# Sickeningly Immersive

Techniques For Reducing Motion Sickness in Virtual Reality

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## ABSTRACT

The present study defines and explores the various techniques available for reducing motion sickness in virtual reality. Specifically, game design in relation to locomotion in games, omnidirectional treadmills, traditional remedies and galvanic vestibular stimulation.
A focus is given to causes and solutions based in sensory conflict theory and postural instability. The issues of cost, immersion, availability and implementation alongside each technique's effectiveness in reducing motion sickness are explored and recommendations are made on which technique will likely perform the best. Game design and, more specifically, teleportation as a player movement control is found to be the most effective way to deal with motion sickness in VR due to its low cost, ease of implementation and effective prevention of motion sickness.

## Keywords

VR, Virtual Reality, Motion Sickness, Omnidirectional Treadmills, Galvanic Vestibular Stimulation, GVS, Locomotion, Teleportation, Sensory Conflict, Postural Instability

## 1. INTRODUCTION

In recent years, the resurgence of virtual reality (VR) as platform and its most widespread adoption to date has required hardware manufacturers and developers to address the widespread re-emergence of motion sickness (Smith, 2017). Often referred to as cyber or simulator sickness in this context, motion sickness is a barrier to entry for both games and simulation (Biocca, 1992; Virtual reality has a motion sickness problem, 2017).

The present study aims to highlight the different methodologies in use for reducing motion sickness, their respective effectiveness, limitations and how these techniques can be combined. This will allow the largest number of players and users possible to be fully immersed in virtual reality without the hindrance of motion sickness.

## 2. MOTION SICKNESS

Although VR-specific motion sickness has not been studied to the extent that more widespread types of motion sickness have, (informally referenced as sea-sickness and travel sickness) it is thought that the causes are likely to be similar. Thus, traditional motion sicknesses are often referenced when dealing with simulator and VR sickness (US Army, 1995; Ohyama et al., 2007). Therefore traditional theories applicable to motion sickness are also applied to VR. There are two leading theories about the cause of motion sickness; sensory conflict theory and postural instability (US Army, 1995).

Sensory conflict theory suggests that motion sickness occurs when there is a disconnect between the information fed to the brain by the vestibular and non-vestibular systems resulting in the nausea commonly associated with motion sickness. It is further theorised that this reaction is a defence mechanism against neurotoxins, because the same part of the brain controls vomiting and resolves conflict with visual and vestibular proprioception (US Army, 2005; Purdue.edu, 2017).

Postural instability theory posits that postural instability, the state whereby a person cannot keep their body balanced in a stable way, results in poor postural adaptations in reaction to odd visual input such as that which can be felt in a VR headset. This theory allows for the prediction of motion sickness ahead of symptoms showing. This is due to the fact that postural instability markers may be measured prior to symptoms occurring (Stoffregen and Riccio, 1988; Hollman et al., 2006).

## 3. KEY PLAYERS

There are currently five main players in the VR consumer hardware space: HTC Vive and Oculus Rift for PC, PlaystationVR for console and Daydream and Samsung Gear VR for mobile (Merel, 2017). All of these systems have largely dealt with the hardware-based issues associated with the initial concerns upon the re-emergence of VR. For example, Oculus' "asynchronous spacewarp" technology which interpolates intermediate frames. The availability of more reliable hardware platforms mean that the remaining motion sickness issues have been left to developers and end users to solve through game design, traditional remedies and hardware solutions.

## 3.1 GAME DESIGN

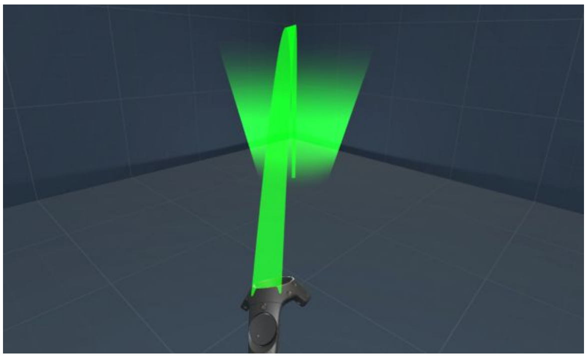

Figure 1. A typical teleportation implementation (Corrall, 2017)

Developers have a huge amount of control over the experience the users of their product have in VR. Firstly, optimisations to ensure frame rates are at a steady 90 frames per second (FPS) or higher are crucial to ensure users do not experience motion sickness (IrisVR, 2017). Secondly, locomotion in VR is a likely source of motion sickness. Movement in games and simulations similar to traditional PC and console games is likely to induce motion sickness due to the disconnect between the vestibular system and the visual system (Purdue.edu, 2017). For example, gliding like movement, especially with head bobbing, indicates movement to the brain through optical flow. However, the stationary player's vestibular system informs the brain there is no motion sickness. Because of this, there has been a widespread adoption of teleportation as the primary movement control in VR (see Fig. 1). This technique was spearheaded in its current form by Oculus in Robo Recall in 2016 and was described as a "fluid" and "seamless" by The Verge (2016). This was predated by a first-person shooter demo by Epic Games in 2015 which allowed for teleportation to fixed points in the game world. It is for these reasons that teleportation has since been adopted in popular titles such as Hotdogs Horseshoes and Handgrenades, Damaged Core and even SteamVR Home. Unity now recommends this technique, referring to it as "blinking" in their "Movement in VR" article (2017). They describe the technique as "a very quick fade to black, move the camera to the desired position, and then fade back up". Teleportation can become part of a game's mechanics in order to reduce the disparity between teleportation and the game world. For example, in Damaged Core, the teleportation is wrapped in a mechanic whereby the player takes control of enemy characters and blinks into their body to teleport.

Unity also offers some other techniques for reducing motion sickness. They posit that fading into a moving scene from black reduces nausea as no acceleration is experienced from the player's perspective.

There have also been positive results from research conducted around dynamic changes in the field of view while the player is in motion. Fiener and Fernandes (2016) found that the perception of VR motion sickness could be reduced in players without "decreasing their subjective level of presence". The same study also found that half of the players did not notice the changes in the field of view at all, showing that the technique was non-invasive to the gameplay.

It is also anecdotally considered that players having a platform or static area around them whilst in motion in VR, for example, the hovering platform in Hover Junkers (Fig. 2), can cause a reduction in motion sickness. Using this technique as a reference, researchers from Purdue University (Purdue.edu, 2017) explored the possibility of using a virtual nose as the in-game reference point. The virtual nose was tested in two environments; a Tuscany villa and a roller coaster. The subjects of the tests were not told that there would be a virtual nose and, as with the FOV changes, did not notice the "nasum virtualis". The tests showed that players were able to navigate the Tuscany villa for an average of 94.2 seconds longer. the roller coaster had less success but players were able to last longer on average by 2.2 seconds. The noticeable difference in increase between the two environments was likely due to the high intensity of the roller coaster demo in comparison to the Tuscany villa.

Ubisoft's Eagle Flight utilises dynamic changes to the field of view, addresses acceleration and adds a virtual nose in the form of a beak (Whitlatch, 2016). As such, UploadVR (2016) described it as a "VR flying game with no nausea" showing the aforementioned techniques, especially when used in tandem, can be highly effective. The dynamic field of view is referred to as "dynamic blinders" and Game Director Olivier Palmieri has been quoted as saying that "[players] didn't even notice [the blinders]" even when aware of the effect prior to playing the prototype. Eagle Flight also tackles the issue of acceleration by adding wind tunnel and particle effects when the player transitions their speed, with a continuous and consistent speed the rest of the time.

Figure 2. A Hover Junker's ship (Stress Level Zero, 2017)

## 3.2 OMNIDIRECTIONAL TREADMILLS

There have also been developments in VR peripheral hardware that can benefit those who suffer from motion sickness. Omnidirectional treadmills such as the Virtuix Omni, Infinadeck and the Cyberith Virtualizer, for example, allow the disconnect between the vestibular system and the eyes to be resolved somewhat. Omnidirectional treadmills allow the user to move in a more natural way by walking on the spot through various techniques. These include wearing custom shoes that slip on the surface of the treadmill, more traditional looking treadmills that also allow for lateral motion or even suspending users from above (Brown, 2017).

Unfortunately, there is little information in peer reviewed literature on the effects of omnidirectional treadmills on motion sickness. Therefore drawing any solid conclusions is difficult beyond referring to anecdotal feedback from users of the system. Through the research conducted for the present study, there were no references to omnidirectional treadmills causing or exacerbating motion sickness in users, and it is often posited as a potential solution for sufferers (Degeler, 2015; Statt, 2016; Oculus, 2017).

That being said, it is possible that we will now see more cases of "mal de debarquement", the inverse of motion sickness where prolonged motion such as being on a cruise ship results in feelings of motion afterwards when there is none. There is again, no published research on these long-term effects and this will likely remain the case until omnidirectional treadmills are more mainstream.

Although adding support for these kinds of devices is relatively trivial, the small number of users that currently have access to treadmills means that the actual impact would be relatively small compared to solutions that are effective across the board and time could be better spent elsewhere (Statt, 2016). The exception to this would be if a game was targeting arcade-like markets, as treadmills such as the Virtuix Omni are targeting VR arcades, gaming centres and shopping malls, therefore, the impact of implementation may be far higher and the game may be more desirable to arcades.

## 3.3 TRADITIONAL REMEDIES

Even with the discussed hardware advances, game optimisations and design techniques, players more susceptible to motion sickness may still suffer from some symptoms. Therefore, several websites will recommend more traditional treatments using over-the-counter antihistamines or ginger.

Although it is not feasible to provide players with either antihistamines or ginger, it is valuable to have a brief, general knowledge of these techniques and know their effectiveness. This enables developers to inform players, possibly even in-game, of ways to reduce motion sickness. It is, however, worth considering the ethical and legal issues surrounding recommending drugs to players.

Marezine and Dramamine are the most common over-the-counter drugs used for treating motion sickness and are both equally effective (Stern, 1997). However, it is of note that antihistamines can cause drowsiness (Nhs.uk, 2017) which is anecdotally known to increase the effects of motion sickness (Karlsson & Tjärnbro, 2017), and so further testing is required to ensure that antihistamines are a viable solution for cyber sickness specifically. Both ginger and antihistamines are used to treat the nausea and vomiting associated with motion sickness. Ginger has been tested alongside a placebo to test the veracity of the claims that it is effective in treating these symptoms. It was found that ginger was favoured over the placebo, including in tests on sea-sickness (Ernst and Pittler, 2000).

## 3.4 GALVANIC VESTIBULAR STIMULATION

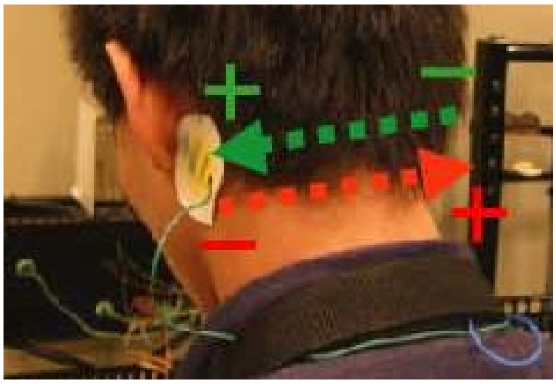

Figure 3. Applying GVS System to the Mastoids

Galvanic vestibular stimulation (GVS) is the stimulation of the inner ear, and therefore the vestibular system, to induce vection in the subject using currents induced by electrodes placed on the mastoids (Fig 3). Vection, similarly to mal de debarquement, is the false feeling of motion that can be caused by viewing motion on large screens. Given that motion sickness is induced through a mismatch of signals from the vestibular and nonvestibular systems, by inducing a feeling of acceleration using GVS whilst in VR, messages to the brain can be syncronised and resolve sensory conflict (Galvanic Vestibular Stimulation (GVS), 2017).

Not only does GVS have the potential to drastically reduce motion sickness, it can also act as a novel feedback method for VR, allowing for an engaging gaming experience. GVS has been shown to increase the intensity of experiences in VR and this has obvious applications in certain genres of games and simulations. For example driving based games and simulators, flight simulators and space combat games alongside any locomotion in VR would be well suited to GVS. Further development of this technology in the future is likely to offer more immersive gameplay alongside the benefits given to motion sickness sufferers.

The current downsides to GVS are the high cost and low fidelity of stimulation. For example, GVS units can cost thousands of pounds and even at that price range still stimulate large groups of nerves, meaning that any input to the vestibular system requiring a medium to high degree of fineness is impossible. This has resulted in the ability to stimulate the vestibular system to give a feeling of roll has been trivial to the extent that players have made DIY versions, but stimulating the feeling of turning the head upright has proven more difficult. Despite these issues, Oculus founder Palmer Lucky has said that GVS “in theory could be a good fit for GVS technology”, however there is some way to go before the technology is ready for consumers (Zhang, 2015; Galvanic Vestibular Stimulation (GVS), 2017).

## 4. SUMMARY

Appendix 7.1 shows a comparison table of the described motion sickness reducing techniques. Each colour represents a score from one to four (green = 1, yellow = 2, orange = 3, red = 4) where the totals are used to give an overall score in the “Good Solution” column. Lower scores indicate better solutions.

Game design attained the best score primarily due to its ease of implementation, lack of cost and the ease of use for the end user. The effectiveness of the technique to tackle motion sickness is, of course, the most important and game design scored joint highest in this category with treadmills. However, game design outshone treadmills overall by reason of treadmills falling short on cost both for development and for the end user. This was due to the relatively high cost of the required hardware, resulting in a worse score overall than that of game design, even when taking the greater immersion and sensory conflict resolution treadmills can offer into account.

GVS suffered similarly to treadmills in its high cost. It also was significantly lacking in the availability of consumer and developer hardware available, especially that which has been designed for VR specifically where it is non-existent. In the long run, however, GVS may be a viable approach considering the immersive and motion sickness prevention capabilities of the technology. GVS' viability does rely on a lowering of the cost or the development of a VR-specific platform.

Unsurprisingly, traditional remedies scored worst overall, scoring well only in implementation difficulty - an area which arguably is inapplicable to this technique.

## 5. RECOMMENDATIONS

Based on the research presented here, it is strongly recommended that game design is the main focus for reducing motion sickness. It is similarly recommended that teleportation is implemented as the chosen form of locomotion in VR games and simulations. The ease of implementation combined with the high rate of adoption of this technique in the VR industry means that users will find the system familiar and easy to use whilst reducing motion sickness effectively. However, care must be taken in the design of the system to ensure that the teleportation does not feel disjointed in the context of the game world. Dynamic field of view changes and a virtual nose are also recommended to further reduce motion sickness as these have little to no impact on the gameplay nor immersion whilst reducing motion sickness.

It is also imperative to ensure that the game is highly optimised to meet the requirement for consistent high frame rates, and the game should be designed with this limitation in mind.

It is also recommended, although it should not be a high priority, to add support for omnidirectional treadmills dependent on demand for that control system and the adoption rate of treadmills as a consumer device. This may require more serious consideration in the event that VR arcades are a target market for the game, as these customers would be more likely to have treadmills.

GVS, although not a useful platform at this time is worth revisiting as more consumer-friendly products are developed and further research is conducted.

It is also strongly recommended that players are not encouraged to use drugs or supplements for reducing VR motion sickness. This is due to the lack of research regarding side effects such as drowsiness when using VR systems, and the ethical issues that arise.

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# 7. APPENDICES

## 7.1 Table showing the comparative effectiveness of motion sickness reducing techniques.

| | Immersion | Cost user/development | Easy to implement | Easy to use for end user | Effectiveness | Good solution |
|---|---|---|---|---|---|---|
| **Game Design** | Locomotion may not mesh well with game world/lore however field of view changes and virtual nose go unnoticed by the player | No cost to end user and development costs are purely development time | Tried and tested methods, plenty of resources | No additional difficulty to users who have played other VR titles, minor additional locomotion mechanic to learn for new users | Works well for reducing motion sickness, but may negatively impact immersion depending on the disparity between locomotion implementation and the game lore | Besides the risks to immersion, dynamic field of view, virtual nose and locomotion techniques can be effective in reducing motion sickness (7) |
| **Treadmills** | Allows for natural movement in VR | Expensive systems, relatively low density of users have these systems | Additional support and development required | User can use natural movement for control | Good for immersion and reduces sensory conflict but high cost means few players have access to the hardware | Has the potential to add immersion for players with access but the additional cost and development to support multiple hardware systems means less long-term effectiveness (10) |
| **Traditional Remedies** | Completely detracts from immersion | User has to buy drugs/ginger | No development time beyond educating users | Players have to actively take supplements/drugs in order to be able to use the system | May not work for all users, drastically reduced immersion, issue of drowsiness | The additional costs to the player, lack of research on the effectiveness in VR and liability to developers for 'prescribing' means this solution is poor (15) |
| **GVS** | More immersive than current hardware setups | Device cost currently very high for fidelity required | No APIs Limited research on types of stimulation required | A consumer grade device would add little difficulty for an end user | Effective at reducing motion sickness but high cost and current fidelity means it is largely infeasible | In the longer term this may be a good solution but until costs are reduced and fidelity of stimulation is increased it is not a good solution (13) |