like that of walking around in a virtual world.

We also looked at experiment design and measurement.

The standard method appears to be to firstly do a baseline measurement of symptoms using the SSQ. Then once the experiment concludes perform another measurement.

Confounding factors or conditions are those that are not part of the experiment and may influence both the dependent variable and independent variable in an experiment. The following confounding factors are to be taken into account:

10.2.1 *Confounding Factors.*

- Vivid, flashing lights - May potentially trigger an epileptic fit for a participant with epilepsy. It is also likely to induce headaches or irritation to participants without epilepsy.
- Smells - Some smells may trigger feelings of disgust and may make the participant feel queasy or nauseous.
- Full or empty stomach - Nausea seems to be more likely to occur in participants who are either have a very full or very empty stomach. It therefore may be good to record the time of the last time the participant ate.

11 CONCLUSIONS

The issue of travel in virtual reality is due to the propensity for sickness to occur and thus ruining the experience. It is a difficult issue to address and the multiple proposed theories behind it show that it is a problem not yet fully understood. While different approaches attempt to address it is not surprising that none of them get very far at addressing it. While these approaches all have some benefit when applied correctly and in the suited environment there is still no definitive solution. If experiments are to be done the pursuit to find such a solution it is advised they make use of the SSQ in tandem with other physiological measures. It is also advised consider what confounding factors may be present and account for them appropriately. This will ensure that work done may be compared with other studies and will be consistent with the standard that has emerged in VR research.

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