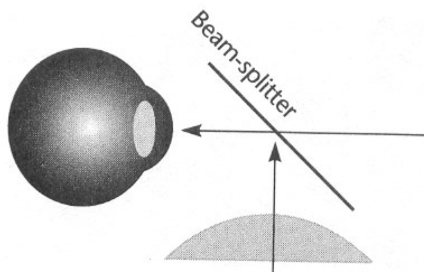
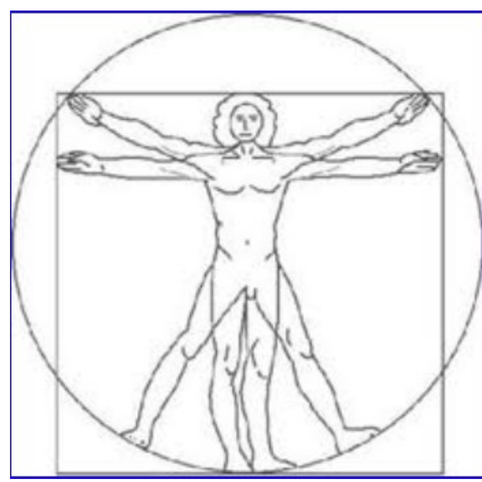
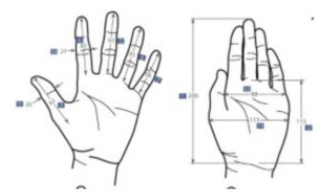
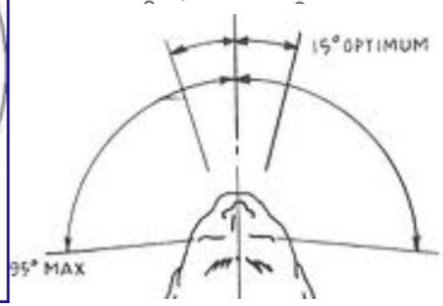
Universidade de Aveiro
Departamento de Electrónica,
Telecomunicações e Informática

Human Factors in Virtual and Augmented Reality





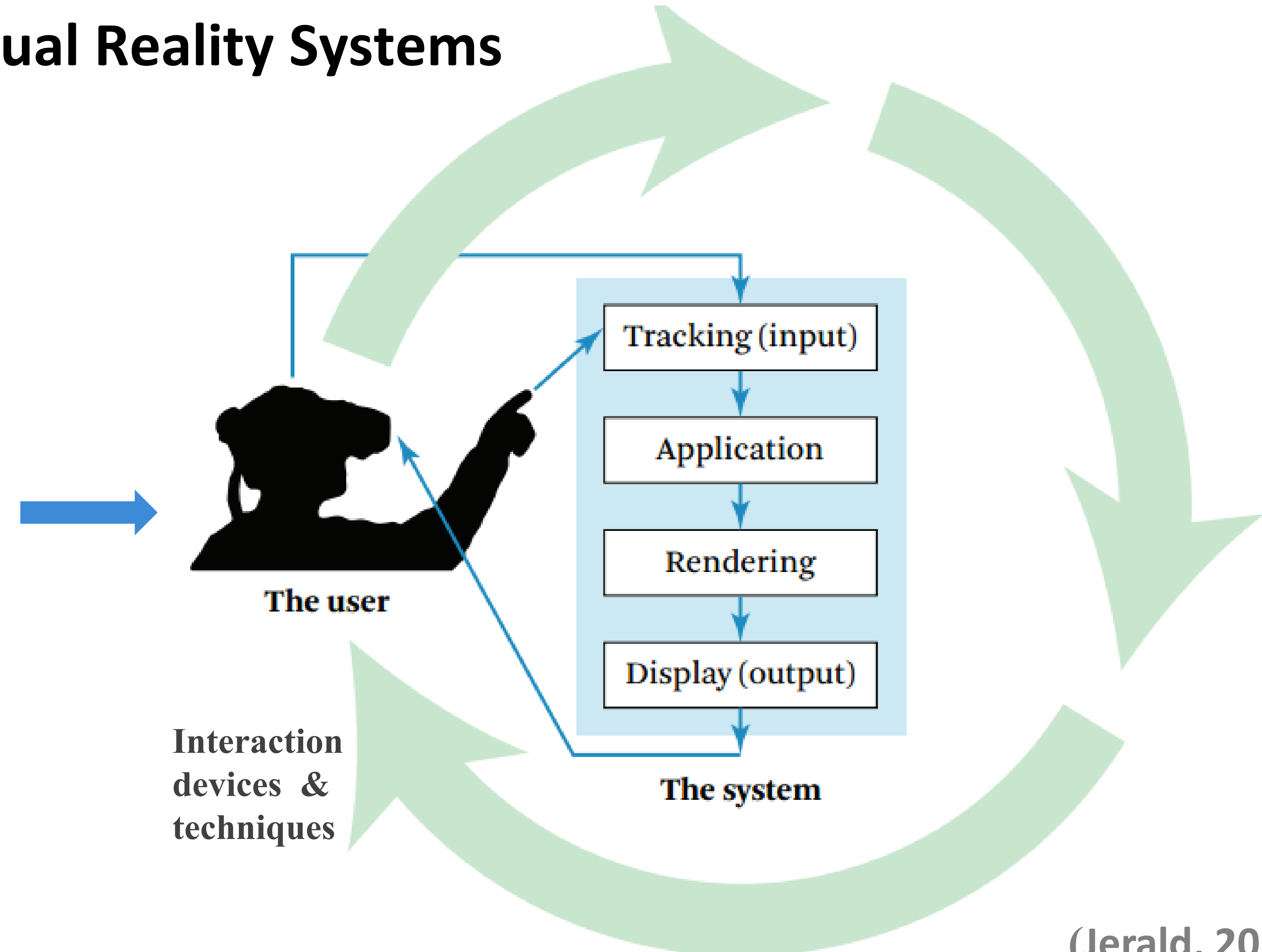




Realidade Virtual e Aumentada 2021

Beatriz Sousa Santos

Virtual Reality Systems



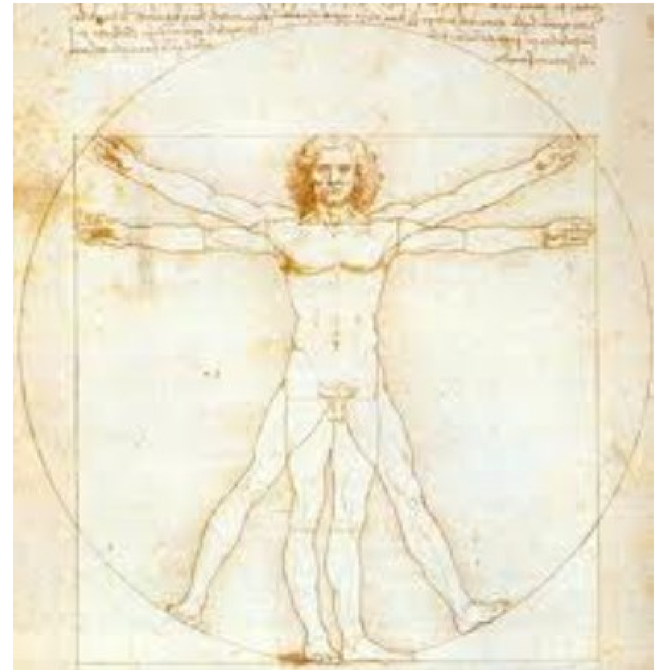
(Jerald, 2016)

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 essentially 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

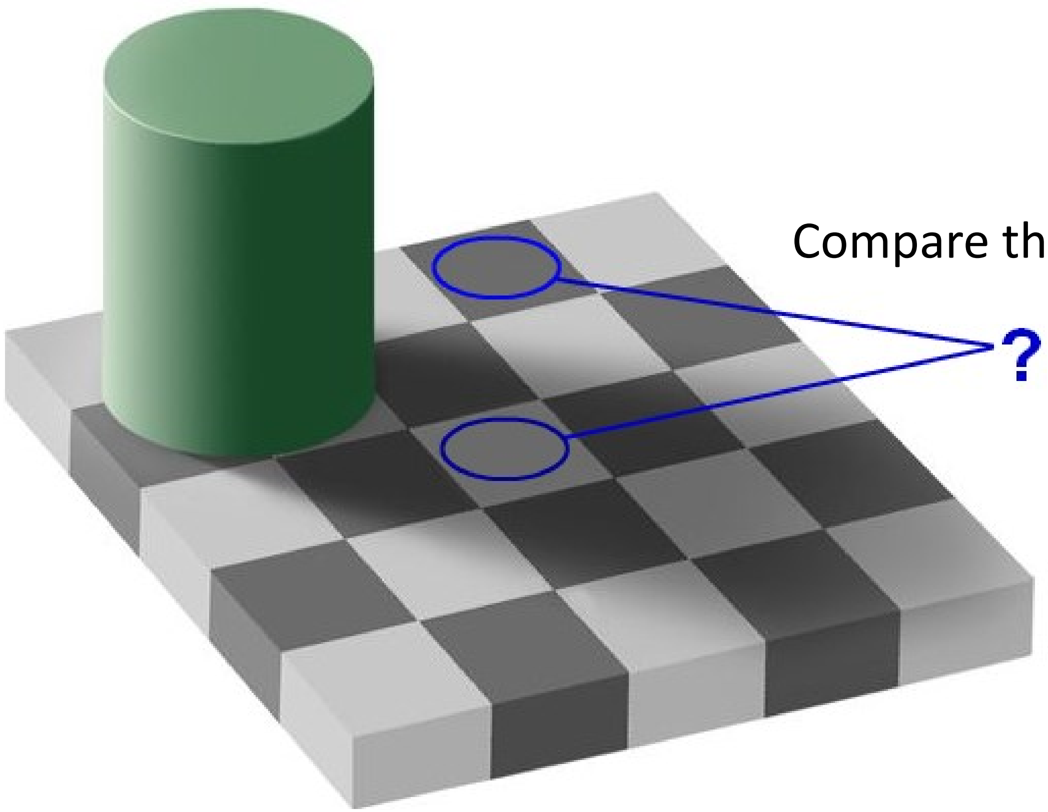
- It is not the only path, the ears are especially good for:
- situational awareness and monitoring alerts
- sensing environmental changes and speech.

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

Human Perceptual Modalities

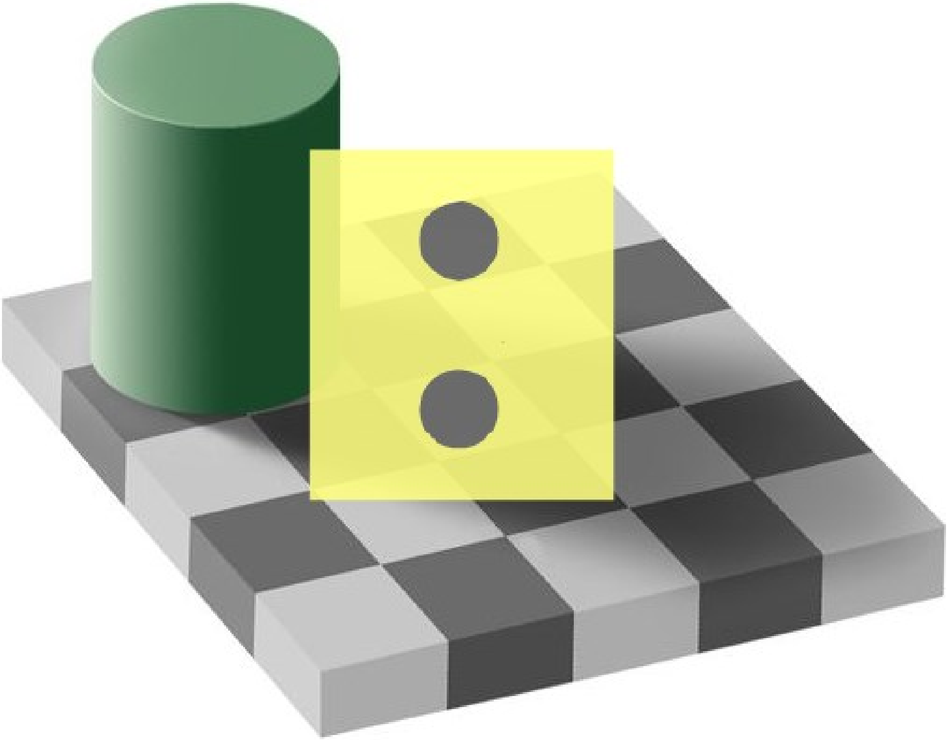
- Vision
- Hearing
- Touch
- Proprioception
- Balance and Physical Motion
- Smell and Taste
- Multimodal Perceptions

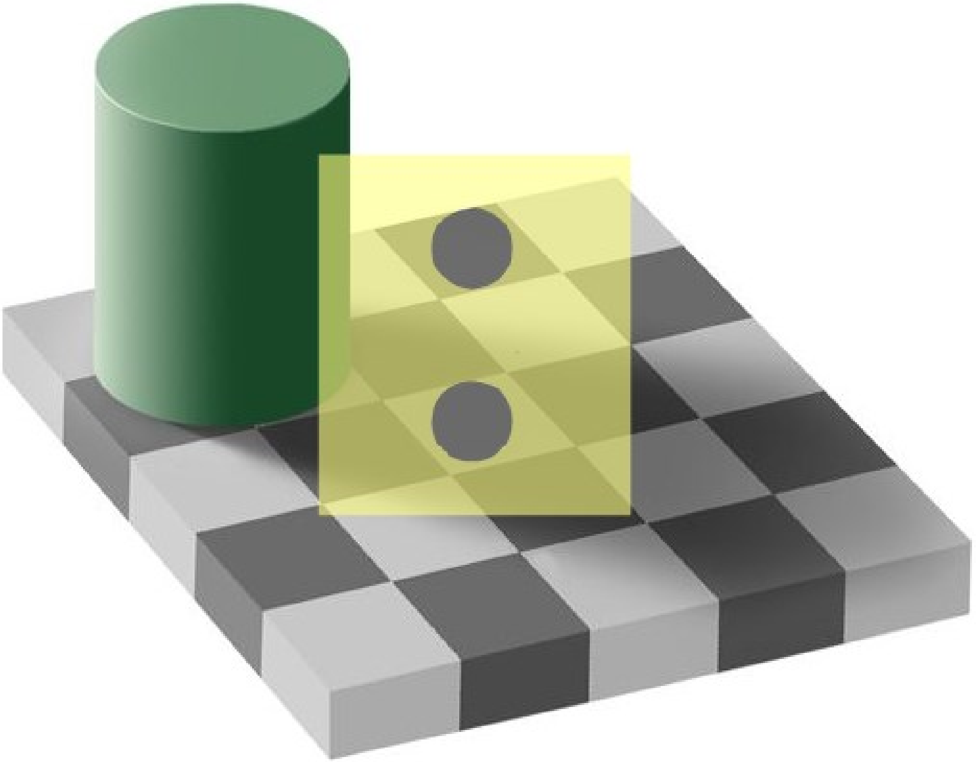
What we see does not depend only on the intensity



Compare the relative brightness

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





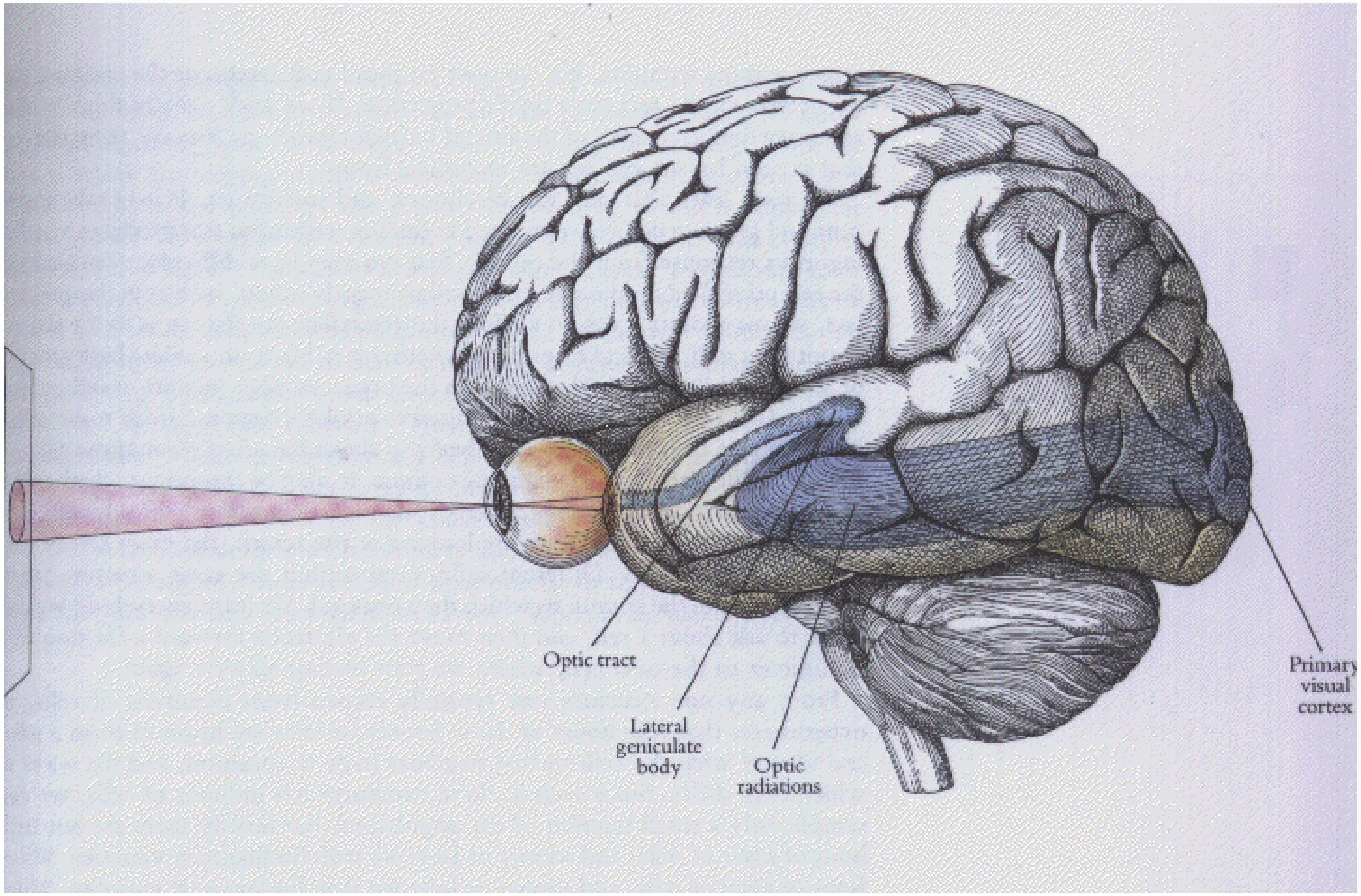
For 3D scenes, the visual system estimates a lighting vector and uses it to judge the material

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

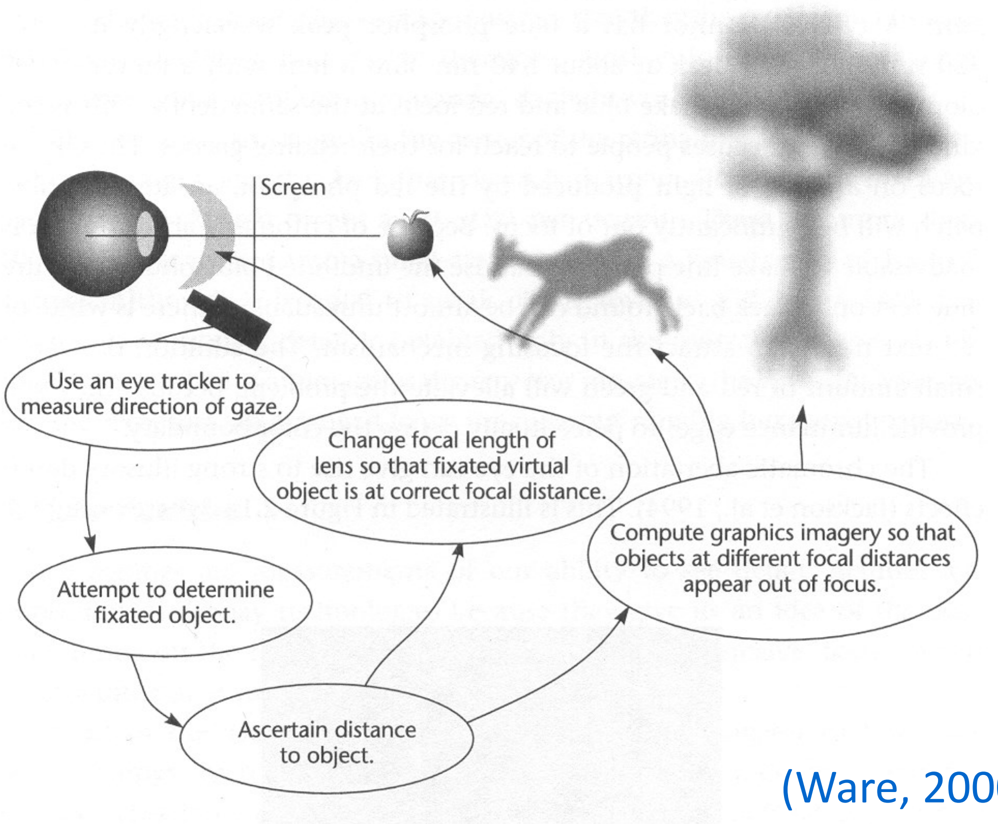
The eyes are sensors; most processing occurs at the visual cortex



(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, 2000)

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

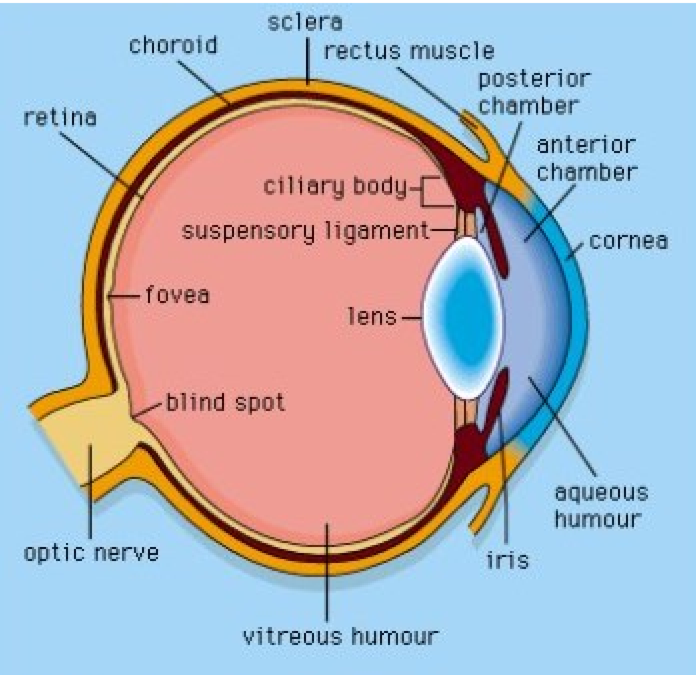
Rod sensitivity 500 higher then the cone sensitivity

Maximum rod sensitivity at 0,51 µm (green)

Maximum cone sensitivity at 0,56 µm (orange)

Dynamic range: 10^{16}

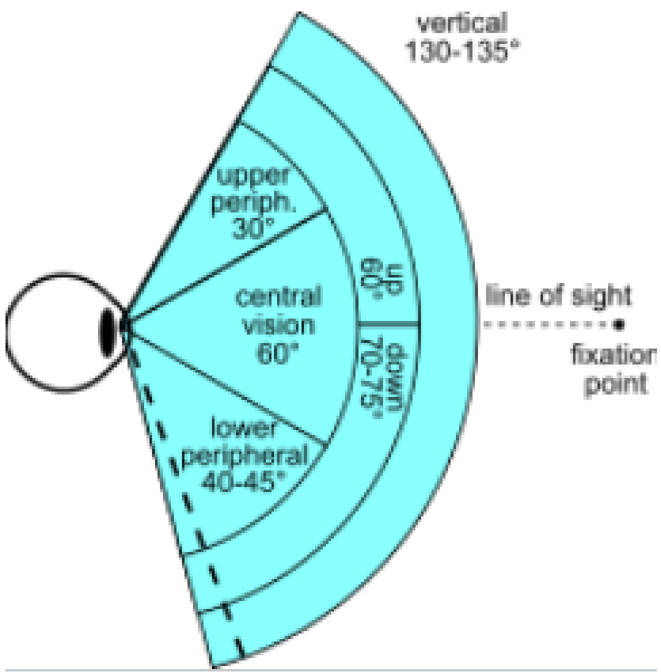
https://www.britannica.com/science/fovea-of-retina

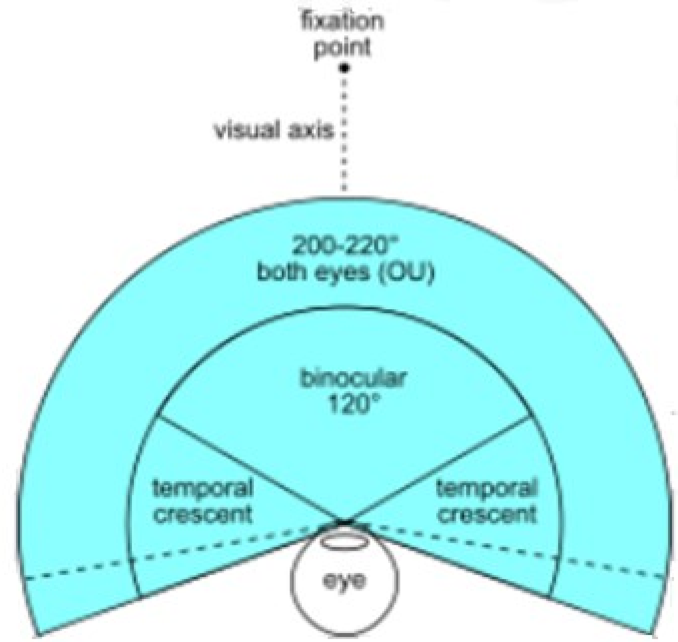


Field of View

Horizontal >~200°

Vertical >~130°





(Wikipedia)

Central vs. Peripheral Vision

Have different properties, due the retina and different visual pathways

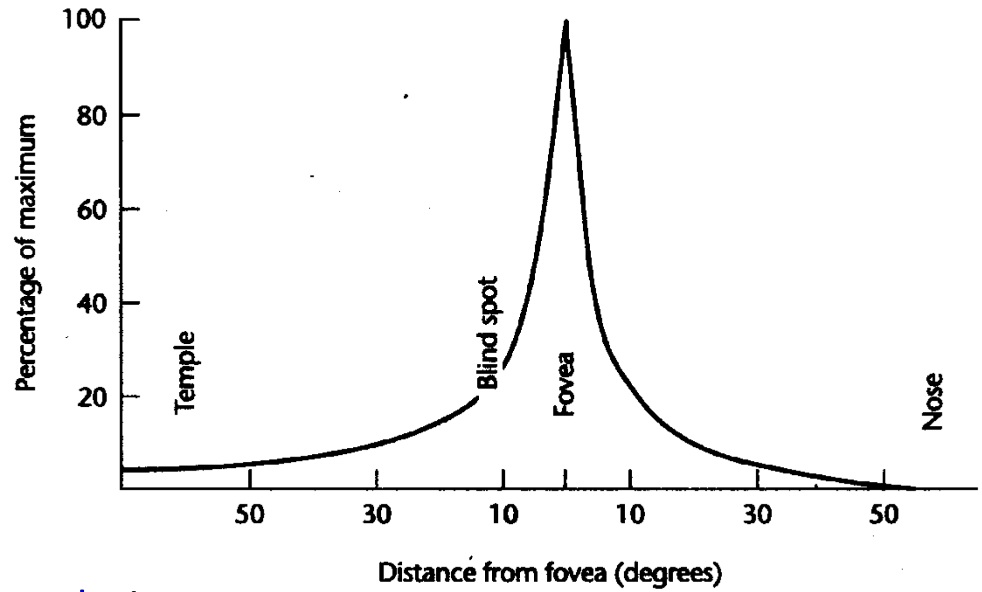
- Central vision:
  - has high visual acuity,
  - is optimized for bright daytime conditions, and is color-sensitive

- 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, 2000)

- 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 temporal requirements for the “ideal display”

~50 Hz is the lower 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

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!

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)

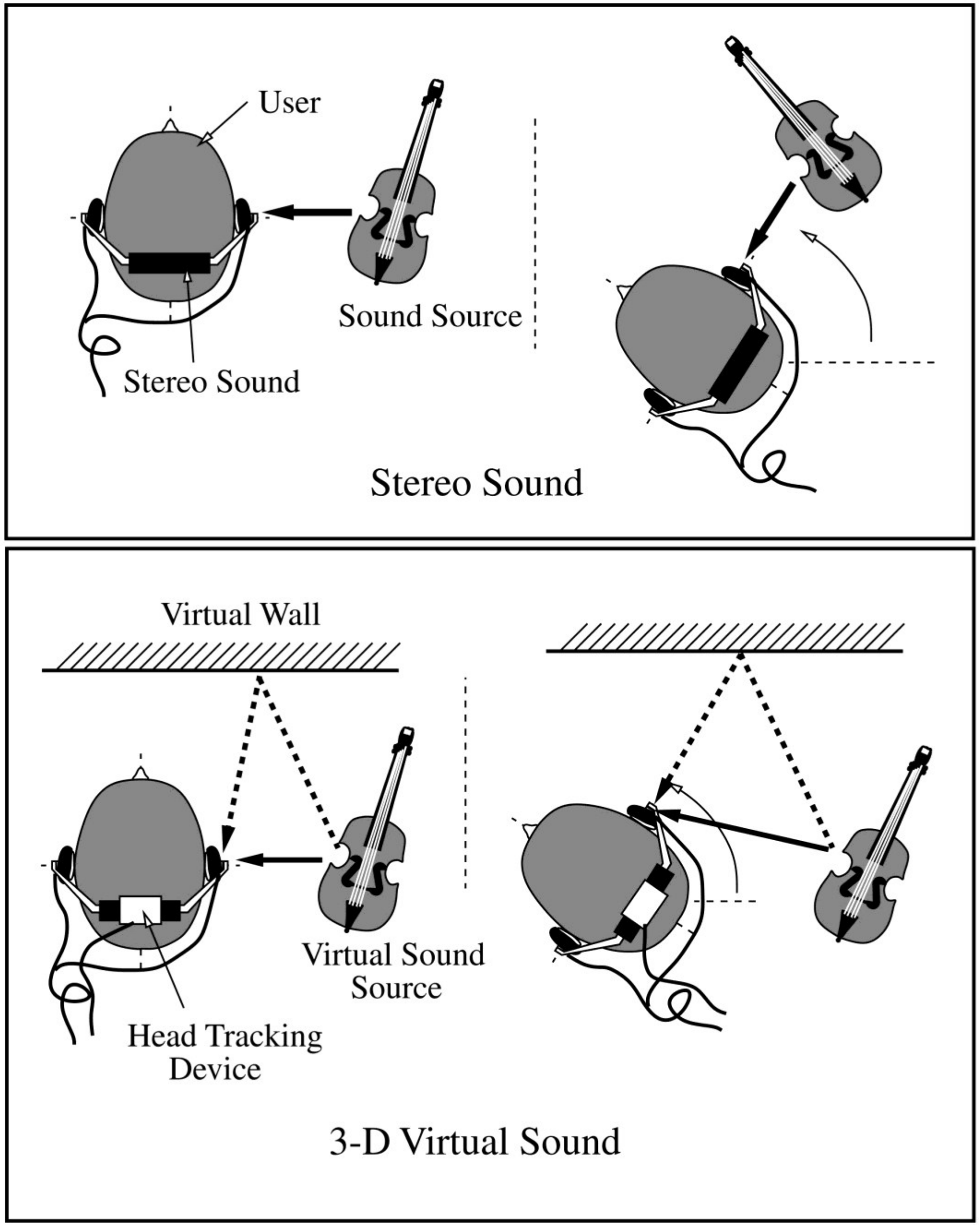
- Binaural cues (aka stereophonic cues) are two different audio cues
- One for each ear, that help to determine the position of sounds
- Each ear hears a slightly different sound (in time and in level)
- Interaural time differences provide an effective cue for localizing low-frequency sounds
- Spatial 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)

https://www.youtube.com/watch?v=cB_-IW9KKu4

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:

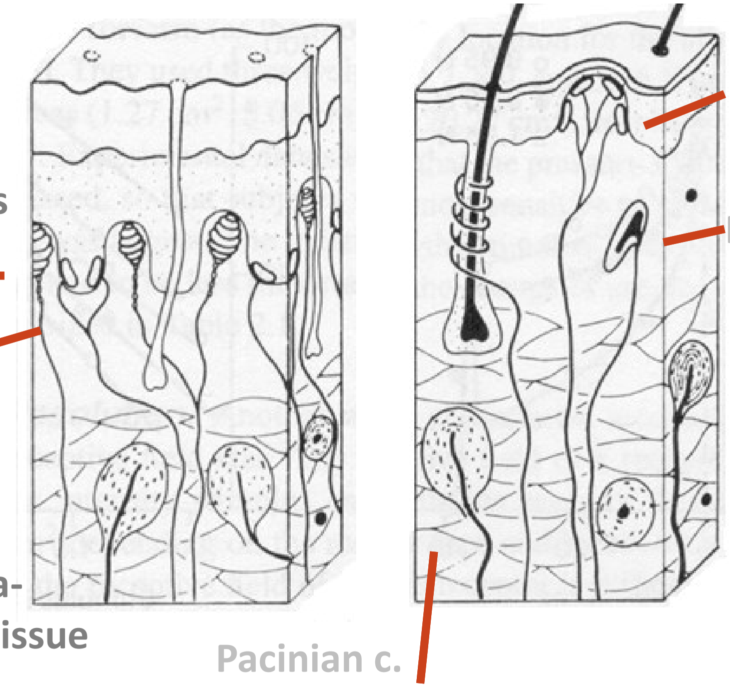
VR application designers should consider how sound might be used to positive effect in the applications they build

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

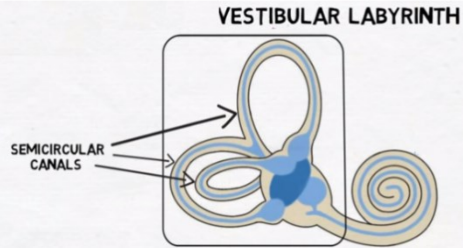
Kinesthesia is the perception of movement or strain from within the muscles, tendons, and joints of the body.

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

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

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, drowsiness pallor, sweating and vomiting (in extreme cases)

Measuring Sickness:
The Kennedy Simulator Sickness Questionnaire
Postural Stability
Physiological Measures

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

Theories of Motion sickness

Sensory Conflict Theory:
Is the most 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 …

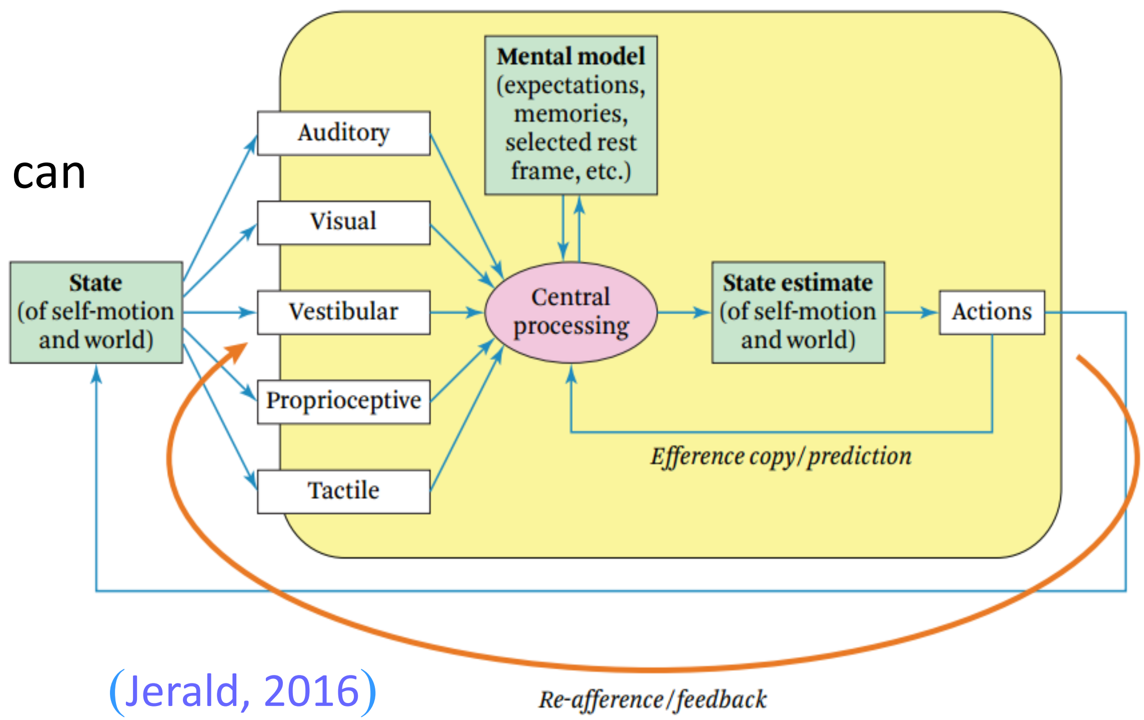
This should be considered when designing a VR system

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

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 not to avoid bias

Eye Strain, Seizures, and Aftereffects

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

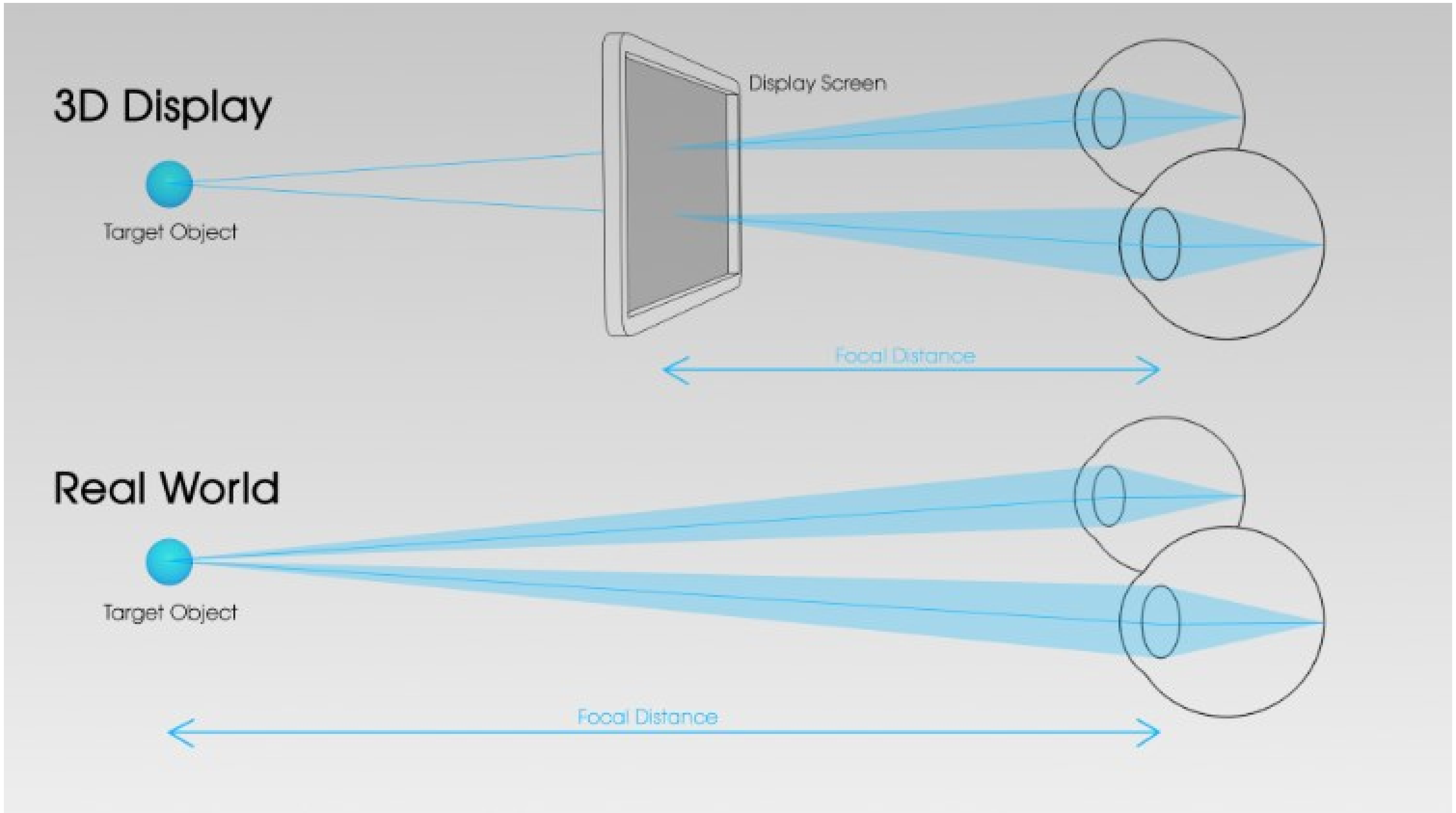
- Accommodation- Vergence Conflict (in HMDs the image is near the eyes)

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

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

- Aftereffects:
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**

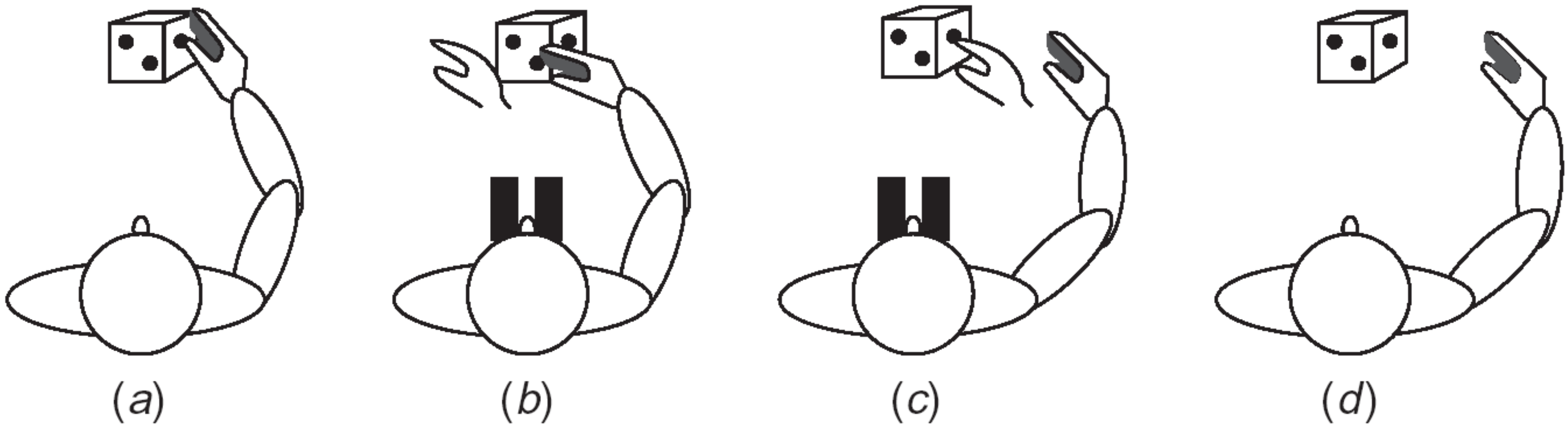
Those who experience the most sickness during VR exposure usually experience the most aftereffects

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)

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 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

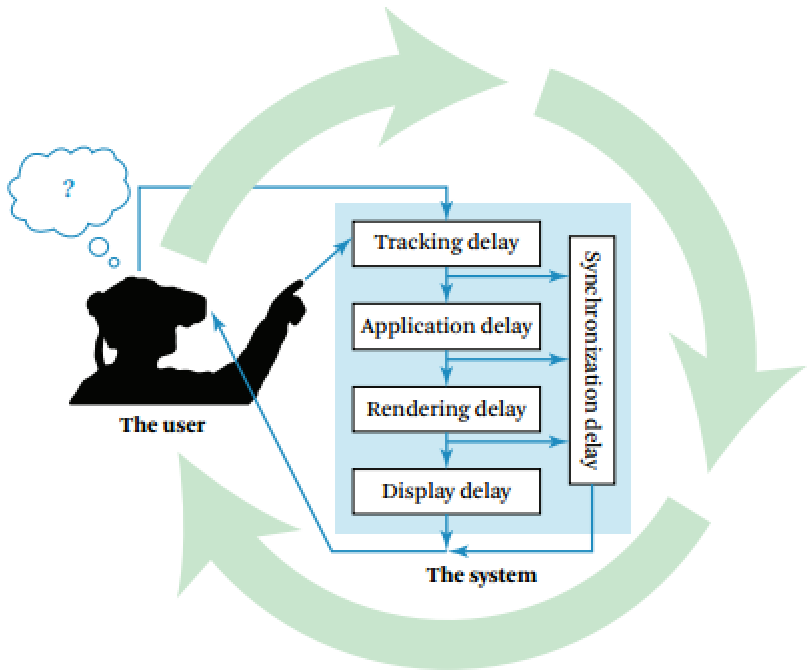
Optical-see-through displays have much lower latency thresholds (under 1 ms)

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

Note: 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

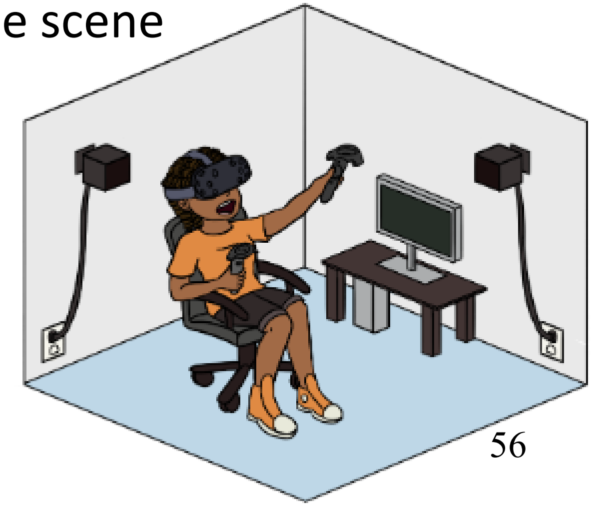
Design for short experiences

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)

Usage design guidelines

Consider:

- forcing users to stay within safe areas via physical constraints
- carefully watching the users and help stabilize them when necessary
- providing a clean cap to wear underneath the HMD
- wiping down equipment and clean the lenses after use and between users
- keeping (hidden) sick bags, drinks, light snacks, and cleaning products nearby

For new users:

- be especially conservative with presenting any cues that can induce sickness
- consider decreasing the field of view

Measuring motion sickness guidelines

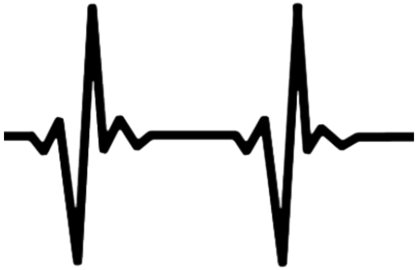
For easiest data collection, use symptom checklists or questionnaires.

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)



Guidelines for Before, During and After the Immersion

Meant to **minimize the onset and severity of cyber sickness**; largely qualitative

Before Immersion

- Screen users whenever possible for susceptibility to cybersickness;
- Place warning labels and educate users of potential adverse effects from VR exposure;
- Limit exposure to users that are free from drugs and alcohol consumption;
- Encourage users to be well rested before exposure;
- Discourage VR usage by those with cold, flu, binocular anomalies, susceptibility to migraines or photic seizures.

(Gregory and Burdea, 2003)

During Immersion

- Provide proper airflow and comfortable air temperature (preferably below 70° F);
- Ensure equipment fits users comfortably through necessary adjustments;
- Minimize initial exposure time for strong stimuli (10 minutes or less);
- Monitor users for signs of cybersickness;
- Inform users they can/should discontinue the simulation if they so wish.

After Immersion

- Measure user hand-eye coordination and postural stability;
- Introduce a time period immediately after VR exposure in which users are not allowed to perform high-risk activities (driving, piloting, biking, etc.);
- Possibly re-immerse users in a re-adaptation simulation;
- If necessary, follow up with users to monitor prolonged aftereffects;
- Introduce intersession periods of three to five days.

(Gregory and Burdea, 2003)

Oculus and cyber sickness

Oculus "… seems worried that bad experiences with competing products could sour the entire market on virtual reality"

Oculus "… currently seeking an exceptional researcher to perform cutting-edge research into perception, visual and/or vestibular mechanisms, and human factors"

http://arstechnica.com/gaming/2014/11/oculus-to-competitors-dont-release-bad-vr-headsets/

Social implications of VR

Negative potential after-effects of VR:

Violence of VR games: additive response could result

desensitization to real-world violence

Increased individual isolation

…

Example:

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

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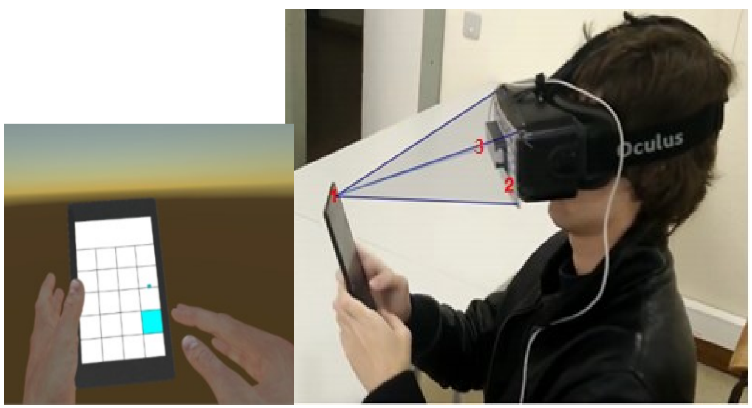
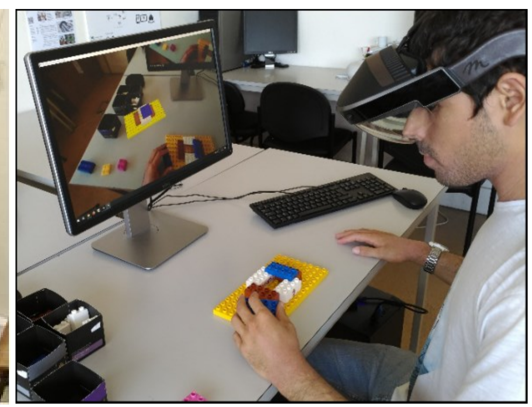
Evaluation in VR
some examples





Beatriz Sousa Santos

I - Comparing AR visualization methods for assembly

Assembly requires more than ever new ways to improve efficiency

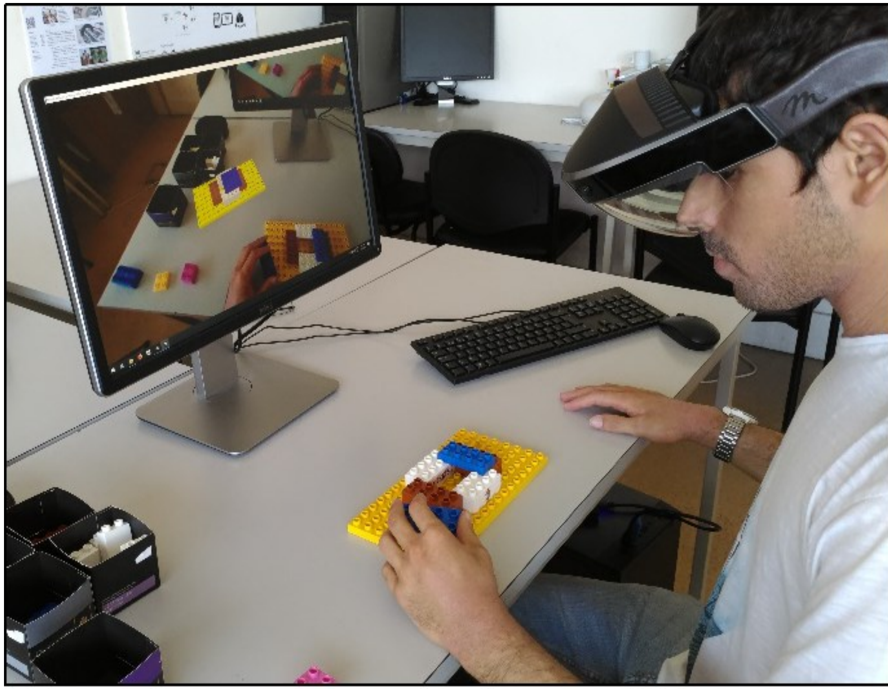
AR has been used to enhance environments and influence UX

AR-based methods can support users in assembly procedures

More user studies are needed

João Bernardo Alves, Bernardo Marques, Carlos Ferreira, Paulo Dias, Beatriz Sousa Santos, “Comparing Augmented Reality visualization methods for assembly procedures”, *Virtual Reality*, June, 2021

https://link.springer.com/article/10.1007/s10055-021-00557-8



Comparing AR visualization methods for assembly

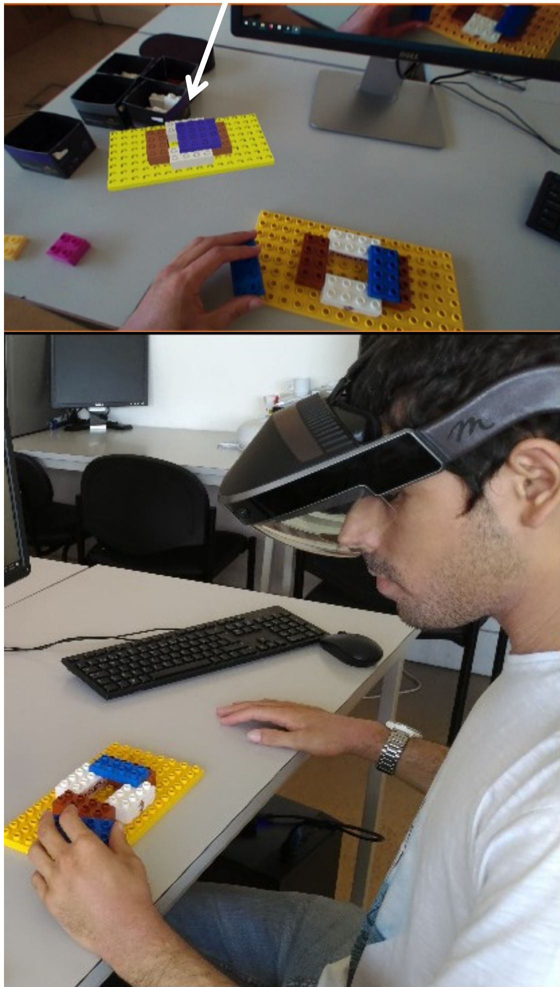
Evaluate three different **AR-based methods**

- mobile AR,
- indirect AR,
- see-through HMD

User study/controlled experiment to assess

- performance,
- mental/physical workload,
- preferences

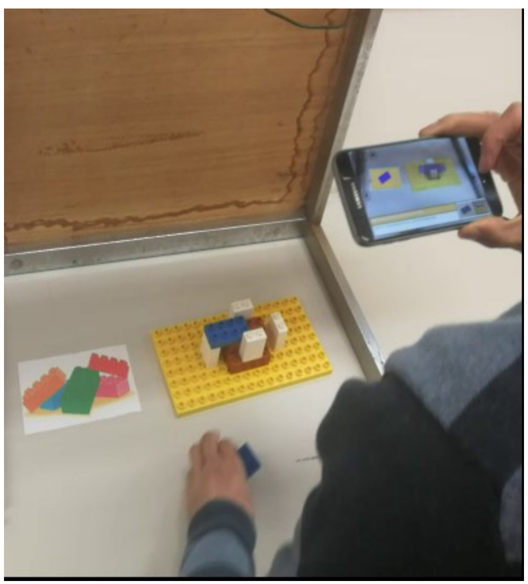
Virtual model



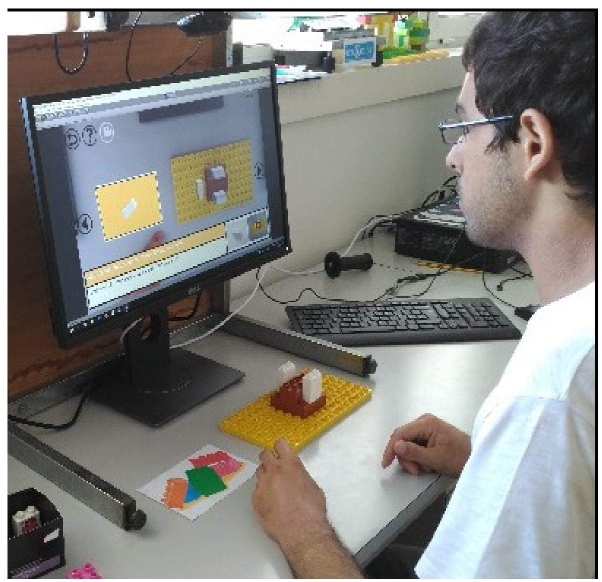
Comparing AR visualization methods for assembly

H_0 = all methods lead to similar user performance and acceptance

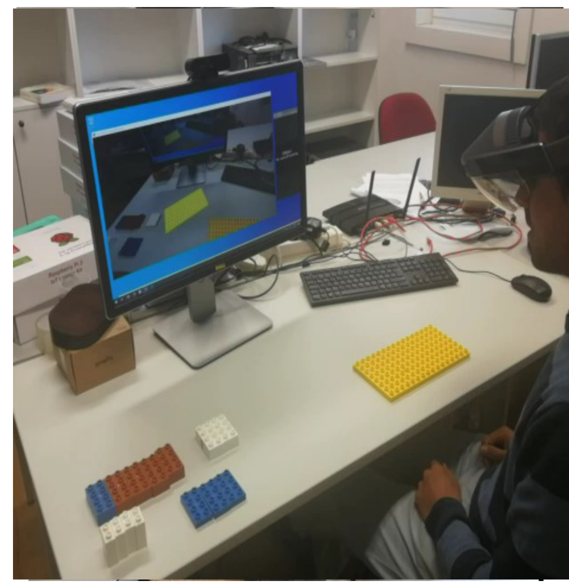
Three experimental conditions (independent/input variables):



Mobile



Indirect



HMD

Comparing AR visualization methods for assembly

Experimental design: Within Groups (condition order randomized)

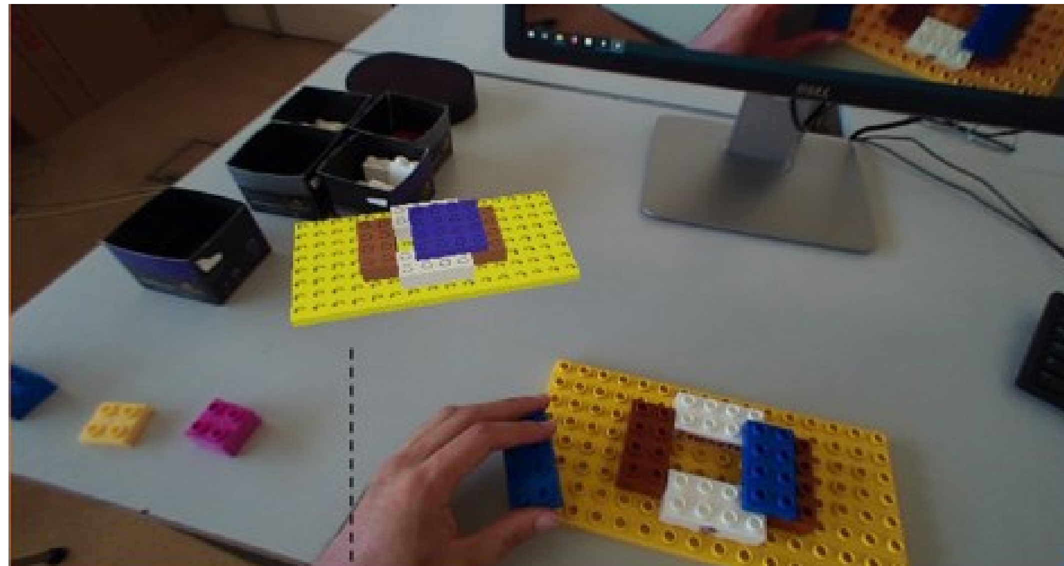
Dependent (output variables):
- Performance (times and types of errors)
- mental/physical workload
- Preferences/opinion

Secondary variables:
- order in using the conditions
- demographic data
- previous experience with AR and assembly

Comparing AR visualization methods for assembly

Tasks:

Assembly of 18 Lego blocks
in 18 step-by step 3D instructions



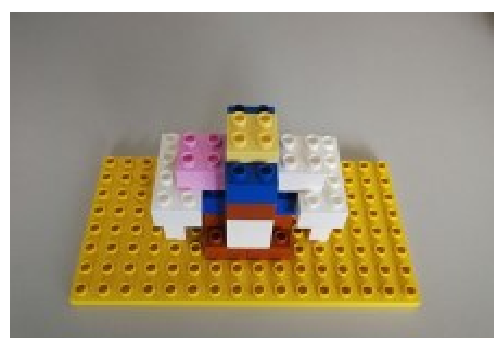
Virtual model

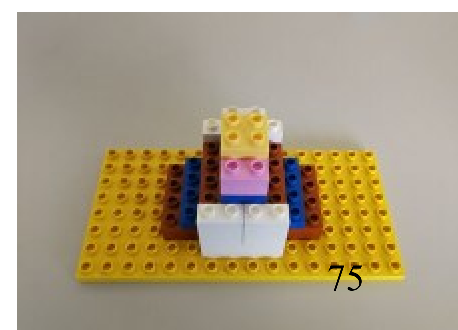
Analysis:

EDA, non-parametric tests
multivariate analysis

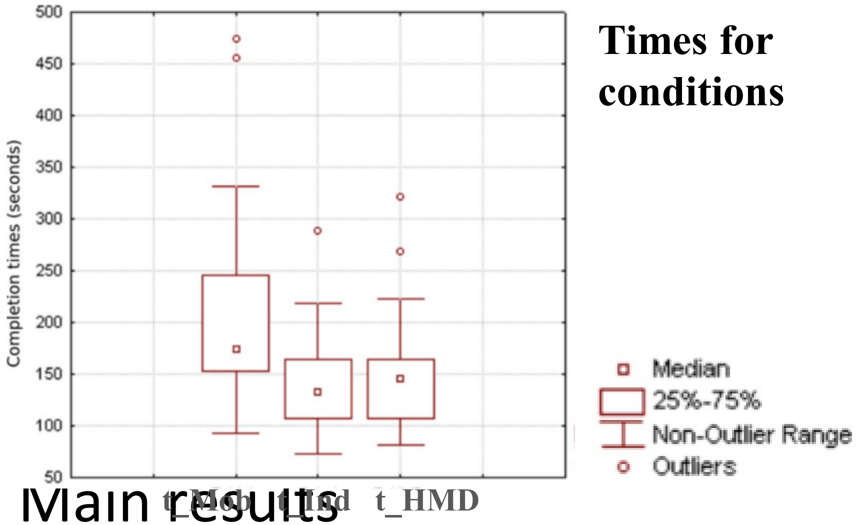
Thirty participants

Similar but different goals for different conditions





Comparing AR visualization methods for assembly



Times for conditions

Types of errors for conditions

Condition	Errors		
	E_Color	E_Location	E_shape
Mob	0	9	15
Ind	0	1	7
HMD	3	16	3

Main results

- all methods may support users
- no “best method” concerning performance and preferences
- insights on the strengths and weaknesses of each method
- suggesting guidelines for specific use cases

Comparing AR visualization methods for assembly

Future work

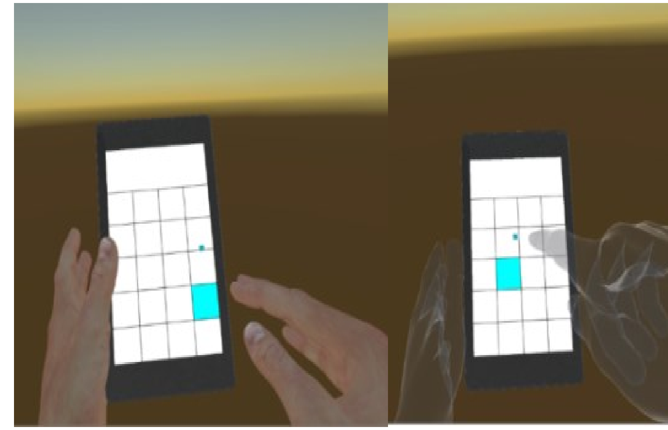
- Improve the methods to overcome technical limitations

- Further study with more:

  - complex tasks to better differentiate among methods

  - realistic settings (noise, illumination, movement, …)

II - Studying the effect of hand-avatars in a immersive VE using a tablet as input device for a selection task



Motivation

- Mobile devices have already been used as input to perform interactions in VEs
- Literature suggests their usage as input devices is viable and presents benefits
- The effect of using avatars in this situation is still an open issue

Luís Afonso, Paulo, Dias, Carlos Ferreira, Beatriz Sousa Santos, “Effect of Hand-Avatar in a Selection Task Using a Tablet as Input Device in an Immersive Virtual Environment”. *IEEE Symposium on 3D User Interfaces (3DUI2017)*, pp. 247-248, Los Angeles, March 2017.

https://ieeexplore.ieee.org/document/789336
4

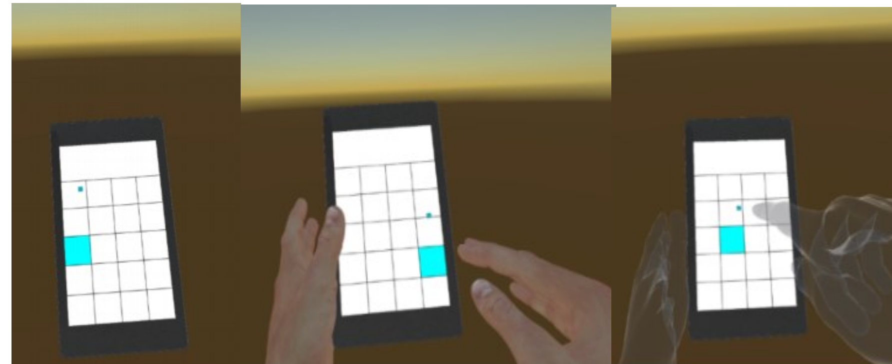
Studying the effect of hand-avatars in a immersive VE using a tablet as input device for a selection task

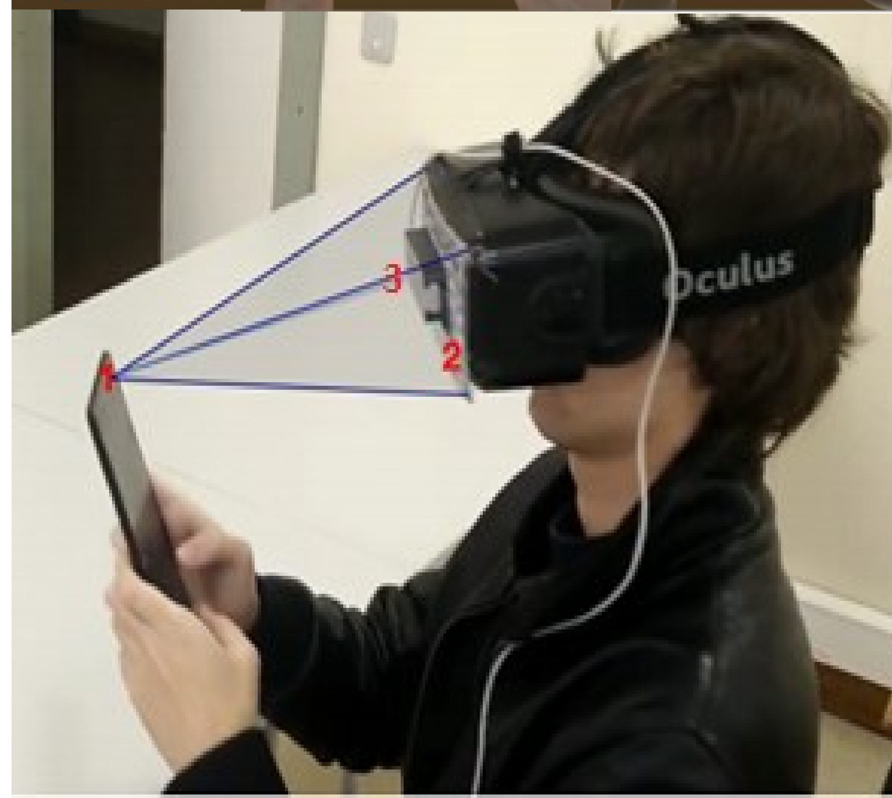
- **Task:**

- Selecting as fast as possible a highlighted button from a group of 25 buttons on the virtual tablet screen

- **Experimental Setup:**

- Oculus + Tablet + Leap Motion
- Unity + Vuforia
- Tablet front camera (1) tracking
- AR marker on the Oculus (2)
- Leap Motion (3) mounted on Oculus providing hands tracking





- **Hypothesis (Ho):**

- All conditions concerning hand avatar have similar usability (performance and opinion)

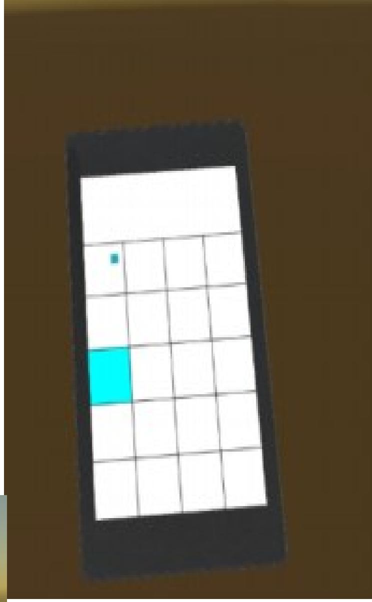
- **Independent variable: type of hand avatar (3 experimental conditions):**

- No hand avatar
- Realistic hand avatar
- Translucent hand avatar

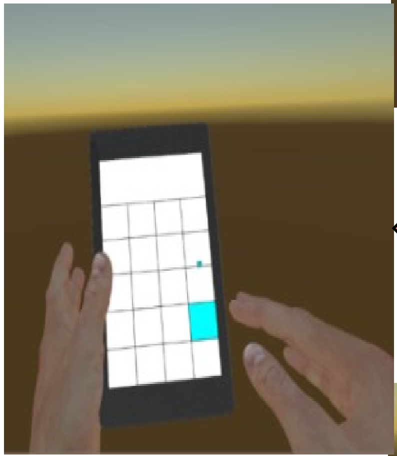
- **Dependent variables: performance and opinion:**

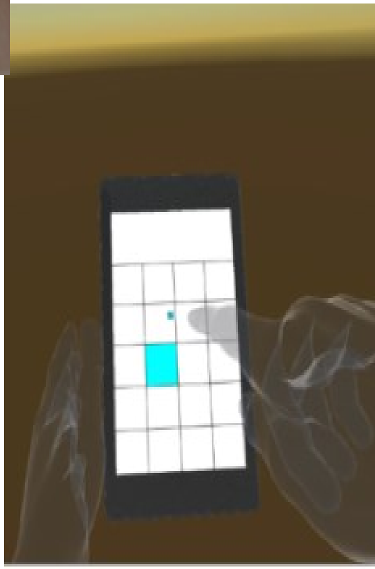
- Task completion time (seconds)
- Selection errors: number of incorrect buttons pressed
- Opinion (Lickert-like scale)

- **Experimental design: within-groups** (all participants used the three experimental conditions in different order to compensate for learning)



No avatar
Realistic
Translucent





- **Experimental procedure:**

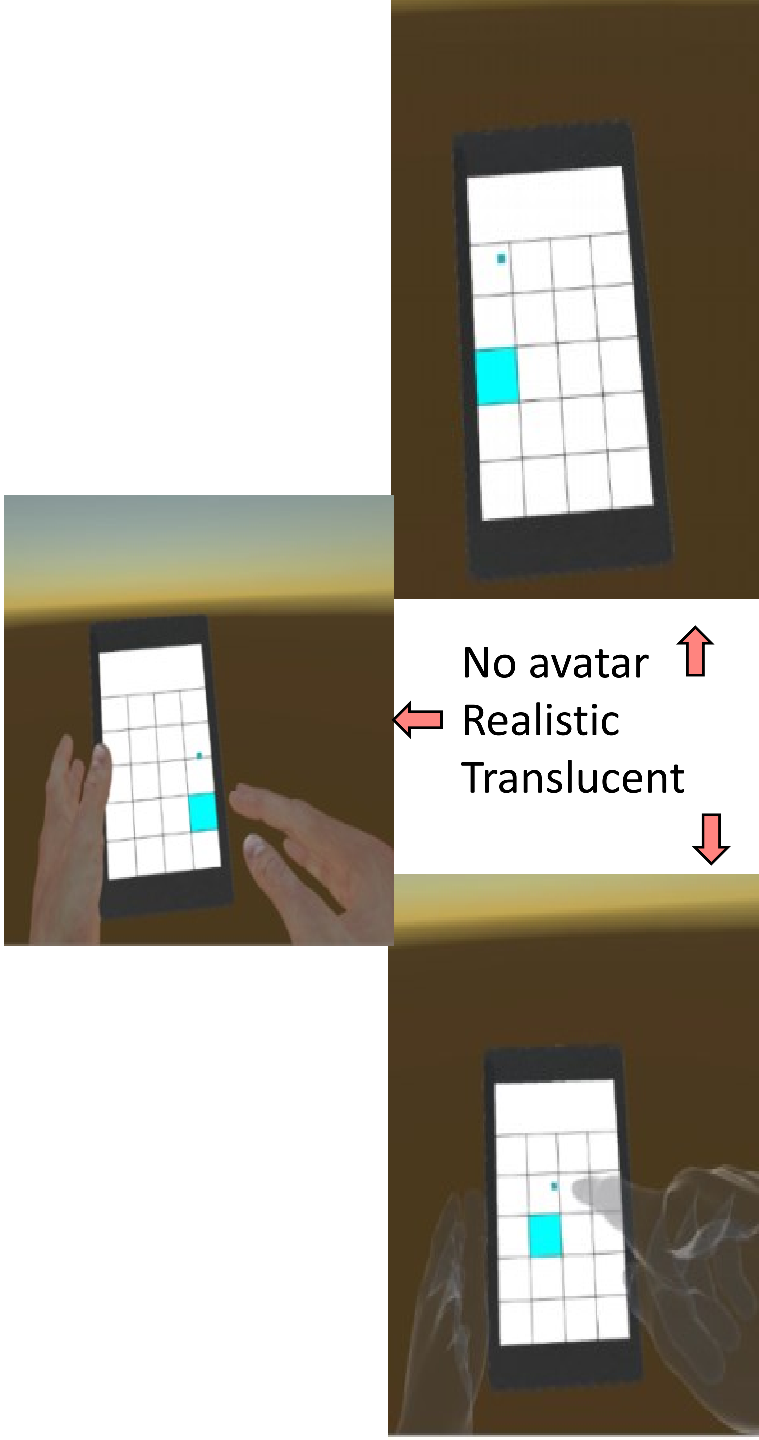
- Briefing about the experiment
- Familiarization with the setup
- Selecting 25 buttons
- Using three experimental conditions
- Questionnaire

- **Participants:**

- 55 students performed the tasks
- 52 answered the questionnaire
  (4 females; aged 19 to 28 years)
  (30 had never used VR before)

- **Statistical analysis:**

- Non parametric tests (Friedman) due to:
  - non normality of time and error data
  - ordinal nature of questionnaire data



Questionnaire

Hand representation experiment questionnaire

1. User ID: ______________
2. What is your age? _____
3. What is your gender? ☐ Female ☐ Male
4. Have you used Virtual Reality before?
   - ☐ Yes
   - ☐ No
5. Dominant hand:
   - ☐ Right
   - ☐ Left
6. How often do you use smartphone/tablet devices:

   Never ☐—☐—☐—☐—☐ Regularly
7. Please rank the three modes by preference:

   No Hands (1) _____
   Realistic Hands (2) _____
   Transparent Hands (3) _____
8. Explain why the mode [1/2/3] was your favorite:

   ____
   ____
   ____
   ____
9. How much physical fatigue did you experience in your arms while interacting with the environment?

   None ☐—☐—☐—☐—☐ Extreme

No Hand Representation

10. The task was (1 difficult, 5 easy) to perform.

    Difficult ☐—☐—☐—☐—☐ Easy
11. I felt like I was able to interact with the tablet the way I wanted to.

    Strongly Disagree ☐—☐—☐—☐—☐ Strongly Agree

Realistic Hand Representation

12. The task was (1 difficult, 5 easy) to perform.

    Difficult ☐—☐—☐—☐—☐ Easy
13. I felt like I was able to interact with the tablet the way I wanted to.

    Strongly Disagree ☐—☐—☐—☐—☐ Strongly Agree
14. I felt as if the virtual representation of the hand moved just like I wanted it to.

    Strongly Disagree ☐—☐—☐—☐—☐ Strongly Agree

Transparent Hand Representation

15. The task was (1 difficult, 5 easy) to perform.

    Difficult ☐—☐—☐—☐—☐ Easy
16. I felt like I was able to interact with the tablet the way I wanted to.

    Strongly Disagree ☐—☐—☐—☐—☐ Strongly Agree
17. I felt as if the virtual representation of the hand moved just like I wanted it to.

    Strongly Disagree ☐—☐—☐—☐—☐ Strongly Agree

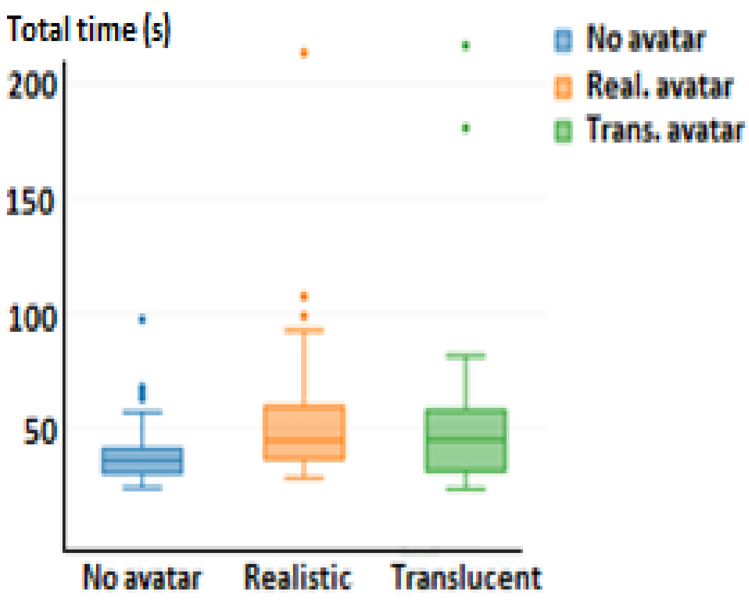
18. Comments and/or suggestions about the equipment or the environment:

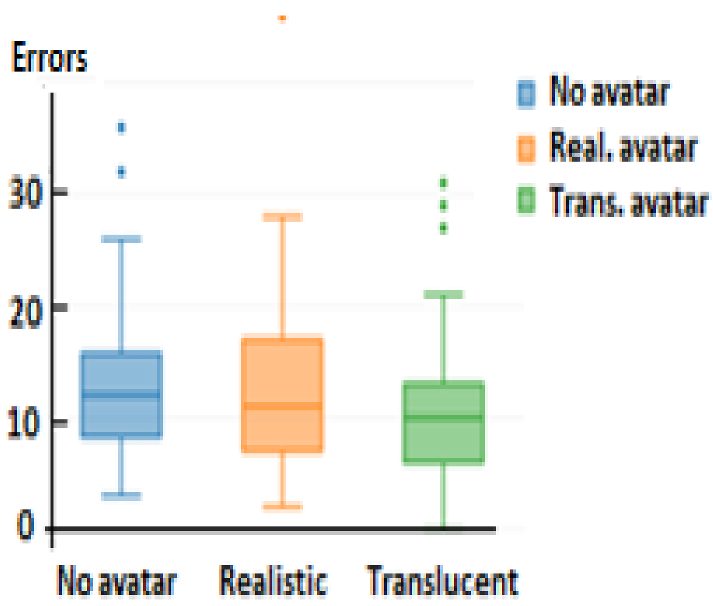
    ____
    ____
    ____
    ____

Main results concerning performance

Total task time and errors:

- Participants were faster but made more errors when there was no avatar
- Translucent avatar was the condition with less errors
- Friedman tests rejected the equality hypothesis -> differences are significant





Main results concerning preference and opinion (median values) (ordinal data in a Lickert-like scale of 5 levels)

Question (scale)	**No avatar**	**Real. avatar**	**Trans. avatar**
Q1- Preference (number of 1st) (number of 2nd) (number of 3rd)	**18** **16** **18**	**9** **25** **18**	**25** **18** **9**
Q2- The task was (1 difficult … 5 easy) to perform	**3.5**	**3**	**4**
Q3-I felt like I was able to interact with the tablet the way I wanted to (1 Strongly Disagree… 5 Strongly Agree)	**3**	**3**	**3**
Q4- I felt as if the hand avatar moved just like I wanted it to (1 Strongly Disagree … 5 Strongly Agree)	**NA**	**3**	**3.5**

All differences were statistically significant (ordinal data -> Friedman test)

Conclusions of the study

The results of our study suggest that:

- An avatar may increase usability
- It does not need to be very realistic
  (in line with previous work regarding avatars in immersive VEs)
- The hands-representation provides feedback; however:
  - it may occlude the virtual screen,
  - and become distracting as a consequence of tracking inaccuracies
- The translucent avatar provides feedback not occluding
- Accurate tracking is crucial

Future work

- Improve tracking
- Continue to explore the influence of the hands avatar, e.g.:
  - with other types of mobile devices,
  - to perform different tasks in VEs,
  - using other non-realistic (e.g. robot or cartoon-like) avatars