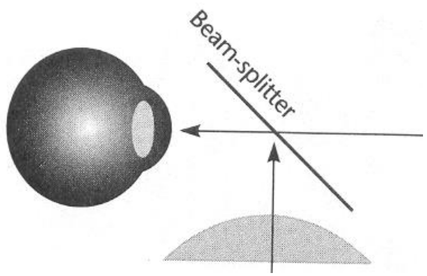
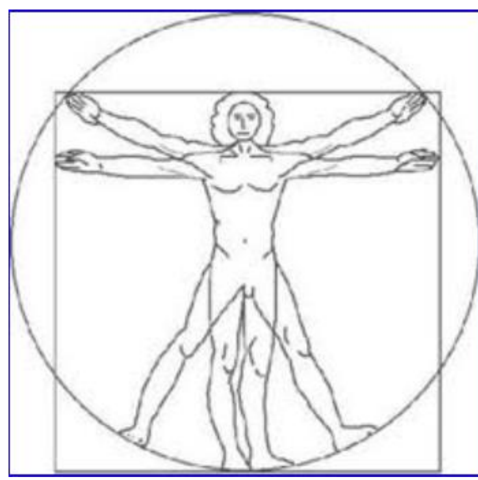
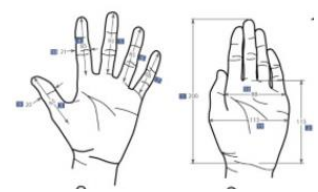
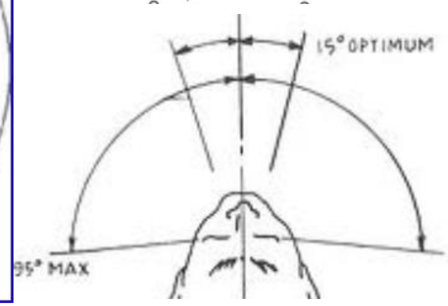
Universidade de Aveiro
Departamento de Electrónica,
Telecomunicações e Informática

Human Factors in Extended Reality



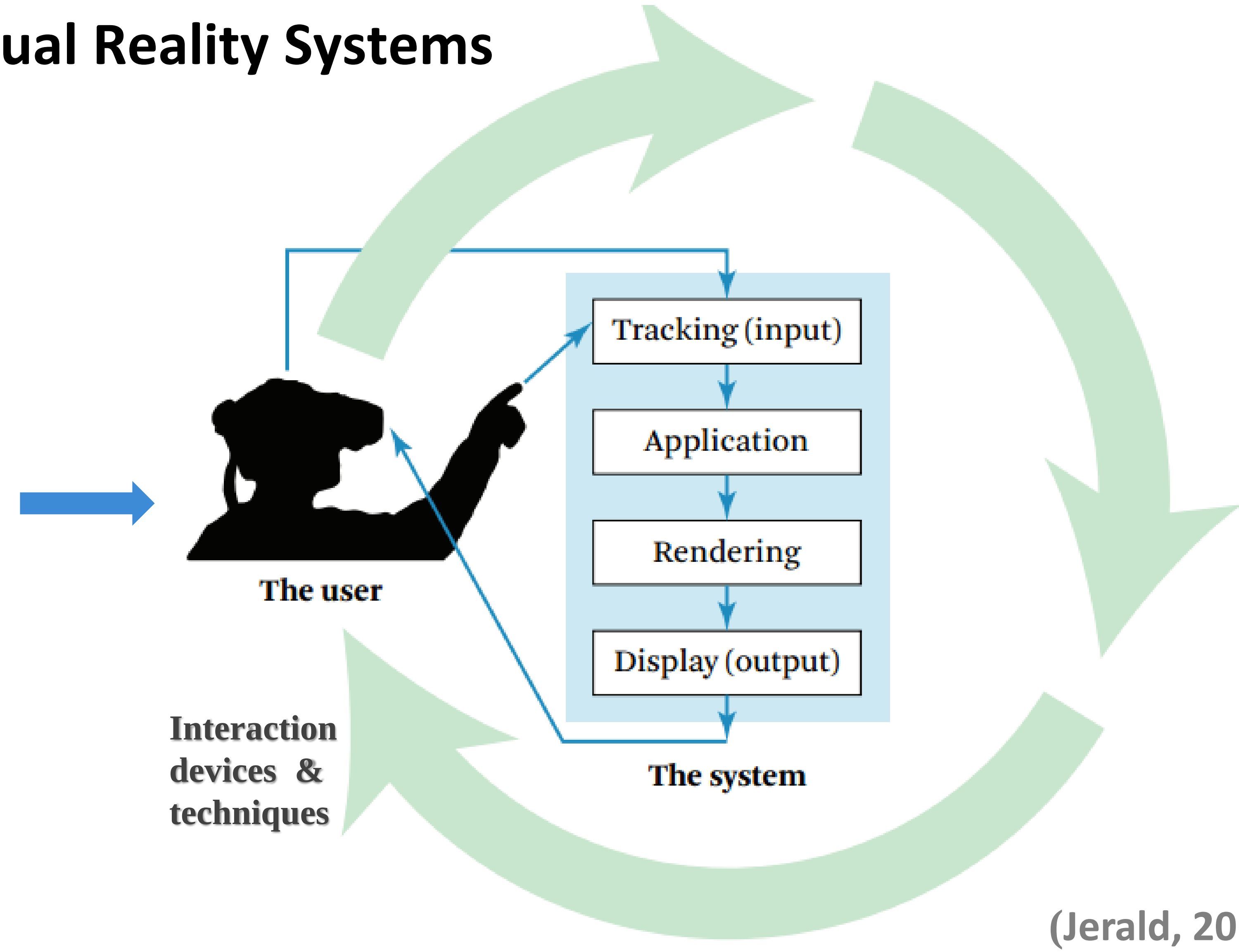






Beatriz Sousa Santos

Virtual Reality Systems



(Jerald, 2016)

Perception

Adverse health effects

Design guidelines

Human factors (or ergonomics)

- It is the study of designing equipment and devices that fit human:

  - body
  - cognitive abilities

- The two terms "human factors" and "ergonomics" are often used as synonymous

- It aims at fulfilling the goals:

  - health
  - safety
  - productivity

Virtual Reality and human perception

VR designers integrate several senses into a single experience, and if sensations are not consistent, then users can become physically ill

Study perception is essential to design VR systems

The better our understanding of human perception, the better we can create and iterate upon quality VR experiences

(Jerald, 2016)

Human Perceptual Modalities

- The broadband path into the mind is via the eyes

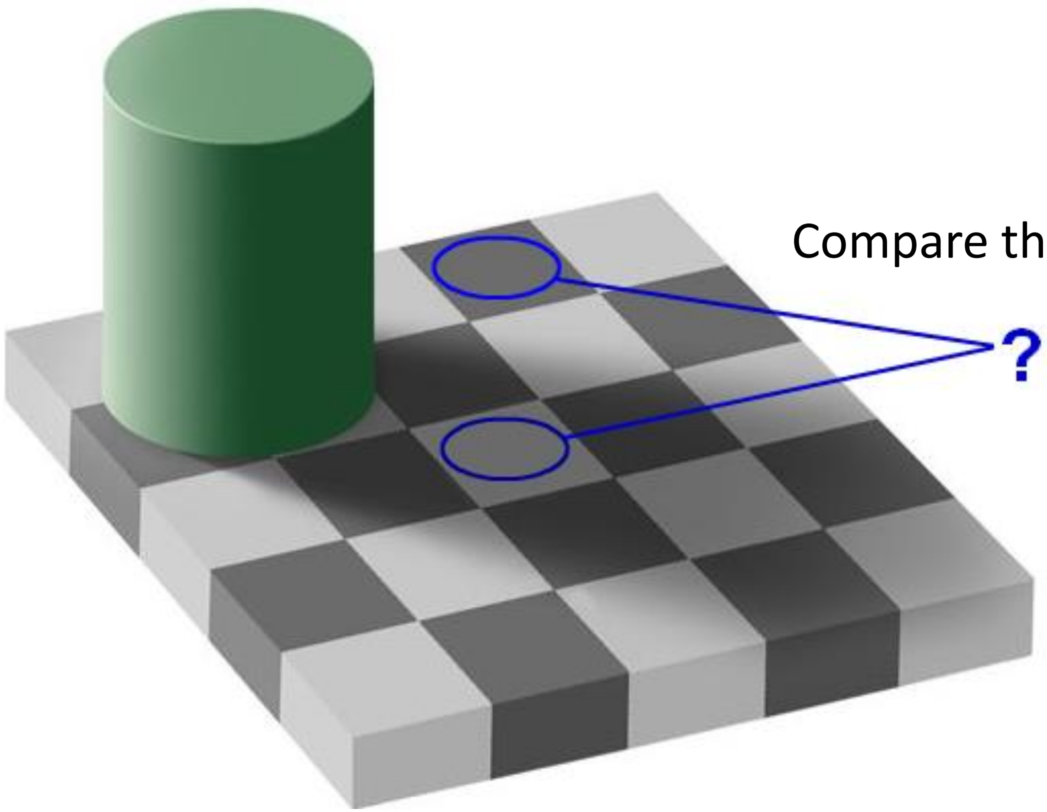
- It is not the only path, the ears are especially good for:
- situational awareness and monitoring alerts
- sensing environmental changes and speech.

- The haptic and the olfactory systems seem to access deeper levels of consciousness

Human Perceptual Modalities

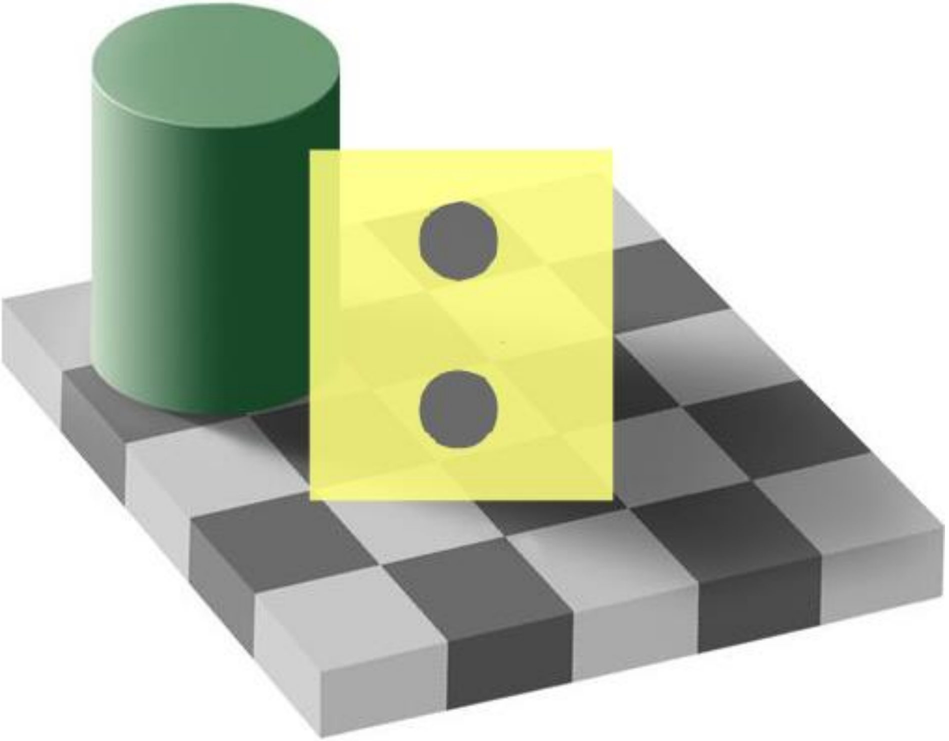
- Vision
- Hearing
- Touch
- Proprioception
- Balance and Physical Motion
- Smell
- Taste

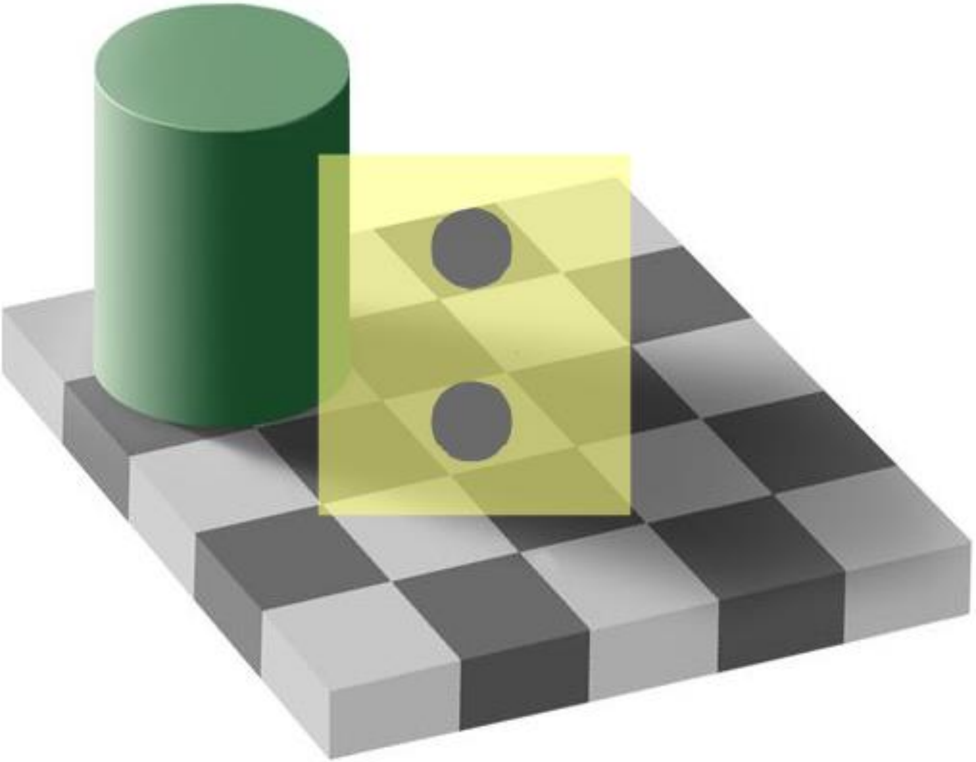
Remember that “**What we see is more than meets the eye!”**



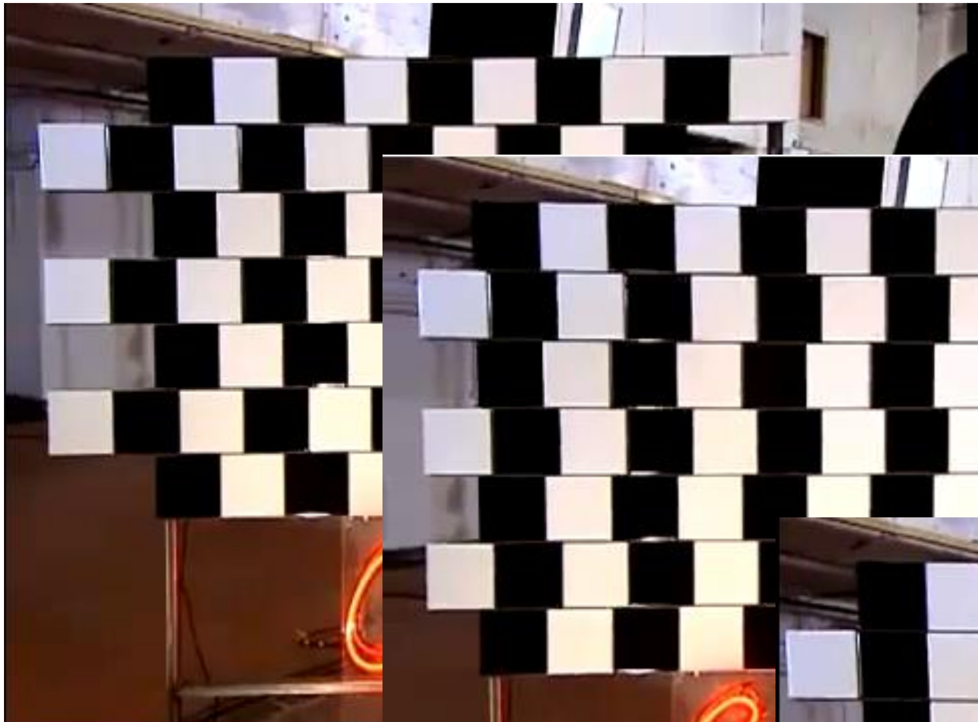
Compare the relative brightness

http://www.michaelbach.de/ot/





For 3D scenes, the visual system estimates a lighting vector and uses it to judge the material

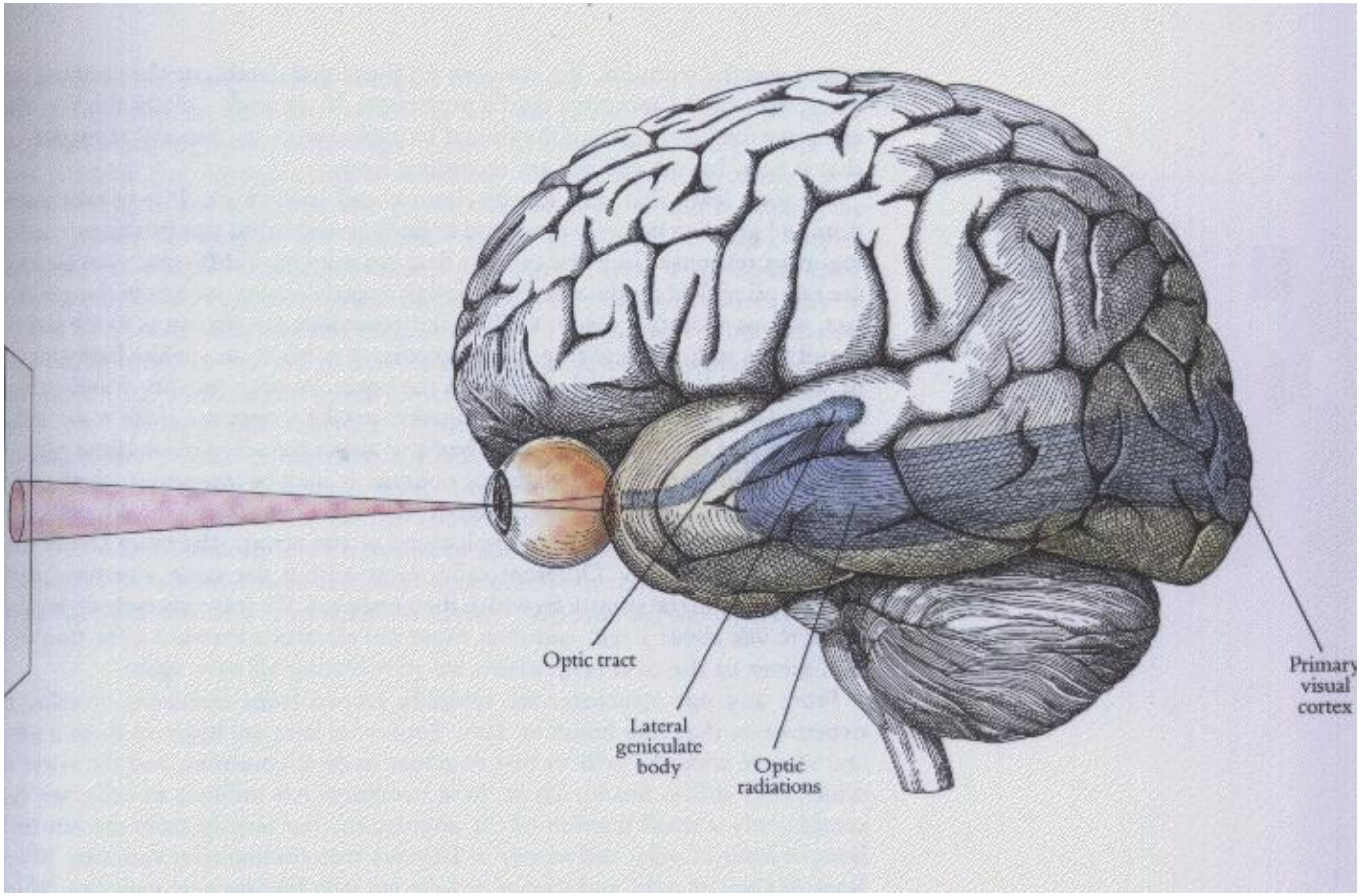


Visual illusions have helped understand visual perception
And may help design VR systems…
(Recall the Imagination dimension of VR)

http://www.youtube.com/watch?v=AuLJzB_pfgE

The Human Visual System

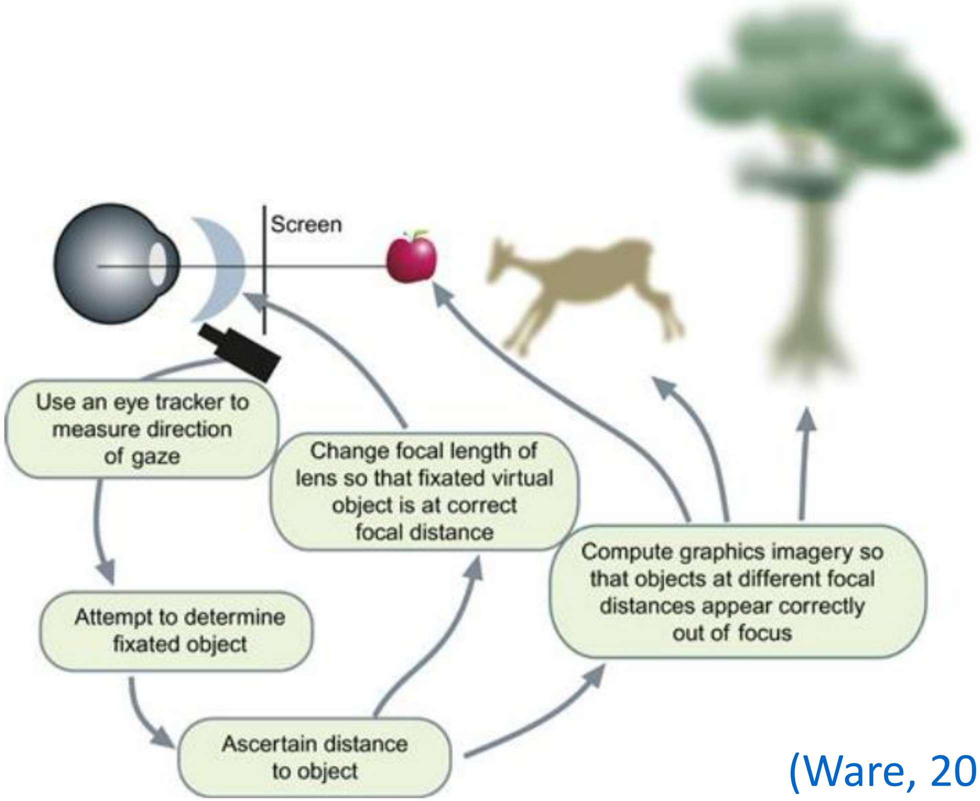
The eyes are sensors; most processing occurs at the visual cortex



(Hubel, 1988)

It is necessary **to know the characteristics of the visual perception system** to develop an effective Virtual or Augmented Reality System

Example: Possible solution to the correct focusing in a Virtual Reality System: the apple is the focused object; others are represented out of focus according to their relative positions and distances



(Ware, 2013)

Some characteristics of the eye:

100 millions of rods in each eye (photoreceptors for low light level vision)

6 million cones in each eye (photoreceptors for vision at higher light levels)

1 million nervous fibers in each optic nerve

Distance between the center of the lens and the fovea: 17mm

Distance between pupils: 50 - 70mm

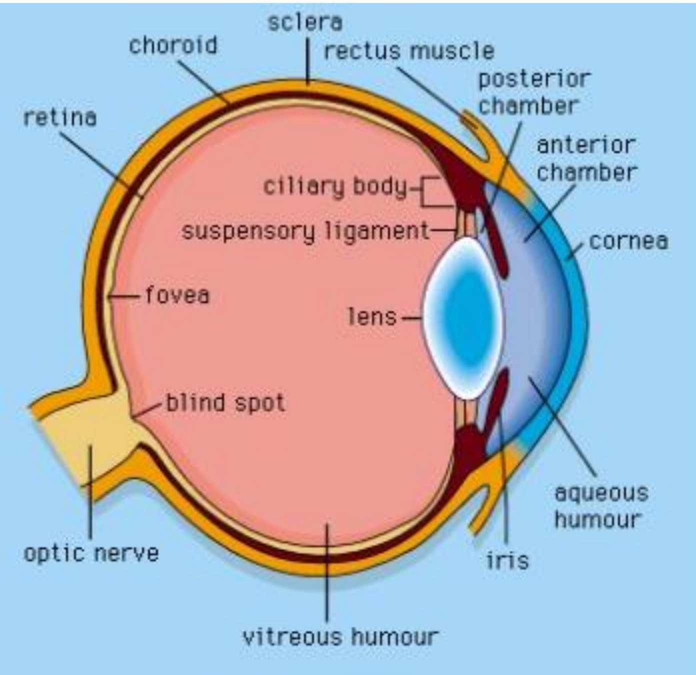
Rod sensitivity 500 higher then the cone sensitivity

Maximum rod sensitivity at 0,51 µm (green)

Maximum cone sensitivity at 0,56 µm (orange)

Dynamic range: 10^{16}

https://www.britannica.com/science/fovea-of-retina



Central vs. Peripheral Vision

Have different properties, due the retina and different visual pathways

- Central vision:
  - has high visual acuity,
  - is optimized for bright daytime conditions, and is color-sensitive

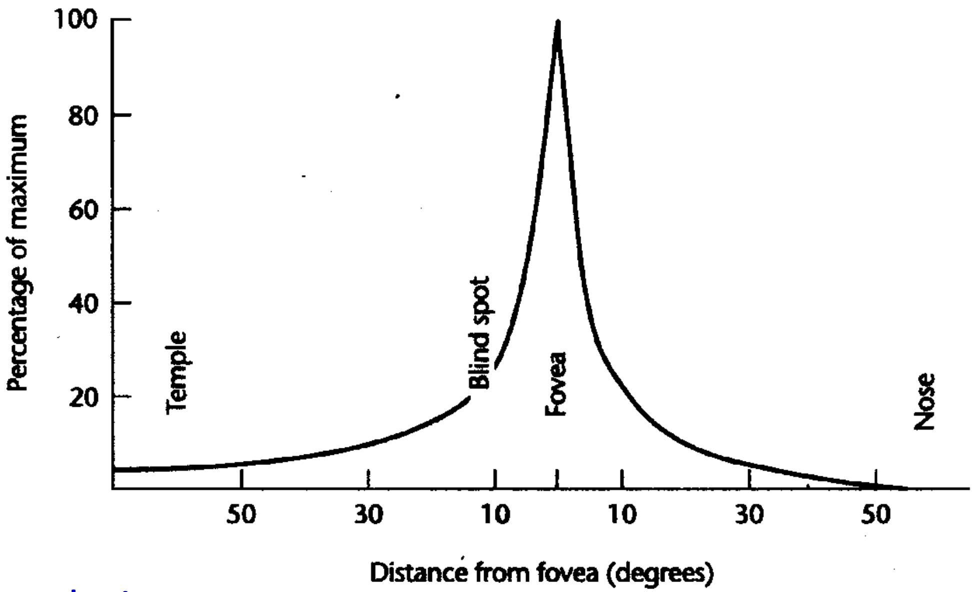
- Peripheral vision:
  - color insensitive,
  - more sensitive to light than central vision in dark conditions,
  - less sensitive to longer wavelengths (i.e., red),
  - fast response and more sensitive to fast motion and flicker,
  - less sensitive to slow motions

- The eyes acuity decreases quickly from the fovea

- Thus: **we may show more detail on the area focused and projected on the retina**
- This implies eye tracking, but allows saving resources

https://en.wikipedia.org/wiki/Foveated_rendering

Cone distribution in the retina



(Ware, 2013)

- In stereoscopic displays **the interpupillary distance** is an important parameter for stereoscopy; **it should be adjustable**

- The human eye has ~180 receptors per degree at the fovea

- Considering the sampling theorem :

  The human eye can tell apart ~50 cycles per degree

- It is possible to establish minimum temporal requirements

  ~50 Hz is the lowest value for image refresh

- Below, individual images start to be noticeable

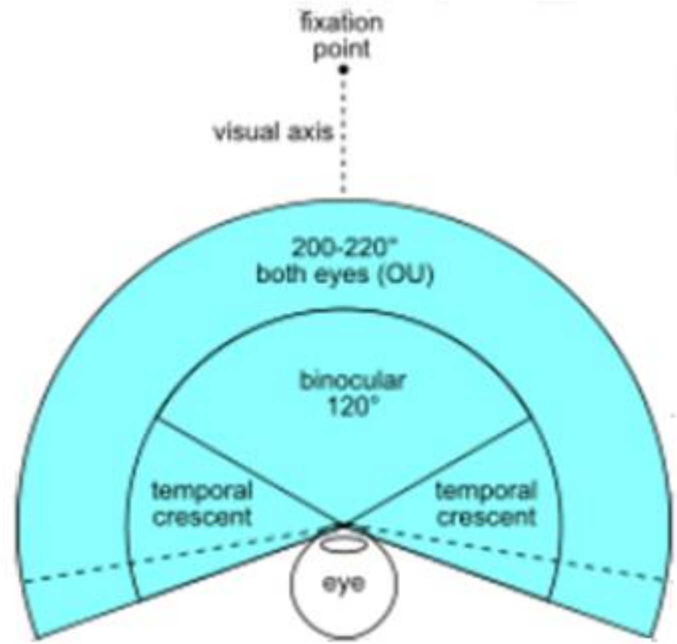
- It is also possible to use temporal anti-aliasing

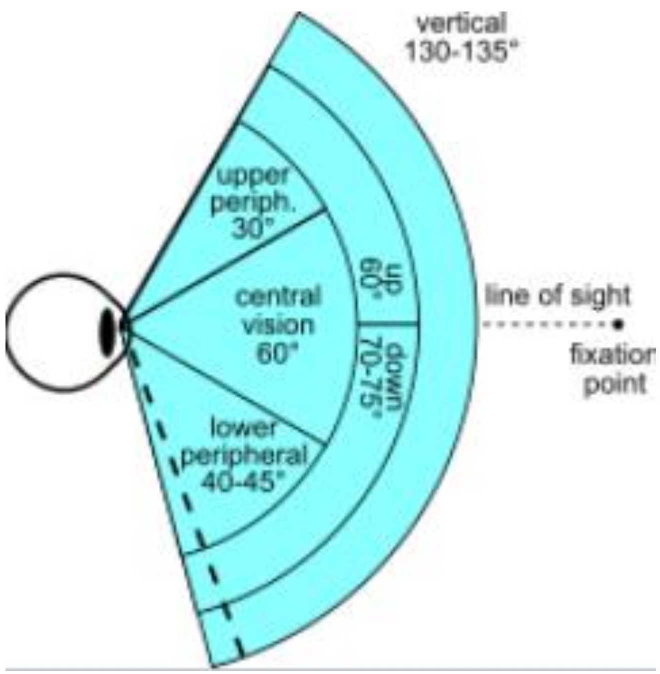
- Example: Oculus Rift S (2019) - 80 Hz
  Oculus Quest (2021) – 90 Hz
  Quest 3 (2023) – 120 Hz

Field of View

Horizontal >~200°

Vertical >~130°





https://en.wikipedia.org/wiki/Field_of_view

Images produced by most displays are very poor when compared to the real world

It is amazing what is possible with such simple devices

Displays have various limitations:

- Low intensity
- Small field of view
- Lack of information concerning focusing distance

More serious!

For more details read (Ware, 2013)

https://learning.oreilly.com/library/view/information-visualization-3rd/9780123814647/xhtml/CHP002.html#ST0075

Hearing

Auditory perception is quite complex and is affected by:

- head pose,
- physiology,
- expectation,
- relationship to other sensory modality cues

We can deduce qualities of the environment from sound
(e.g., larger rooms sound different than small rooms)

and determine where an object is located by its sound alone

(Jerald, 2016)

- Binaural cues (aka stereophonic cues) are two different audio cues

- One for each ear, that help to determine the position of sounds

- Each ear hears a slightly different sound (in time and in level)

- Interaural time differences provide an effective cue for localizing low-frequency sounds

- Spatial acuity of the auditory system is not as good as vision

- From the two signals that reach our ears we extract information about the location of sound sources

- A sound to the right of the listener produces a wave reaching the right ear before the left ear

- Both ear signals are "filtered" by the torso, head, and in particular, the pinna (external ear)

- The left ear signal is attenuated by the head

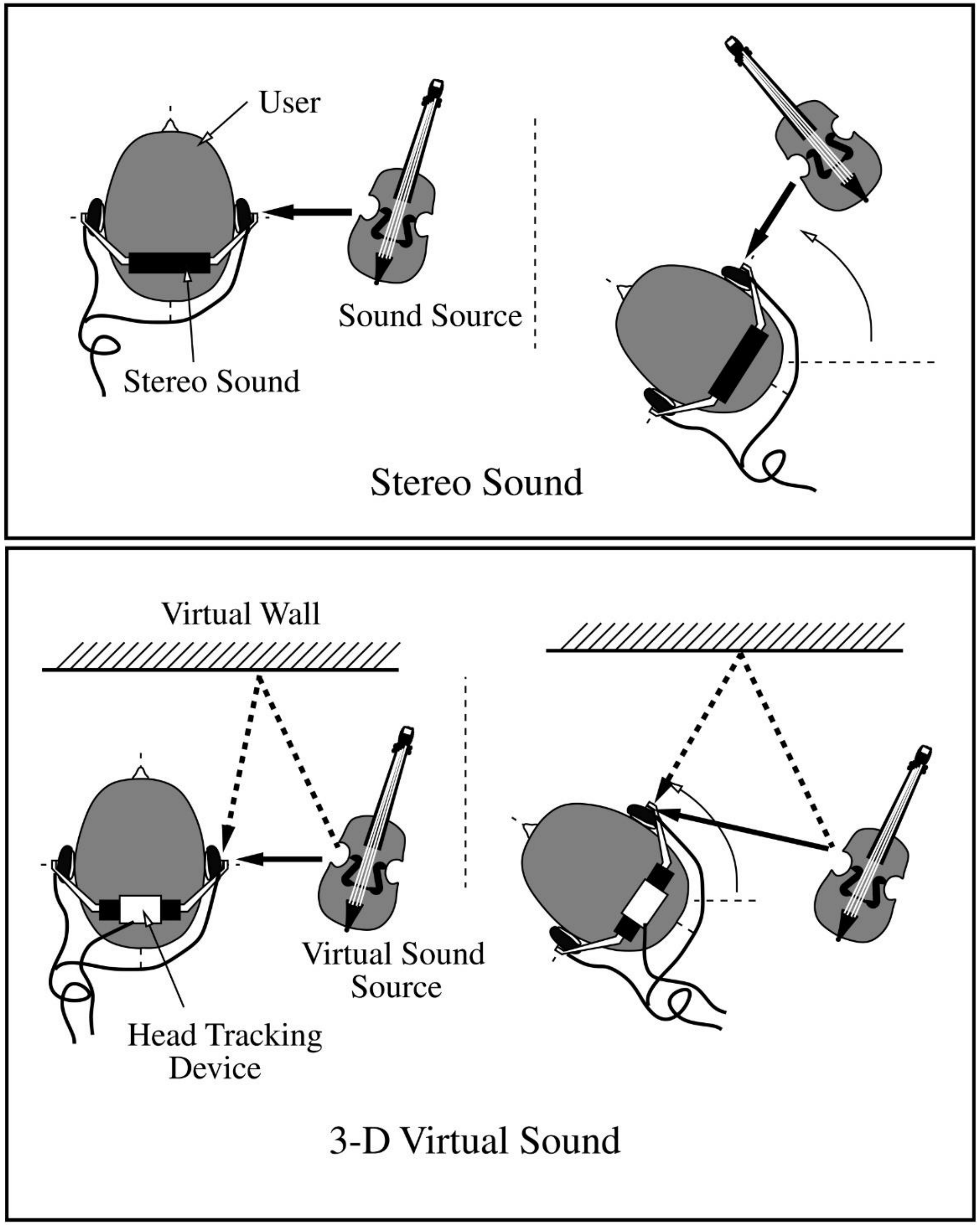
- This can be captured by the HRTFs

  (Head Related Transfer Functions)

[Head-related transfer function – Wikipedia]
[What is an HRTF, or Head Related Transfer Function, and why should it be personalized?]

3-D sound should not be confused with stereo

- With stereo sound the source seems to move when the head moves maintaining its relative position
- 3D sound can ideally position sounds anywhere around a listener



(Burdea and Coiffet., 2003)

- We gain a significant amount of information via sound
- Sound often tells our eyes where to look
- We use our hearing to keep us constantly aware of the world
- Given the importance of sound and relatively low cost in VR:

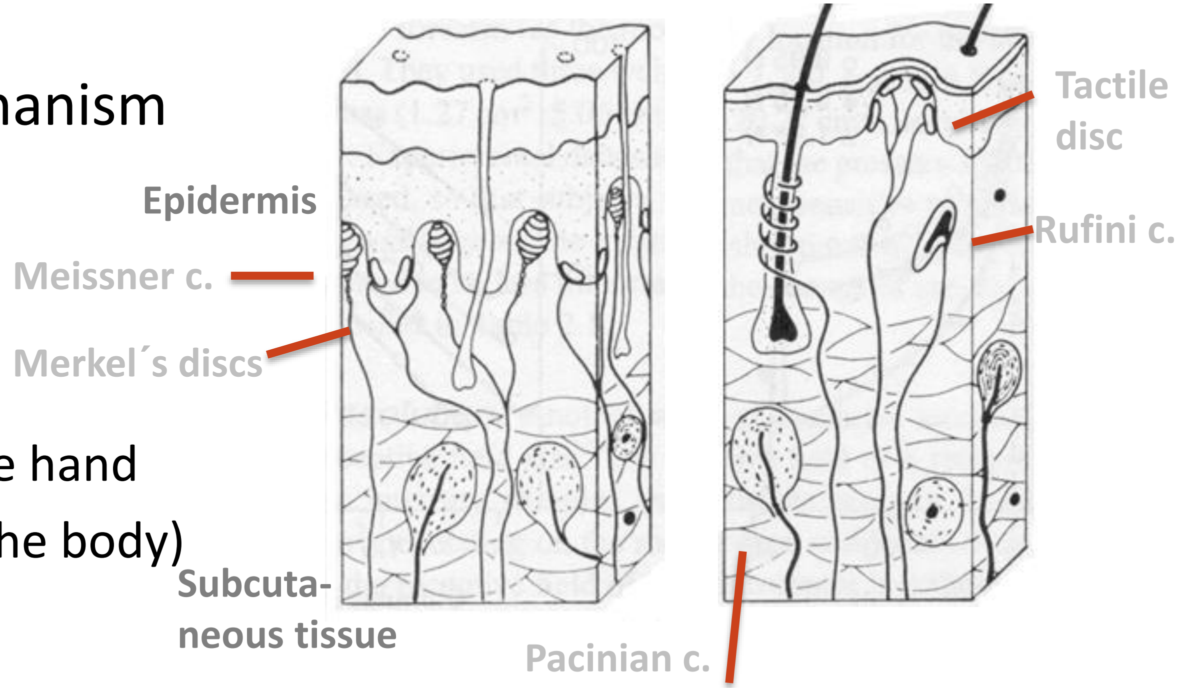
VR application designers should consider how sound might be used to positive effect in the applications they build

Touch

- Relies on sensors in and close to the skin
- Conveys information on contact surface (geometry, roughness, slippage, temperature)
- Without touch, actions as simple as picking objects can be difficult
- Is extremely challenging to implement in VR

By understanding how we perceive touch, we can at least take advantage of providing some simple cues to users

Human touch sensing mechanism



- Most touch sensors are on the hand
  (much less on other parts of the body)

- Four primary types of sensors detect:

  movement across the skin – **velocity** detectors (Meissner's corpuscles)

  measure **pressure and vibrations** (Merkel's disks)

  deeper in skin (dermis) - **acceleration** sensors (Pacinian corpuscles)

  skin shear and **temperature** changes (Rufini corpuscles)

Passive Touch vs. Active Touch

Passive touch occurs when stimuli are applied to the skin

It can be quite compelling in VR when combined with visuals

Active touch occurs when a person actively explores an object, usually with the fingers and hands

Humans use three distinct systems together when using active touch:

- Sensory
- Motor
- Cognitive

These systems work together to create an experience of perceiving the object being touched

K. Vaghela et al., "Active vs passive haptic feedback technology in virtual reality arthroscopy simulation: Which is most realistic?"
Journal of Clinical Orthopaedics and Trauma, vol 16, pp. 249-256, 2021
https://doi.org/10.1016/j.jcot.2021.02.014

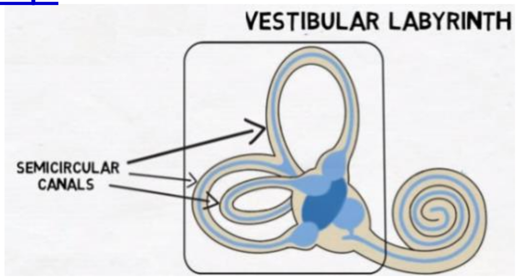
Kinesthesia is the perception of **movement or strain** from within the muscles, tendons, and joints of the body.

Proprioception is the sensation of limb and whole body pose and motion derived from the receptors of muscles, tendons, and joint capsules

also refers to an individual's **ability to sense their own body posture**, even when no forces are acting upon it

The **vestibular** system consists of labyrinths in the inner ears that act as mechanical motion detectors, providing input for **balance and sensing motion**

https://www.youtube.com/watch?app=desktop&v=P3aYqxGesqs



These are important for understanding how VR users physically move to interact with a virtual environment

Multimodal perception

Multimodal Perceptions **Integration of our different senses** occurs automatically

Examining each of the senses independently leads to only partial understanding of everyday perceptual experience

Perception of a single modality can influence other modalities

Vision tends to dominate other modalities

This can be explored in VR

Examples: McGurk effect
The rubber hand effect

https://www.youtube.com/watch?v=2k8fHR9jKVM
https://www.youtube.com/watch?v=Qsmkgi7FgEo

Explore complex illusions in Virtual Reality…

[Mel SLATER, Presence, body ownership and vicarious agency - the Illusions of Virtual Reality]()

Adverse Health Effects

“Any issue caused by a VR system or application that degrades a user’s health”

(Jerald, 2016)

Can indirectly be more than a health problem

Users might adapt their behavior resulting in incorrect training for real-world tasks

Leading to public safety issues!

[What are the risks of virtual reality and augmented reality, and what good practices does ANSES recommend?]

Adverse Health Effects

Virtual Reality sickness - Visual Scene Motion
Motion Sickness and Vection
Theories of Motion Sickness
Unified Model of Motion Sickness

Eye Strain, Seizures, and Aftereffects - Accommodation- Vergence Conflict
Binocular-Occlusion Conflict
Flicker
Aftereffects

Physical issues related to H/W - Physical Fatigue
Headset fit
Injury
Hygiene

(Jerald, 2016)

Motion sickness (cybersickness)

Possible symptoms due to exposure to real or apparent motion:
discomfort,
nausea,
dizziness,
headaches,
disorientation, vertigo,
sweating
and vomiting (in extreme cases)

Vection

Illusion of self motion; does not necessarily always cause motion sickness

Similar to driving, VR users are less likely to get sick if they actively control their viewpoint
https://en.wikipedia.org/wiki/Illusions_of_self-motion

Theories of Motion sickness

Sensory Conflict Theory:
Is accepted for the initiation of motion sickness symptoms
Particularly conflict of the visual and vestibular senses is important

Evolutionary Theory:
(aka poison theory) offers a reason for why motion makes us sick:
The brain interprets sensory mismatch as a sign of intoxication

Postural Instability Theory:
Predicts that sickness results when a user lacks or has not yet learned strategies for maintaining postural stability

There are other theories …

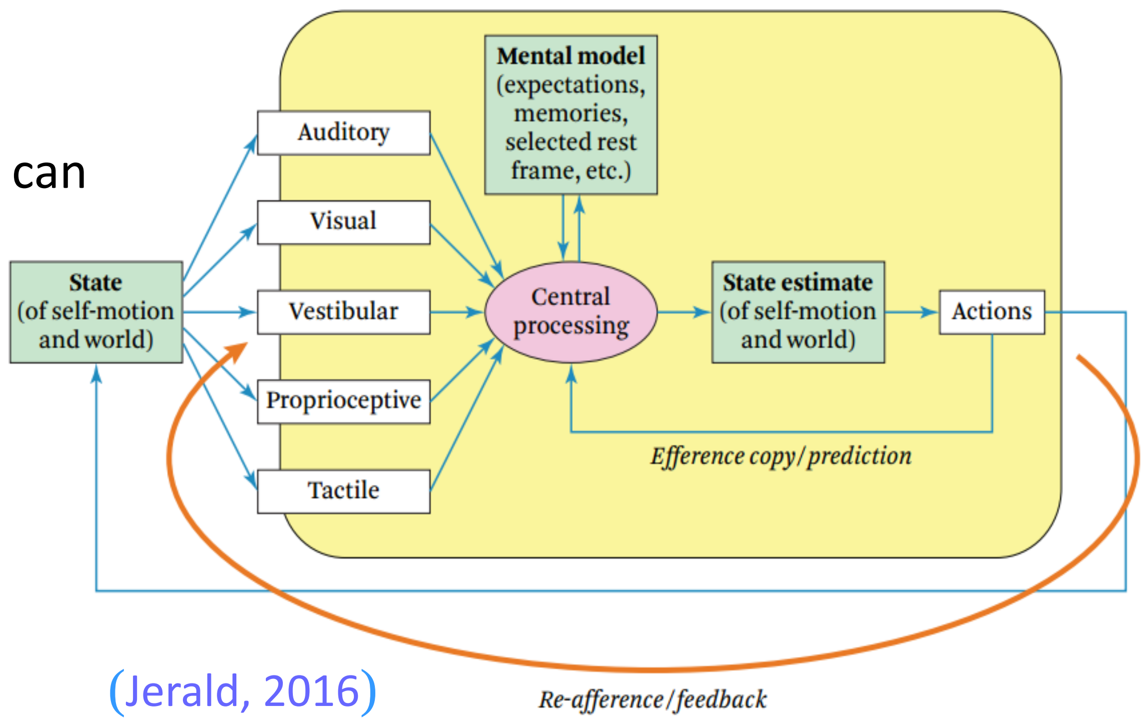
This should be considered when designing a VR system

Unified Model of motion perception and motion sickness

Consistent with the mentioned theories of motion sickness

Help understand how we perceive motion, whether it is perceived as external motion of the world or self-motion, and why motion sickness may result

Inconsistent state estimation can result in motion sickness
(e.g. vestibular cues do not match visual cues)



(Jerald, 2016)

Measuring Motion sickness

Motion sickness is very difficult to measure

Is polysyntomatic and cannot be measure by a single variable

It varies a lot among individuals

Between-subjects experiments with many participants are needed

Can be measured using:

- questionnaires (subjective)
- postural stability tests
- physiological measures

(objective)

The Kennedy Simulation Sickness Questionnaire (SSQ)

Is a **standard** for measuring simulator sickness
Based on data from 1,119 users of 10 US Navy flight simulators
https://psycnet.apa.org/record/1994-19884-001

Three categories of symptoms:

- oculomotor
- disorientation
- nausea

Participants rank each of the 16 symptoms on a 4-point scale:

“none,” “slight,” “moderate,” or “severe”

SSQ results in four scores:

- total (overall) sickness
- three subscores for the three categories

Should be applied only after the immersion to avoid bias

Eye Strain, Seizures, and Aftereffects

Non moving stimuli can also cause discomfort and adverse health effects:

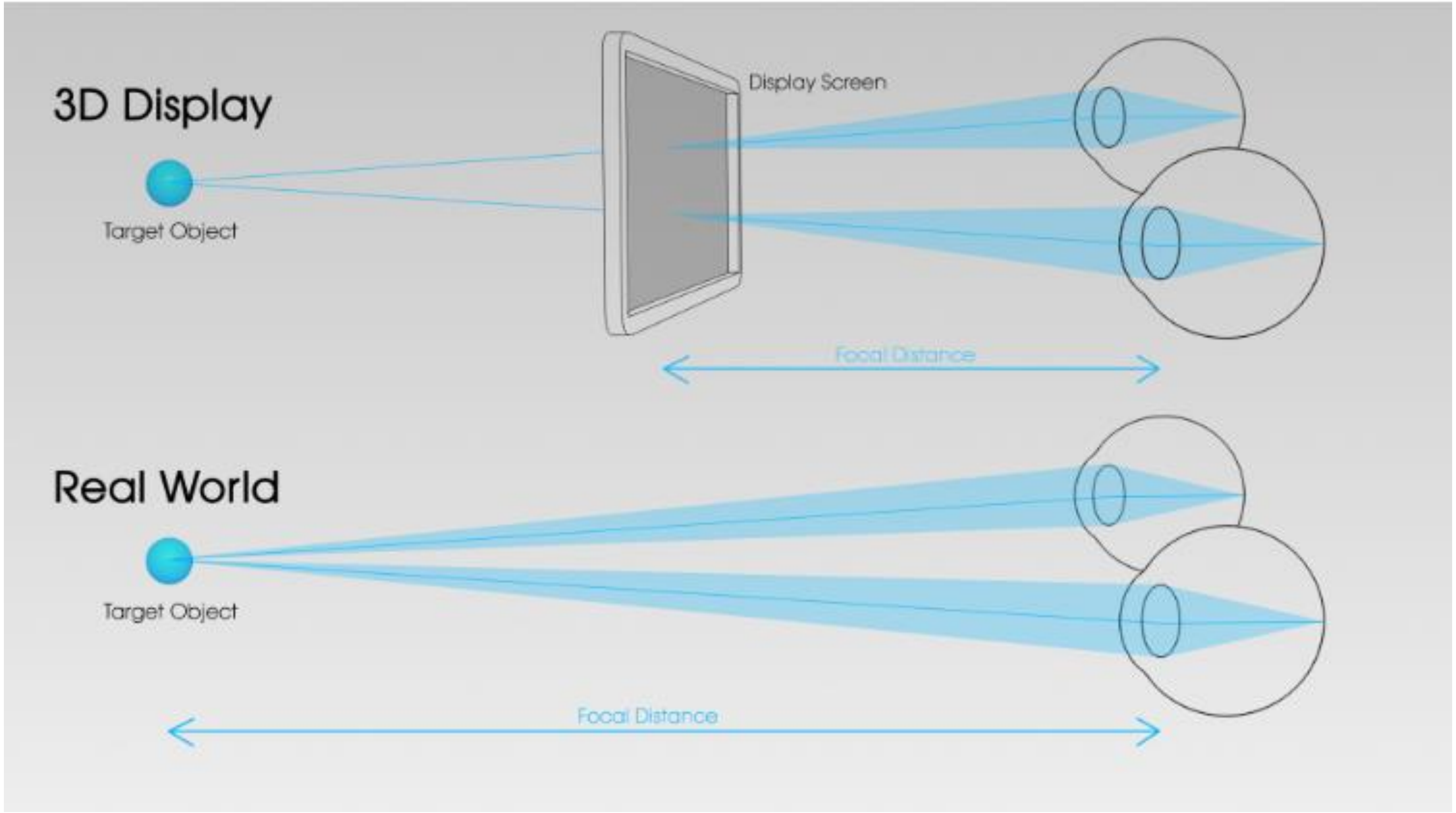
- **Accommodation- Vergence Conflict** (in HMDs the image is near the eyes)

- Binocular-Occlusion Conflict (e.g. text overlay)

- Flicker (caused not only by low frame rates; in extreme may induce seizures)

- **Aftereffect**s:
perceptual instability of the world, disorientations, flashbacks, drowsiness, disturbed locomotor and postural control, and lack of hand-eye coordination

Accommodation-Vergence Conflict (the display image is near the eyes)



https://www.scientificanimations.com/virtual-reality-healthcare-aid-health-hazard/

Accommodation: the lens inside the eye adjusts to bring the object in focus
Vergence: the eyeballs point towards the object

Adaptation, Readaptation and aftereffects

Adaptation :
Change in perception or perceptual-motor coordination that serves to reduce or eliminate sensory discrepancies

Readaptation is **adaptation back to a normal** situation (e.g. see voyagers)

Until the user has readapted to the real world, **aftereffects may persist**

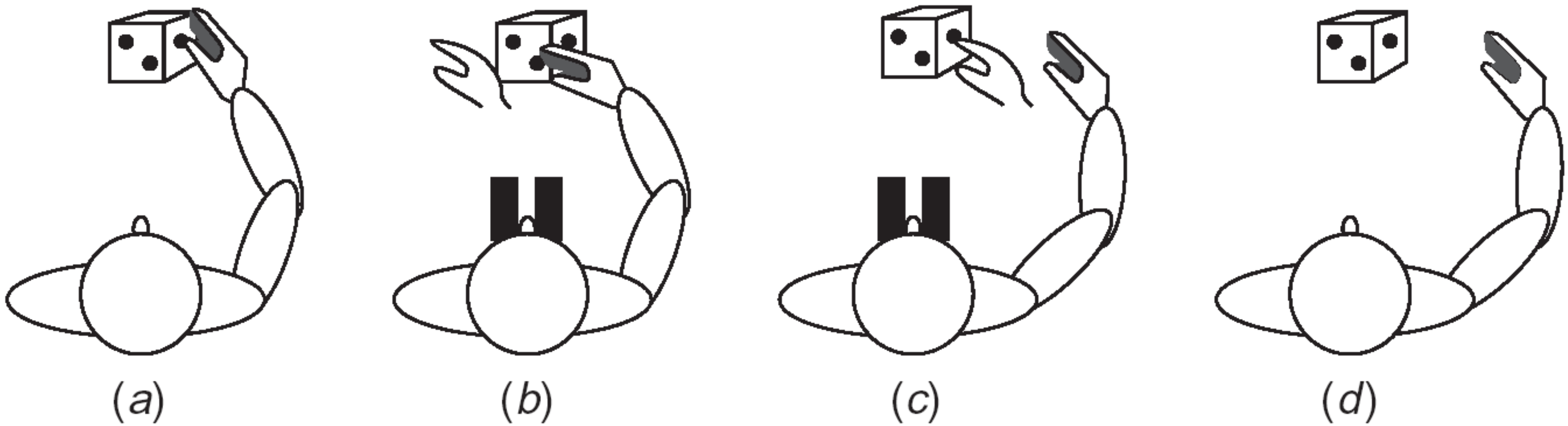
Those who experience the most sickness during VR exposure usually experience the most aftereffects

Most aftereffect symptoms disappear within an hour or two

.

But subsequent activities should be restricted (as for alcohol intoxication)

Adaptation



(Burdea and Coiffet., 2003)

Hand-eye coordination adaptation:

a) before VR exposure

b) initial mapping through artificial offset

c) adapted grasping

d) Aftereffects

Readaptation approaches

Natural decay- refrainment of any activity

- less sickness inducing
- prolongs the readaptation

Active readaptation - use real-life activities to recalibrate the sensory systems

- speeds up the process
- more sickness inducing

Frequent users may have less of an issue with VR sickness

Physical issues related to H/W

Physical fatigue -

- HMD weight when moving the head induces fatigue
- lack of opportunity to rest the arms (e.g. gestural interfaces)
- standing/ walking for long periods of time

Headset fit-

- an issue particularly to users wearing glasses
- poor fit may induce headaches

Injury –

- a risk in fully immersive VR due to multiple factors (e.g. trauma)
- haptic devices can be especially dangerous
- noise-induced hearing loss

Hygiene -

- VR hardware is a fomite
(capable of carrying infectious organisms)
Most serious during the pandemic!

Factors that contribute to Adverse Health Effects

System Factors

Individual User Factors

Application Design Factors

Presence *vs*. Motion Sickness

System factors that may contribute to adverse effects

Latency

Calibration

Tracking accuracy

Tracking precision

Field of view (FOV)

Refresh rate

Flicker

Binocular images, etc.

Latency – the time the system takes to respond to a user's action

Is a **major contributor to motion sickness**

Should be less than tens of ms and should **be consistent** (in immersive VEs)

Added to head motion causes unintended scene motion ("swimming") with serious usability and motion sickness consequences

Other **negative effects**:

- degraded Visual Acuity
- degraded Performance
- breaks in Presence
- negative Training Effects

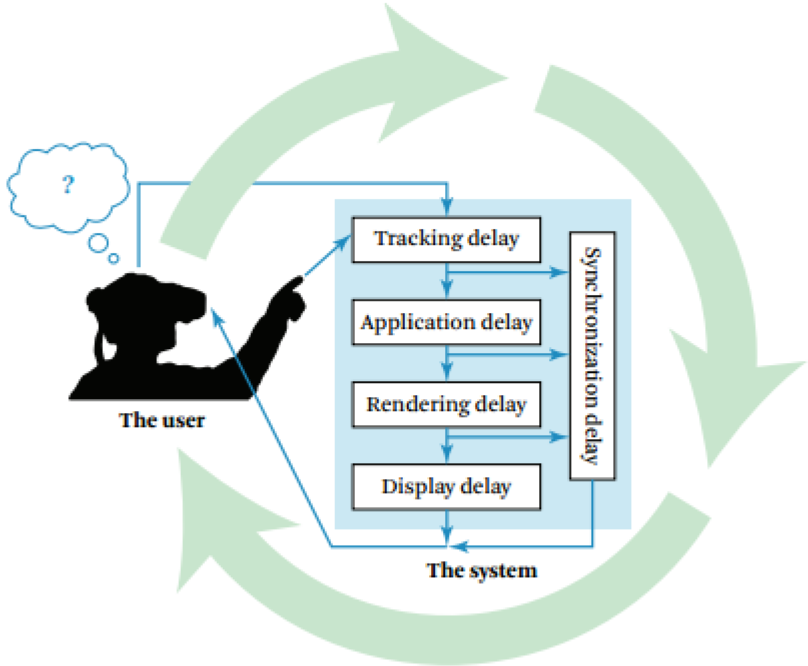
Optical-see-through displays have much lower latency thresholds (under 1 ms)

Latency and system delay

Latency - effective delay

Sources of system delay:

- Tracking
- Application
- Rendering
- Display
- Synchronization among components



(Jerald, 2016)

Total system delay is not simply a sum of component delays

Design guidelines

The potential **adverse effects of VR is the greatest risk for individuals**

as well as for **VR achieving mainstream acceptance**

“Developers are responsible for ensuring their content conforms to all standards and industry best practices on safety and comfort, and for keeping abreast of all relevant scientific literature on these topics….

“User testing of your content is absolutely crucial for designing engaging, comfortable experiences”

(Jerald, 2016)

Design guidelines

Practitioner should follow guidelines concerning:

- Hardware selection (i/o devices, trackers)
- System calibration
- Latency reduction
- General design
- Motion and interaction design
- Usage
- Sickness measuring

(Jerald, 2016)

Hardware Design guidelines

Choose HMDs that:

- are light and comfortable, have the weight centered above the center
- have no perceptible flicker, fast pixel response time, and low persistence
- with tracking that is accurate, precise, and does not drift

Choose trackers with high update rates

Use HMD position tracking

Use wireless systems; if not possible, consider hanging wires from the ceiling

(Jerald, 2016)

Hardware Design guidelines (cont.)

Add code to prevent audio gain from exceeding a maximum value

Choose hand controllers that do not have line-of-sight requirements

Choose haptic devices that cannot exceed some maximum force and/or that have safety mechanisms

Use motion platforms if possible in a way that vestibular cues correspond to visual motion

System Calibration Design guidelines

Calibrate the system and confirm often that calibration is precise and accurate

Always have the virtual field of view match actual FOV of the HMD

Use interpupillary distance for calibrating the system

Implement options for different users to configure their settings differently

Remember: different users are prone to different sources of adverse effects

Latency Design guidelines

Minimize overall end-to-end delay as much as possible

Study the various types of delay in order to optimize/reduce latency

Measure the different components that contribute to latency to optimize

Inconsistent latency can be worse than long latency and difficult adaptation

Do not depend on filtering algorithms to smooth out noisy tracking data

Use displays with fast response time and low persistence to minimize motion blur and judder

(Jerald, 2016)

Interaction and Motion Design guidelines

Design interfaces so that users can work comfortably

Design interactions to be non-repetitive to reduce repetitive strain injuries

If the highest-priority is to minimize VR sickness do not move the viewpoint in any way that deviates from actual head motion of the user

If latency is high, do not design tasks that require fast head movements

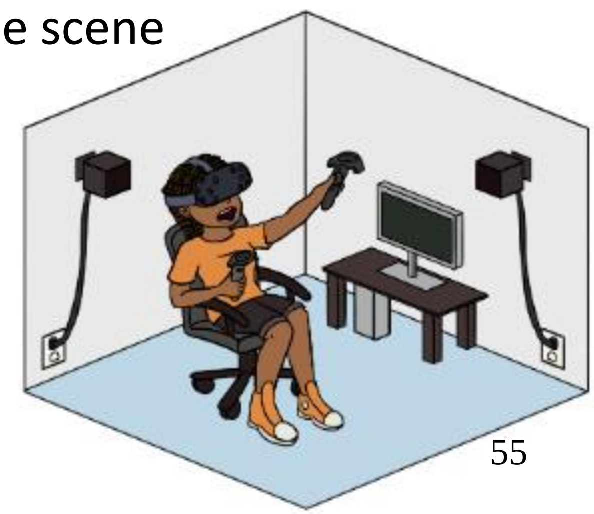
General Design guidelines

Design for short experiences

Consider making scenes dark to reduce the perception of flicker

Minimize visual stimuli close to the eyes (vergence /accommodation conflict)

Avoid flashing low frequency lights anywhere in the scene



Reduce risk of injury designing experiences for sitting or providing barriers

(Jerald, 2016)

Before immersion

Screen users whenever possible for susceptibility to cybersickness

Inform users of potential adverse effects and that they can stop when they wish

Encourage users to be well rested before exposure

Discourage VR usage by those hill, with binocular anomalies, susceptibility to migraines …

During immersion

Provide a comfortable environment

Make sure the equipment fits users comfortably

Monitor users for signs of cybersickness, or any potential hazards

After Immersion

Monitor eye-hand coordination, postural stability, and other aftereffects

Warn against performing high-risk activities immediately after immersion

Measuring motion sickness guidelines

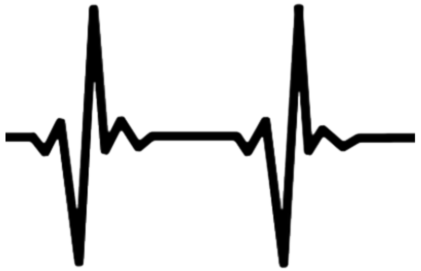
For easiest data collection, use symptom checklists or questionnaires.

The **Kennedy Simulator Sickness Questionnaire** is the standard

Postural stability tests are also easy to use by trained people

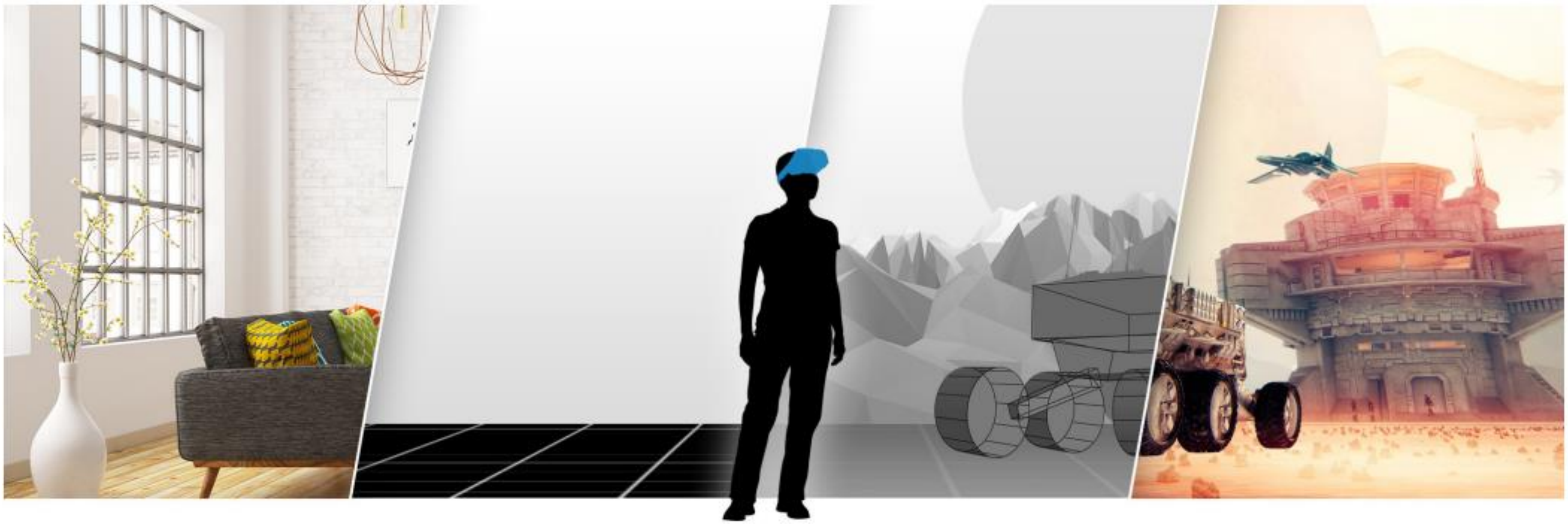
For objectively measuring sickness, consider using physiological measures

(e.g. Heart Rate, EEG, skin conductance)



WHITE PAPER

Client Computing
Virtual Reality



GUIDELINES FOR IMMERSIVE VIRTUAL REALITY EXPERIENCES

Physical foundation

Basic realism

Beyond novelty

https://www.intel.com/content/dam/develop/external/us/en/documents/guidelinesforimmersivevirtualrealityexperiences.pdf

Adverse Social implications VR

Negative potential aftereffects of VR:

Inadequate learning transfer from simulators

Privacy and security issues

Violence of VR games: additive response could result in desensitization to real-world violence

Increased individual isolation

Etc.

Social issues:

Particpants in a Pokémon Go crawl in San Francisco on July 20, 2016. LAURA MORTON

https://www.wired.com/2016/08/ethics-ar-pokemon-go/
https://www.anses.fr/en/content/what-are-risks-virtual-reality-and-augmented-reality-and-what-good-practices-does-anses

Worst cases triggered by superrealism ….

- vulnerability of certain groups of people,

- aftereffects following XR use,

- discrimination between real and virtual,

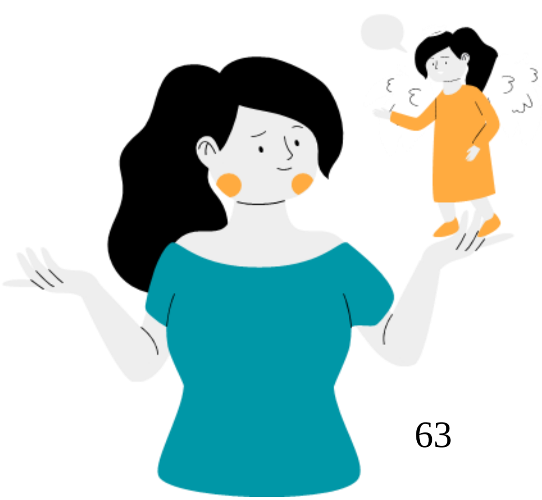
- data and privacy issues,

- XR as an interface to inflict physical harm,

- potential psychological and social implications.

(Slater, et al., 2020)

https://www.frontiersin.org/articles/10.3389/frvir.2020.00001/full



Principles for action….

- Minimizing Potential Harm of Immoderate Use,
- Minimizing Content-Induced Risk,
- Selecting Levels of Deception,
- Educating Implementers and Participants,
- Protecting Personal Information.

(Slater, et al., 2020)

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