Qualcomm
developer network

Reducing Cybersickness in Virtual Reality

What is Cybersickness and how it can be reduced or prevented when developing virtual reality experiences

Introduction

As a developer or designer of XR and specifically virtual reality (VR) experiences, you not only want to create a compelling and exciting concept, you also want to create a great experience for your user. With great power to create these experiences comes great responsibility to ensure the user has an enjoyable experience! Accordingly, a great VR design should consider ways to reduce or prevent cybersickness.

This is especially important in the field of VR (and to a lesser extent augmented reality or AR), which sometimes has a reputation of being nausea inducing. Discomfort due to cybersickness has been reported to affect 50% to 80% of VR users[1] and continues to be one of the largest barriers to VR adoption.

In this eBook we look at what cybersickness is, the most common causes of cybersickness in VR experiences, and techniques that VR developers and designers can use to help reduce or prevent it.

[1] Reference gathered from multiple sources including: J. Quarles (2018); K. Stanney (2017); J. Munafo, M. Diedrick, & T. Stoffregen (2017); C. Chang, W. Pan, L. Tseng, & T. Stoffregen (2012); Y. Kim, H. Kim, E. Kim, H. Ko & H. Kim. (2005).

What is Cybersickness?

You may have experienced motion sickness at some point in your life, which refers to the discomfort (e.g., nausea) that occurs when the motion perceived visually doesn't match the movement detected by your vestibular system[2].

There are three general categories of causes for motion sickness:

- Motion which is felt (sensed) but not seen, such as sea, air, or car sickness.
- Visually-induced motion sickness where motion is seen but not felt, such as cybersickness.
- Disagreement between the visual and vestibular systems[2] on detected motion.

For example, sea sickness can occur while on a boat because your eyes are unable to detect the fixed points needed to visually judge motion while the boat is rocking.

Cybersickness is a form of motion sickness that occurs when immersed in a computer-generated environment such as VR. When motion portrayed in the viewport is detected by our visual sense but does not match the motion detected by our vestibular sense, cybersickness symptoms can occur. Symptoms can include: disorientation, oculomotor[3] discomfort (e.g., eyestrain), and nausea. Users can also experience aftereffects of dizziness and lack of coordination after a VR session. We'll bet that you wouldn't want your VR experiences to be remembered for any of these symptoms.

Three types of contributing factors to Cybersickness

In VR, there are over 50 factors that can contribute to these physiological disagreements for your users. They are broken down into three categories of factors as follows:

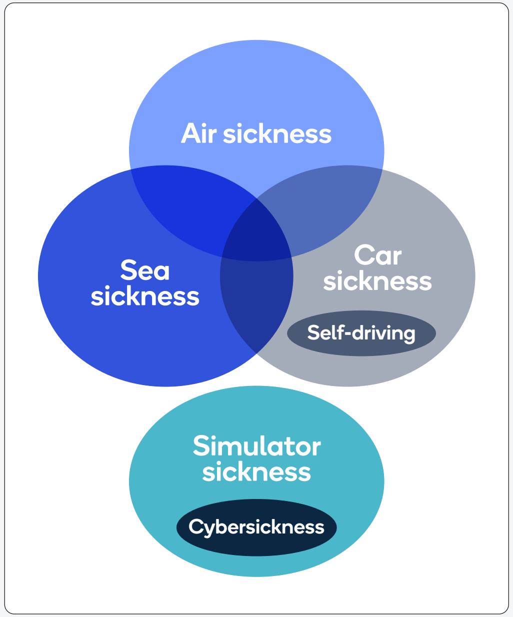
1. **System factors**: introduced by the hardware and operating system.
2. **Application and User Interaction factors**: caused by the design of the software (e.g., game), the user experience, and how the user chooses to interact.
3. **Individual and various perceptual factors**: specific to a user based on their health and wellbeing.

Let's review each of these categories in more detail.

[2] The vestibular system is a sensory system in most mammals. It's generally part of the inner ear that supports a sense of balance and spatial orientation, and coordinates movement with balance.

[3] Oculomotor refers to movement of the eyes.

Types of motion sickness



System factors

There are several system factors from both VR hardware systems and operating systems that can cause or increase cybersickness symptoms as identified in the table.

The main factors are:

- **Head Tracking**: it's critical that the rendered viewport and any updates due to movement correspond to the position and movements of the head. Any sensory mismatches such as drift or inaccuracy can cause shifts in the position of objects leading to cybersickness symptoms.
- **Rendering**: motion-to-photon latency[4], especially when it varies during the experience, is another leading cause of discrepancy between what is seen and felt by the user. Constant latency allows the experience to be much more predictable and thus less sickness inducing.
- **Field of View (FOV)**: a wider FOV can increase cybersickness symptoms from increased scene motion and flicker perceived by the user's peripheral vision.
- **Optics**: a head mounted display's (HMD) optical subsystem can include displays, lenses, mirrors, filters, Interpupillary Distance (IPD)[5] adjustments, and focus adjustment lenses may introduce distortion which changes how images are projected and perceived, while displays can contribute to chromatic aberration and dispersion.

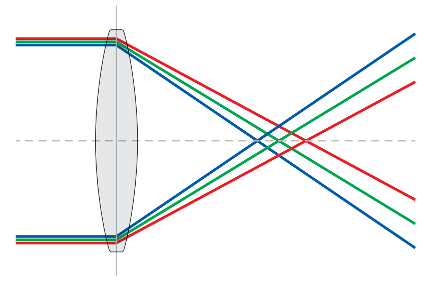
System factors contributing to Cybersickness

- Head Tracking (accuracy, drift, precision, degrees of freedom, calibration)
- Rendering (latency, frame rate, binocular image offset)
- Display (refresh rate, response time, persistence, flicker, dirty screen)
- Field of View
- Lenses (distortion, chromatic aberration, interlens distance)
- Vergence/Accommodation Conflict
- HMD & Fit (ergonomics, open to periphery, weight and center of mass, excessive heat, poor eye alignment with lenses, uneven or excessive pressure, hygiene)
- Temperature

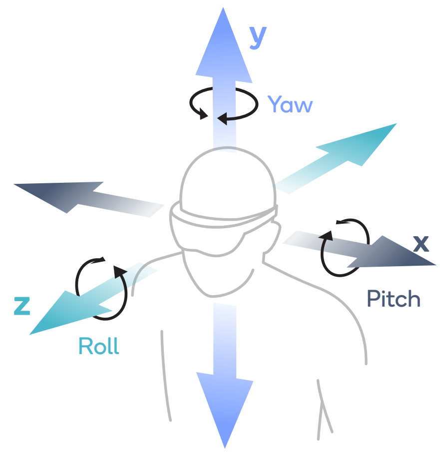
[4] Motion-to-photon Latency: the time between when the user moves their head and when the viewport is finally updated and rendered to reflect that movement.

[5] Interpupillary distance (IPD) is the distance between the centers of the two eyes.

Chromatic aberration example



Head Tracking



The rendered viewport needs to correspond to head movements.

Application and User Interaction factors

It's not just the hardware—the VR application itself and the way the user interacts with it can also cause cybersickness symptoms or exacerbate those introduced by system factors. The following are the top four application and user interaction factors:

- **Lack of Control**: the ability for the user to control their position and orientation (e.g., navigation, viewpoint) in a VR app helps the user anticipate upcoming visual motion. As in other situations where users cannot anticipate or control visual motion (e.g., on airplanes or roller coasters), users may experience an increase in symptoms.
- **Visual Acceleration and Vection**: the duration and intensity of acceleration in a viewport tends to increase vection[6], which can lead to an increase in cybersickness symptoms.
- **Duration**: longer VR experiences tend to increase the intensity of symptoms. However, studies show that steadily increasing exposure and duration over several days can sometimes help users adapt and reduce their symptoms.
- **Head Motion**: the frequency and intensity of head movement, especially yaw[7], tends to increase symptoms. As a result, users may try to limit their head movements in an attempt to reduce cybersickness.

[6] Vection: the feeling of motion that occurs solely by visual stimulation.

[7] Yaw: the rotation around an entity's vertical axes. In the context of VR, this usually refers to the rotation of the user's head as they look left or right.

Application and User Interaction factors contributing to Cybersickness

- Visual Acceleration and Vection
- Virtual Rotation
- Scene Motion and Complexity
- Rest Frames
- Height Above Ground
- Graphic Realism
- Conflicting Depth Cues
- Excessive Binocular Disparity
- Luminance
- Control
- Duration
- Head Motion
- Position (standing/sitting)
- Eye Motion

Individual factors

Finally, in addition to system and application factors, individual users can be predisposed to cybersickness at varying levels due to their physical and mental state and health. Here are a few key factors to understand for your users:

- **Motion Sickness History**: susceptibility to motion sickness varies by individual, with some having a stronger disposition and history of symptoms than others.
- **Lack of VR/Game Experience**: new users tend to be more susceptible than experienced users because symptoms can often decrease after repeated exposure over time as the user learns to adapt to the environment.
- **Interpupillary Distance (IPD)**: a mismatch between the user's IPD and a device's inter-lens distance (ILD) can lead to headaches, eye strain, and discomfort. Females may be more susceptible because they tend to have smaller IPDs than males, and HMD tend to be optimized for the average IPD of males.
- **Illness and Health**: illnesses such as the flu or cold can affect how visual motion is perceived by the brain, as can overall health and lifestyle choices such as sleep, medication, etc.

Individual factors contributing to Cybersickness

- Motion Sickness History
- VR/Game Experience
- Real-world Task Experience
- Gender, Age, Ethnicity
- Illness
- Sleep Deprivation
- Medication
- Migraine History
- IPD
- Head Size for HMD Fit
- Balance Control
- 3D Motion Sensitivity
- Flicker/Fusion Frequency Threshold
- Anxiety, Emotional Stress
- Expectations

Developer approaches when designing VR experiences

As we have seen, there are many factors that may cause your VR experience to induce cybersickness for your users. Here are a few approaches to consider that may reduce or prevent it when developing and designing your VR experience:

1. **Viewpoint Control**:
    - Users should have active control of the viewpoint and be responsible for initiating movement. The resulting scene movement should be predictable, and users should be able to anticipate upcoming visual motion.
    - Similarly, all movement of the viewpoint by the camera should be as predictable as possible.
    - Reduce or eliminate any non-user-initiated movement (i.e., any movement not related to the user's own navigation around the space). Artificially moving the user increases the risk of nausea, especially for sensitive individuals.
2. **Visual Acceleration**:
    - Avoid or limit linear or angular accelerations without corresponding vestibular stimulation.
    - Maintaining constant velocity is preferred since it doesn't affect the vestibular system for most users.
    - In general, developers should think about the different types of allowable camera-initiated movements in their experience as a spectrum of tolerance, where the latter movements listed are more likely to cause symptoms: user locomotion (natural) > linear visual movement > visual acceleration > visual rotation > visual acceleration + rotation.
3. **Visual Leading Indicators**: Display visual indicators or motion trajectories (e.g., arrows indicating the upcoming travel direction) so that users can anticipate upcoming visual movements.
4. **Rest-Frame Cues**: Display visual cues that remain stable as the user moves. This provides users with fixed points that can help them judge motion. There are two general types of cues you can display:
    - Foreground Cues: cues that remain locked in the viewport as the user moves (e.g., cockpit, car dash, helmet, etc.);
    - Background Cues: cues that are locked to the user's inertial frame of reference (e.g., clouds, mountains, horizon, etc.).
5. **Reduce or Modify the FOV**:
    - Dynamically scale down the FOV based on the linear or angular velocity of the virtual environment, so as to reduce the amount of scene motion perceived by the user's peripheral vision.
    - Perform dynamic blurring of unimportant/non-salient areas.

Final suggestions

Here are a few final suggestions to help you create the most compelling and healthy VR experience for your users:

- Virtual objects should be placed at a comfortable viewing range (e.g., 0.75 to 3.5 meters).
- Reduce or avoid repeating patterns (e.g., gratings) and high spatial frequency content (e.g., stripes, fine textures, etc.) as they can induce feelings of vection and lead to discomfort. Instead, use flatter textures such as solid-colored rather than patterned surfaces.
- Reduce or avoid including elements that induce vertical acceleration (e.g., stairs), because vertical acceleration and horizontal optical flow when climbing (vection) can induce symptoms. Ramps may be better but should also be used sparingly.
- Avoid linear oscillations, which are most discomforting at 0.2 Hz; avoid off-vertical-axis rotation.
- Teleportation is a useful navigation technique that can reduce symptoms for new users but may lead some users to lose their bearings and become disoriented.
- Encourage new users to try the experience a few times over several days, to help them adapt and develop a tolerance to the environment.
- Inform users if your game or application poses a probability of inducing cybersickness, so that users can make the choice to participate and prepare themselves for the experience.

If developers and designers understand their role in contributing to cybersickness and work to alleviate it, this not only makes the experience better for users, but it can also help build up the reputation of VR as a fun and useful medium and expand the opportunity for everyone.

Key developer resources

Get Started with XR on Qualcomm Developer Network: software and hardware resources along with latest blogs and information on QDN.

Qualcomm® Snapdragon™ VR SDK: provides developers with access to optimized, advanced VR features on Snapdragon VR devices.

Snapdragon XR2 5G Platform: world's first XR platform to unite 5G and AI.

How to Better Plan your VR Development Process: considerations for planning and designing VR projects.

How-to Guide: Developing for Immersive Realities: recommendations for building good VR user experiences.

Experience Six Degrees of Freedom in XR Development: developing experiences with complete immersion.

Tobii Helps Bring Eye Tracking to XR Development: a look at Tobii's eye tracking functionality and its role in VR.

Oculus Quest: home page for the Snapdragon-powered Oculus Quest VR headset.

Innovate together

Qualcomm Developer Network is a collection of software and hardware tools, inspiring our community of developers to push the boundaries of mobile. We're continuously creating some of the most innovative, powerful and disruptive technologies in the world, and Qualcomm Developer Network is the gateway through which you can discover the tools you need, whether you're building high-performance apps, smart Internet of Things (IoT) devices, immersive virtual reality experiences or other emerging technologies.

developer.qualcomm.com

Qualcomm
developer network