Conception d’environnements en Réalité Virtuelle

Eulalie.verhulst@lecnam.net

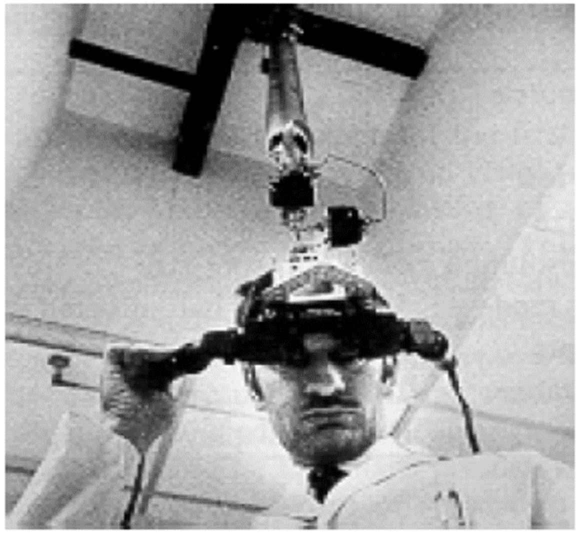
le cnam cedric EA4629

Virtual Reality

- technologie qui simule la réalité à l'aide d'un logiciel recréant les sensations d'une situation qui n'est pas matérialisée (Yoh, 2001)

- l'utilisateur peut alors interagir avec les objets qui composent la scène virtuelle (Bowman & Hodges, 1997)

Sensorama (Heilig, 1956)



Damoclès sword (Sutherland, 1968)

Virtual Reality

- RV implique une sollicitation des sens de l'utilisateur de sorte à ce qu'il agisse de façon similaire en virtuel et en réel (Lee et al., 2017)

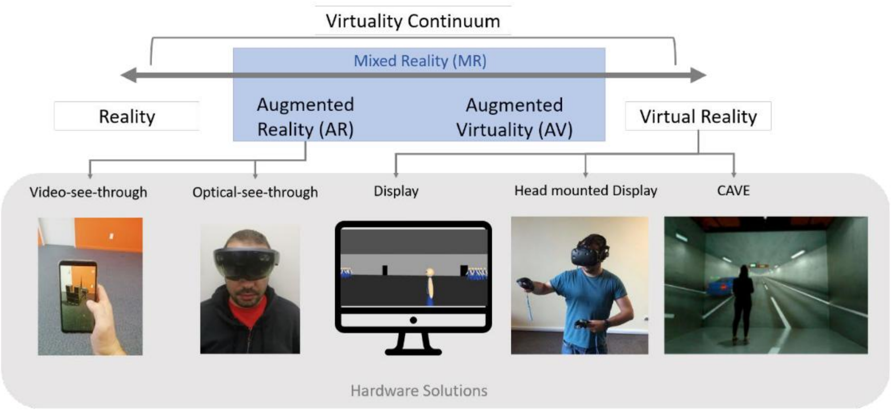
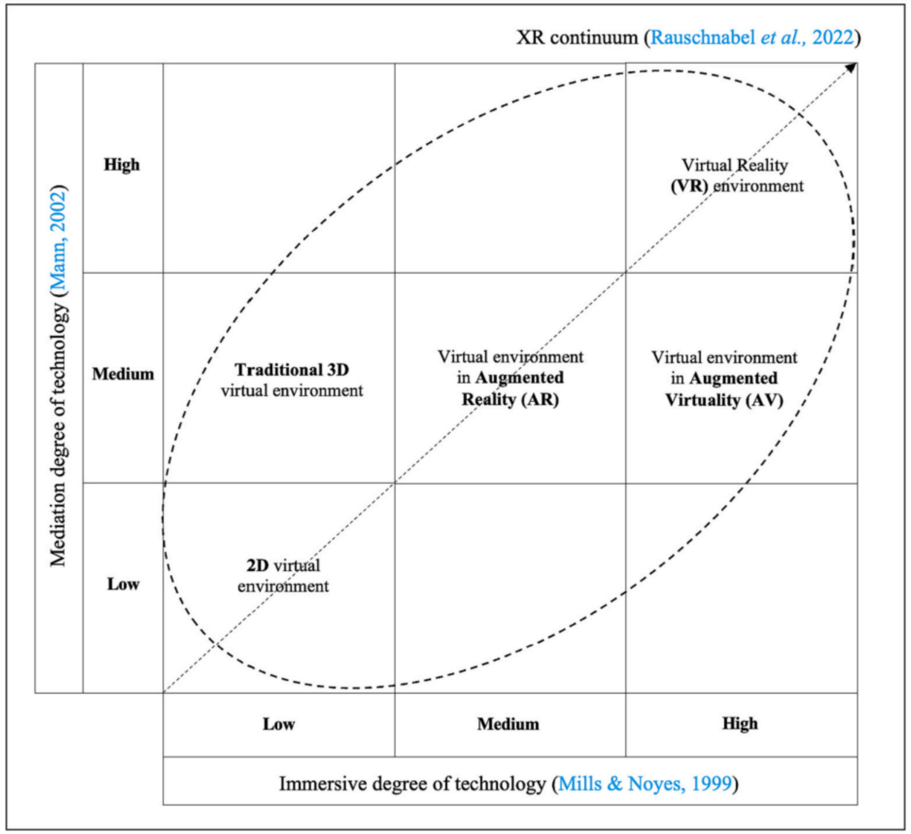
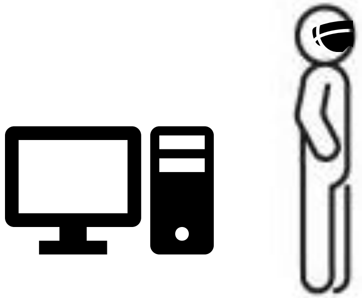
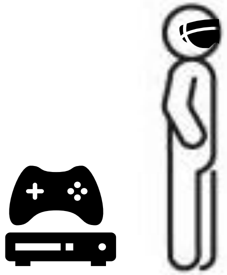


Figure 1: Virtuality continuum by Milgram & Kishino (1994) and hardware solutions for VR and AR. This figure uses modified figures published in (Ruggiero Lovreglio, Borri, Dell'Olio, & Ibeas, 2014; Ruggiero Lovreglio & Kinateder, 2020; E. Ronchi et al., 2016).



VR Setting

- Type d’utilisation de la VR

Type	 HMD connected to PC	 Standalone	 HMD connected to video game station
Example	 HTC Vive Pro Eyes	 Meta Quest 3	 PSVR + pS5

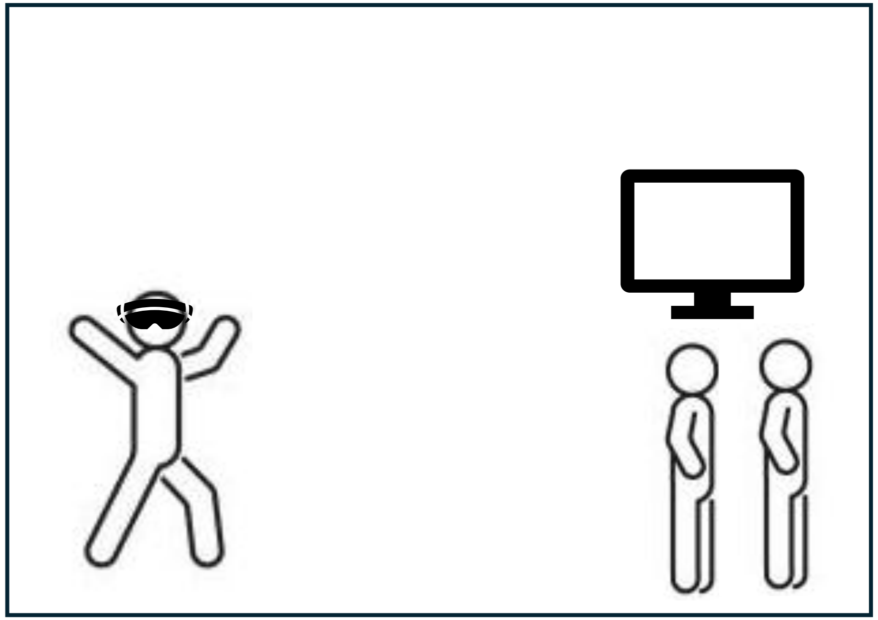
VR setting

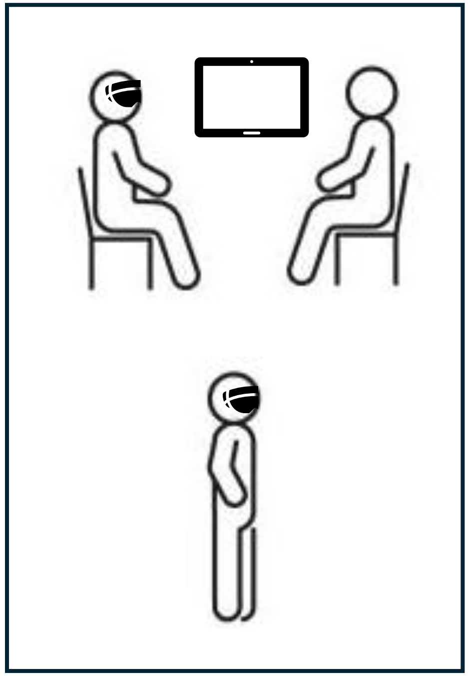
- Interactive space is the physical space where user can interact
  - Is not infinit
- Virtual space is the virtual environment where user can interact
  - Is potential infinit

Fig. Steam VR Room scale

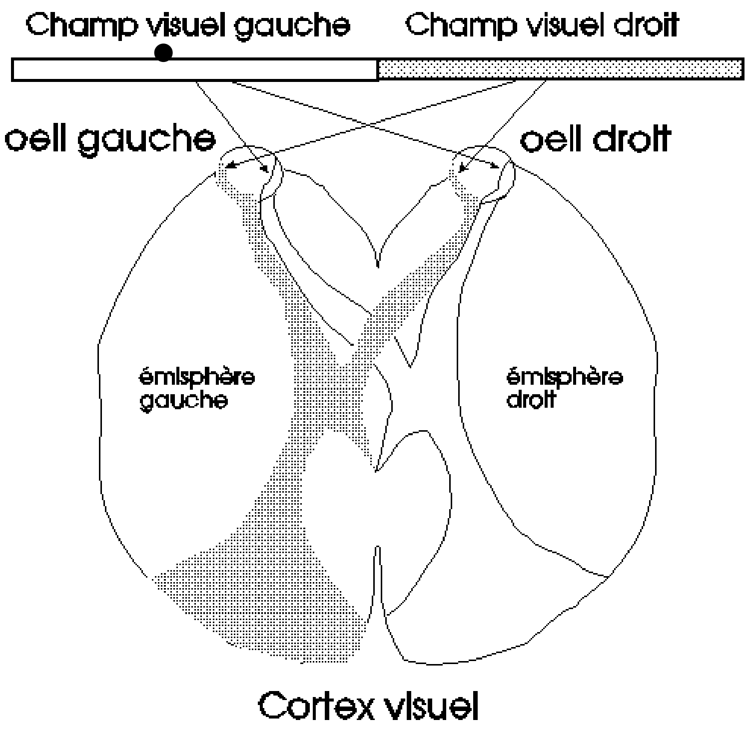
VR Setting

- Sharing interactive space & virtual space
  - Single vs multiuser
  - Seated vs standing
  - Static vs dynamic
  - Immersive vs non-immersive
  - Local vs distant

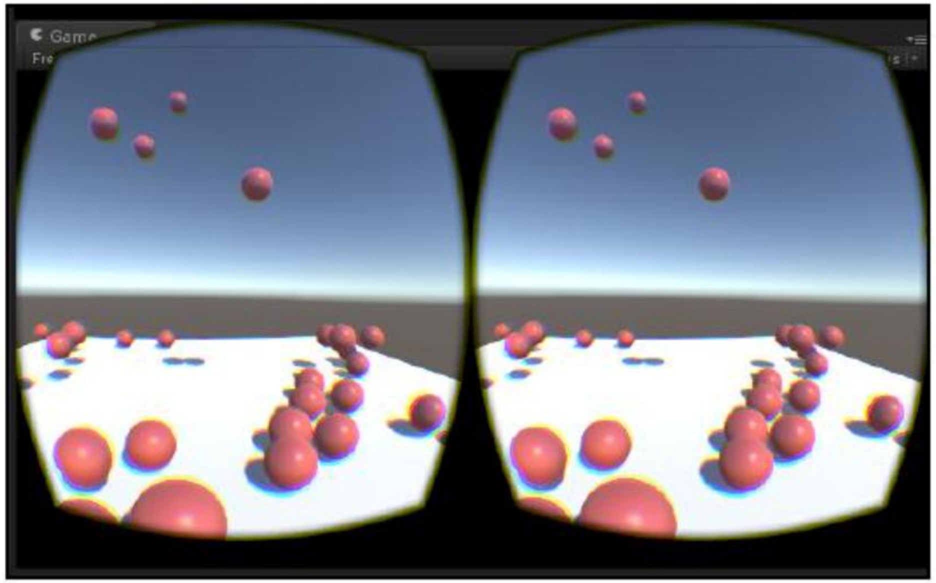




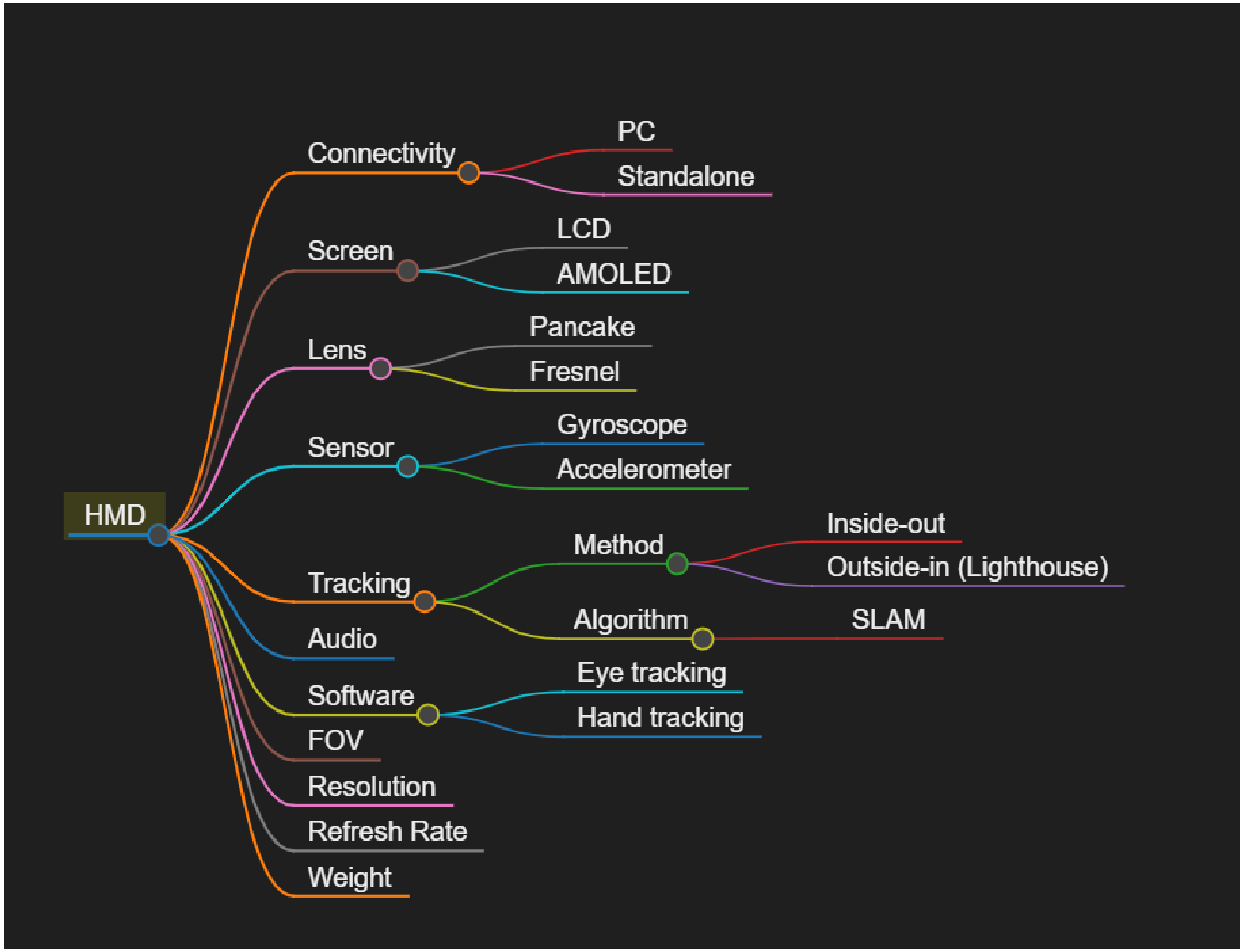
Virtual Reality



Stereoscope, Holmes, 1876



HMD features



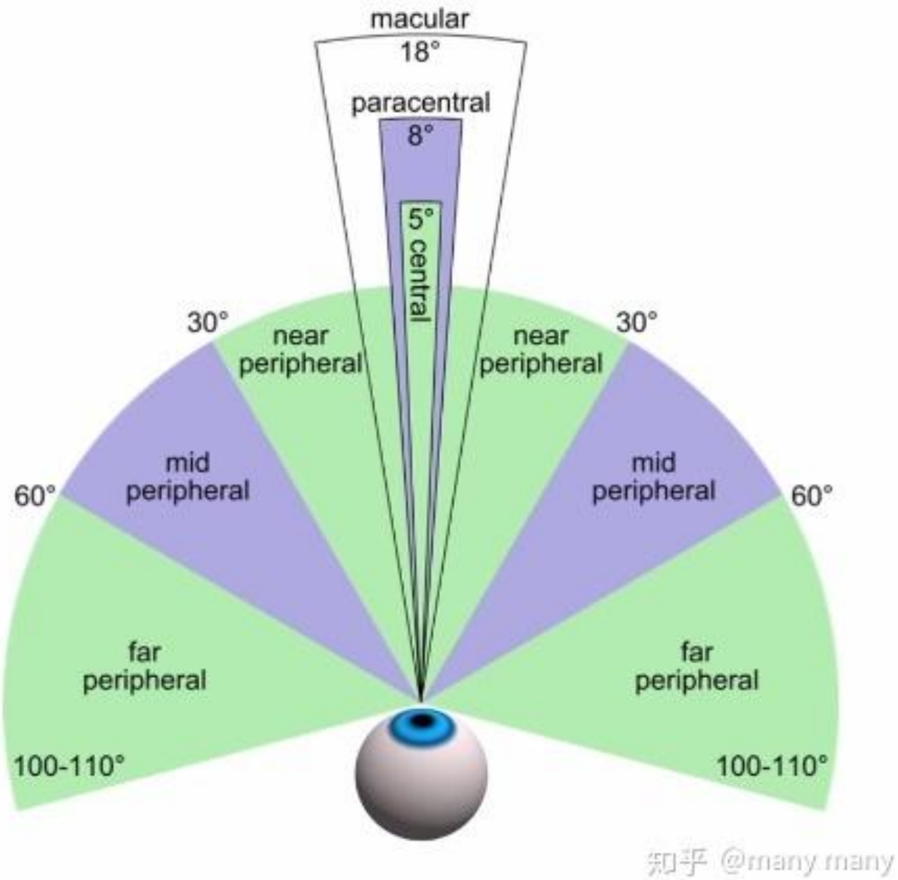


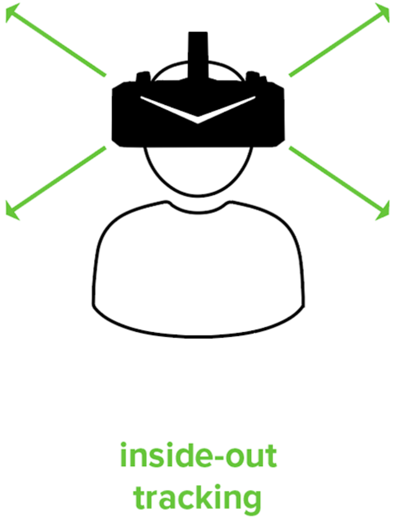
Illustration champ de vision

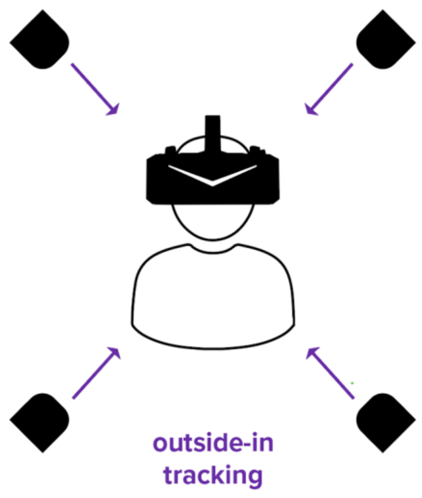
Caractéristiques des casques

Méthodes de tracking

- *Inside out :* détection du HMD grâce à des capteurs internes (e.g., caméra)

- *Outside in :* détection du HMD grâce à des capteurs externes (e.g., Lighthouse)





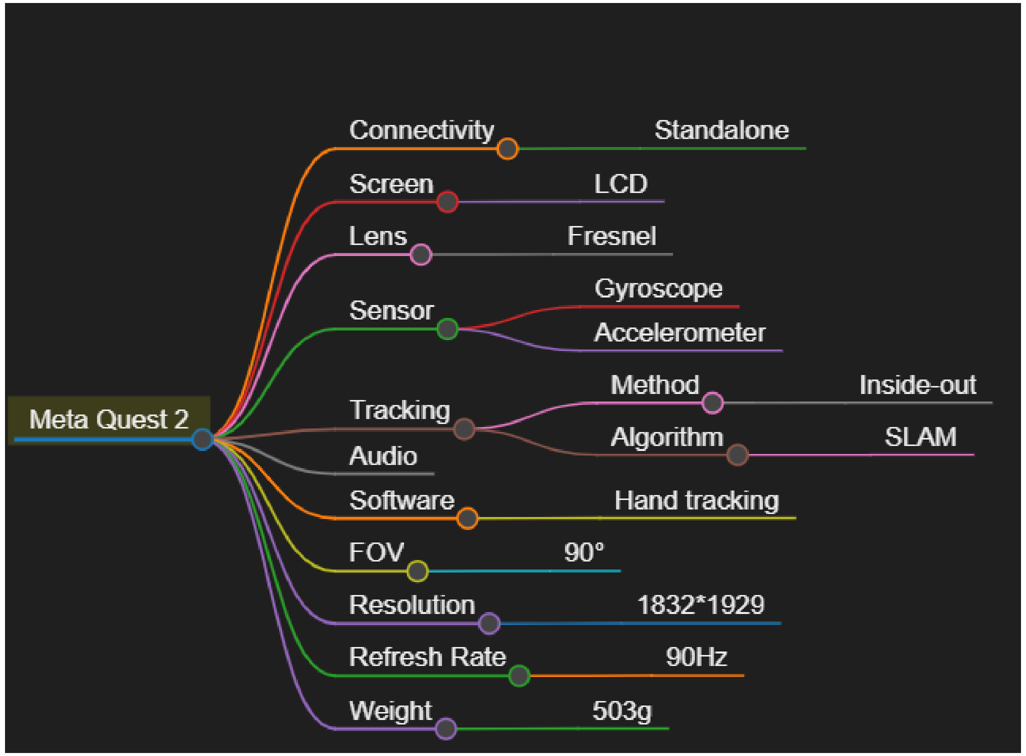
Caractéristiques des casques

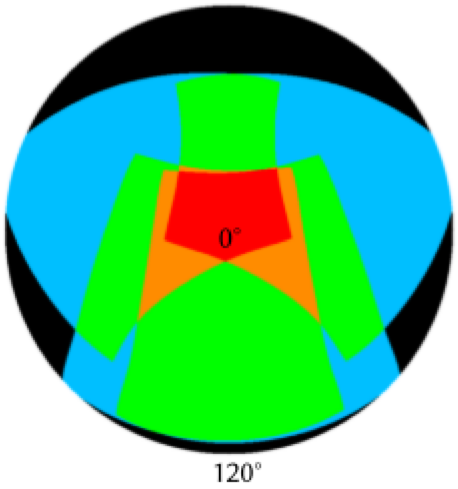
Types d'écran :

- LCD – écran à critaux liquides. Ecran plat à faible consommation életriques.
- AMOLED - Les écrans AMOLED contrôlent chaque pixel, ce qui signifie qu'ils ne sont allumés que lorsqu'ils doivent l'être
- OLED

Virtual Reality

- Quest 2 characteristics





Zone seen by camera red (4), orange (3), green (2), 1 (blue) and 0 (black)

see also https://en.wikipedia.org/wiki/List_of_virtual_reality_headsets

Mirror Therapy

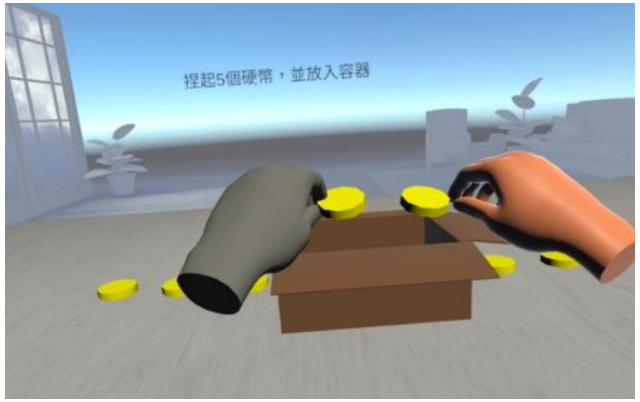
- Can we use mirror therapy in Virtual Reality?
- Tasks :
  - Put coins
  - Flip cards
  - Draw circle with a pen
  - Throw basketball

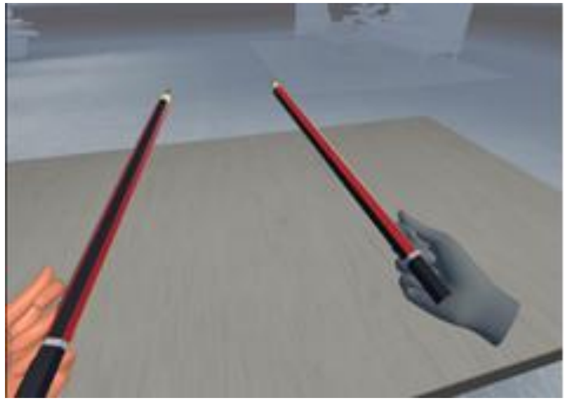
“VRMT”

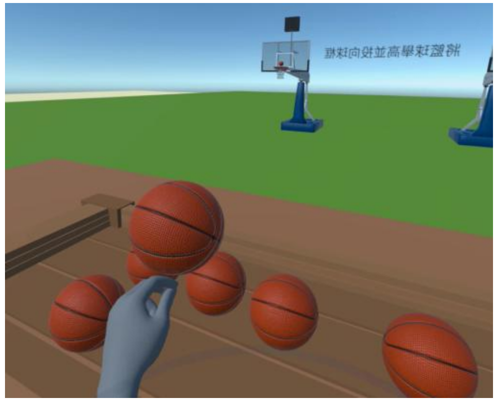
Virtual Reality Mirror Therapy

The Revolution of Stroke Rehab

2nd version (no study found)

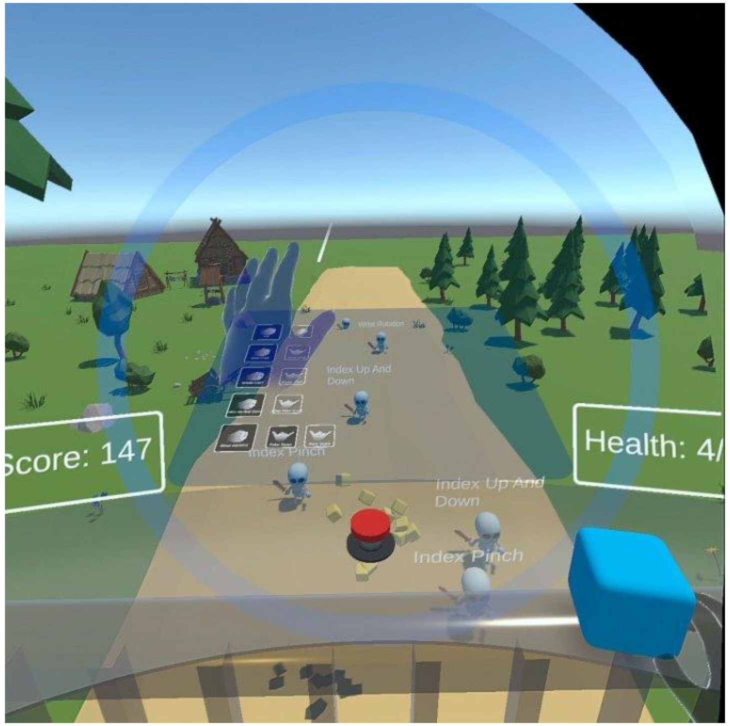






VR rehab

First prototype:

Mirror the hand	Action zone	Gamification
 Figure 4 Mirroring Root Position Only		

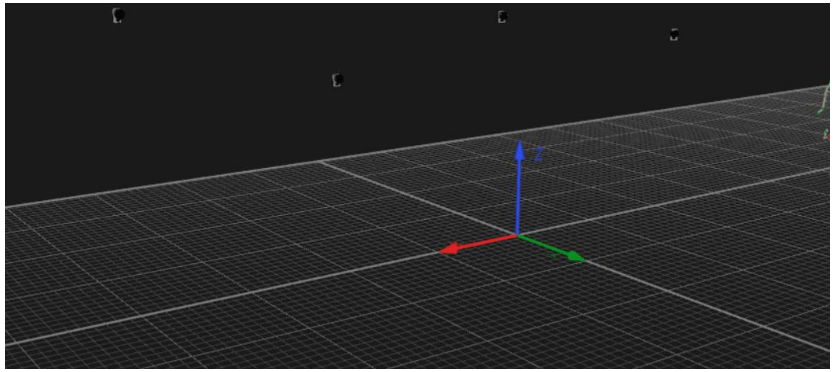
VR Rehab

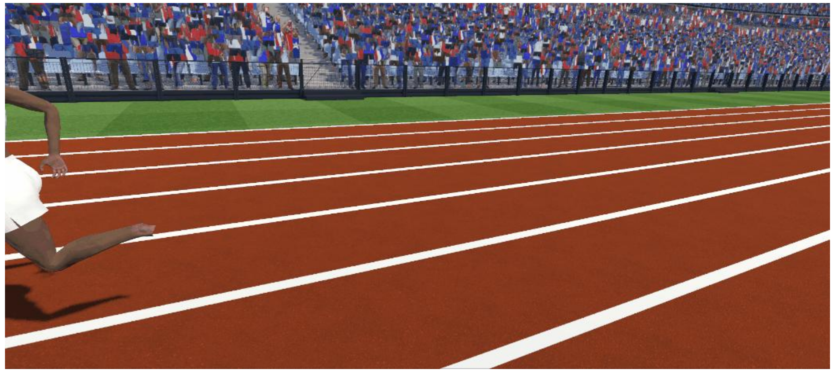
Box and Block Test

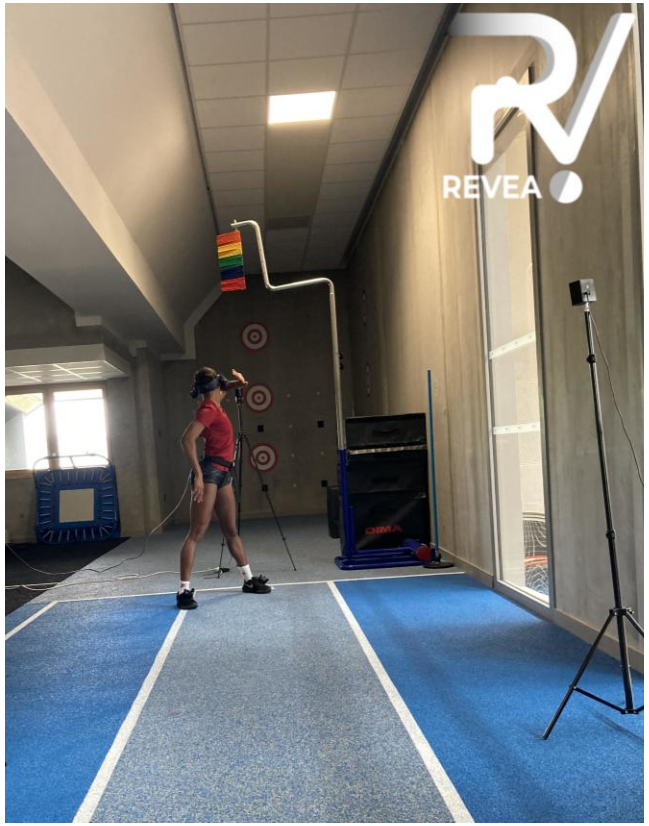
Resiliage

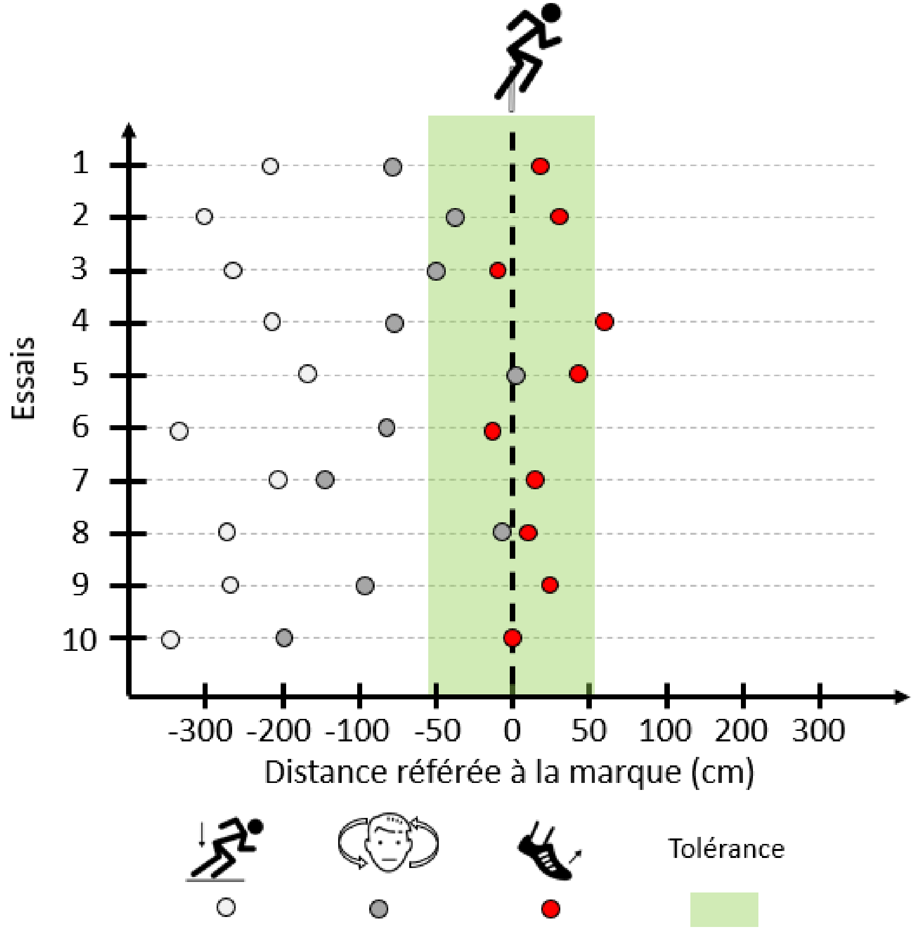
- Validation écologique
- Rôle du scenario dans la perception du risque
- Facteurs environnementaux et sociaux
- Développement d'outils de visualisation

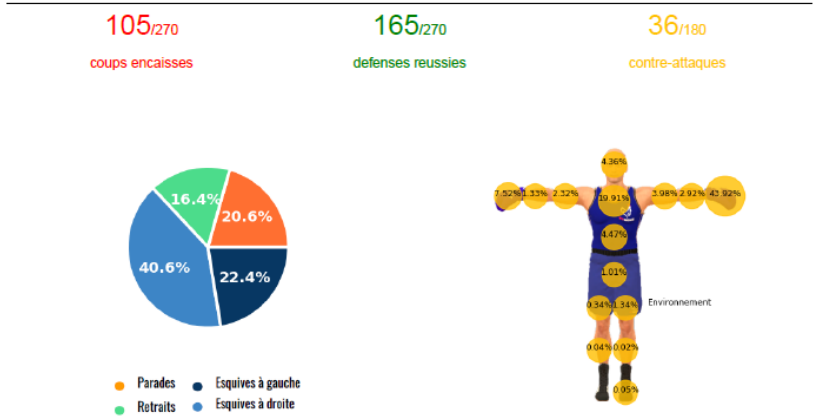
Simulation course de relay 4*100m





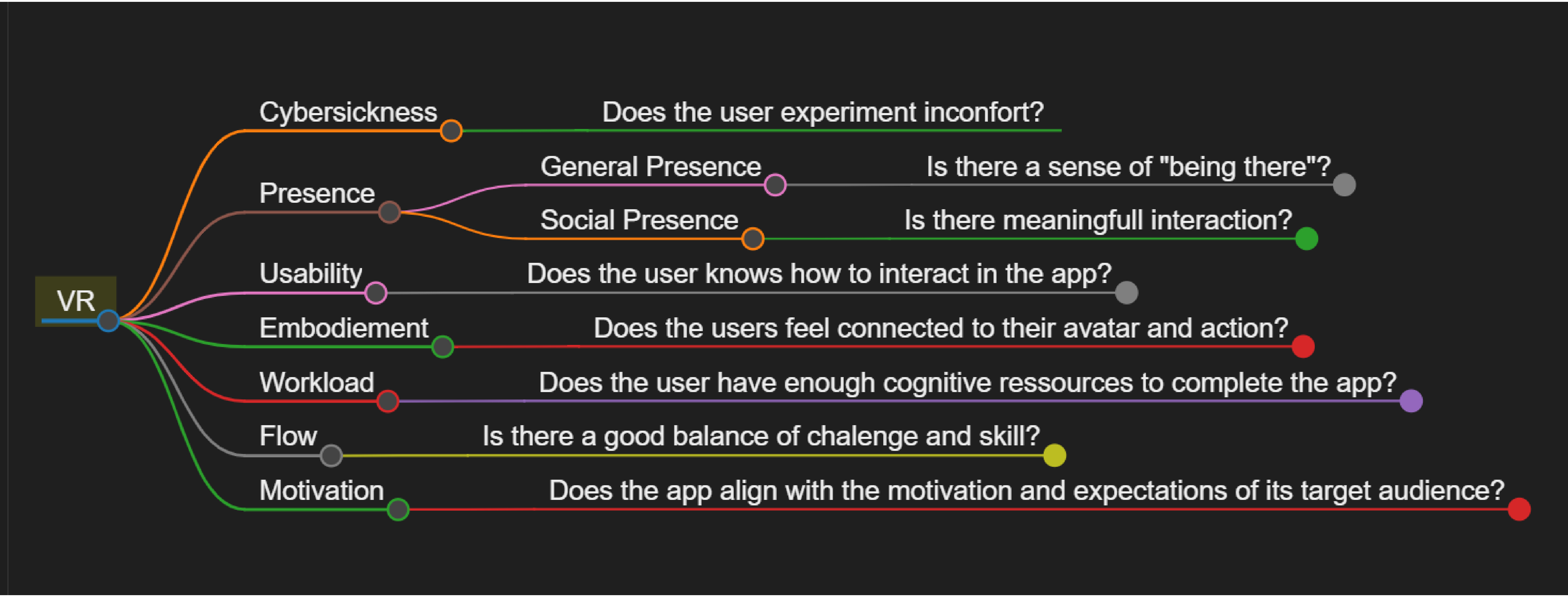






Simulation de boxe

Associated Concepts



Cybersickness

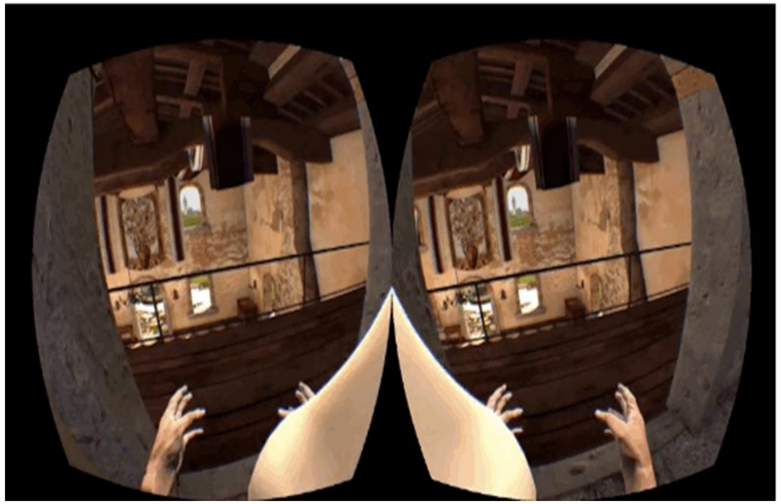
- Keywords for cybersickess (Almeida et al., 2018)
  - simulator sickness : malaise ressenti lors d'un simulateur (vol, conduite)
  - Cybersickness: lié à l'immersion en virtuel
  - *Motion cysickness* : malaise lié aux transports de la vie quotidienne (mal de mer)

Common symptoms :

- Nausea
- headaches

Cybersickness – Theoritical fundations

- **Sensory conflict theory** (Oman 1989) : conflit entre le système vestibulaire et le système visuel. Le système visuel indique un mouvement alors que le système vestibulaire stipule que nous sommes immobiles
    - Most accepted theory
- **Postural instability theory** (Riccio and Stoffregen 1991) : le malaise survient car le participant n’est pas en mesure de maintenir une posture stable dans l’EV
- **Poison Theory** (Treisman, 1977): l’expérience en virtuel pourrait affecter les systèmes sensoriels du corps et déclenché un système d’alter dans le corps qui pense qu’il a ingéré un produit toxique
    - Less valid theory



Cybersickness - Factors

- Studiyng factors
  - To understand cybersickness
  - To reduce it
  - To predict it

- Factors
  - Content

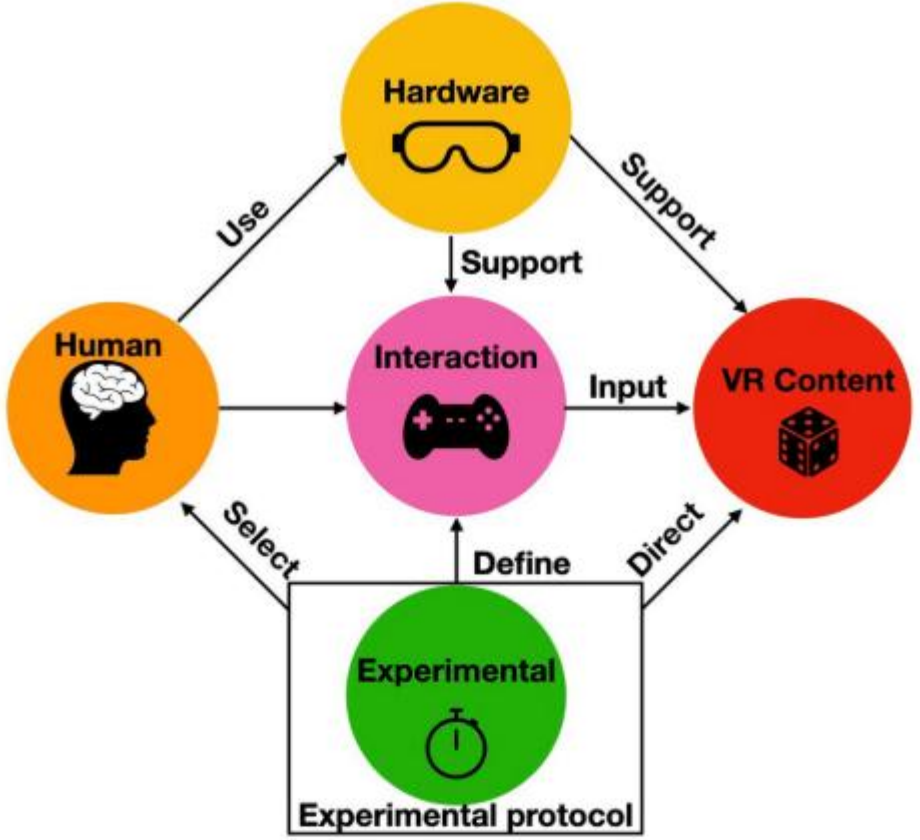


Fig. 3 Links between categories of factors. The participants use the hardware to interact with the VR content, hardware supports VR content and the interaction. The experimental protocol guides the selection of the participants and directs the VR content design

Factors (Tian et al., 2022)

Cybersickness - Factors

VRZoo in Frommel et al. (2017)

- Interactions
  - Locomotion techniques
    - Less cybersickness with teleportation than steering (Frommel et al., 2017)
    - No advantages of teleportion over steering (Clifton and Palmisano 2020)

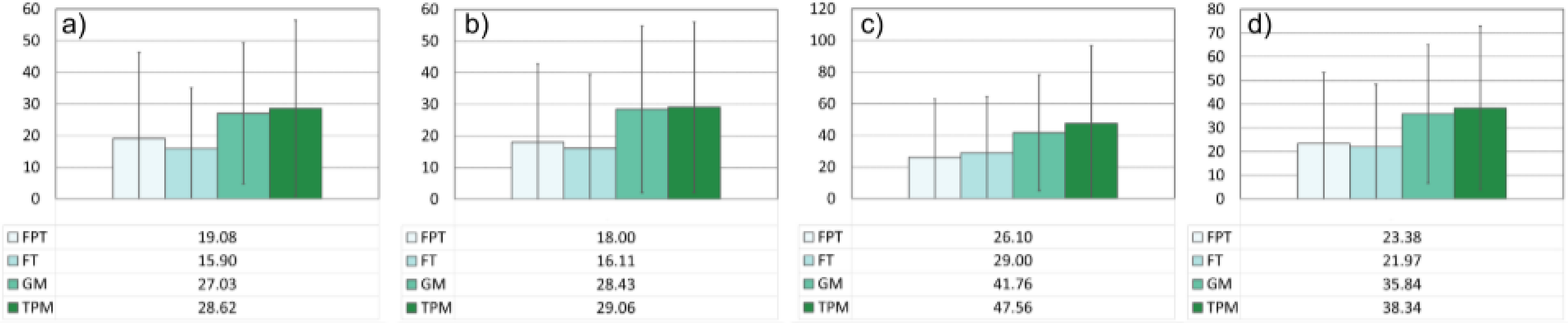


Figure 4: Overview of the (a) SSQ nausea, (b) SSQ oculomotor, (c) SSQ disorientation, and (d) SSQ total scores for fixpoint teleport locomotion (*FPT*), free teleport locomotion (*FT*), guided locomotion (*GM*), and touchpad locomotion (*TPM*). Displayed values are means while error bars indicate ± standard deviations. Lower scores indicate less discomfort.

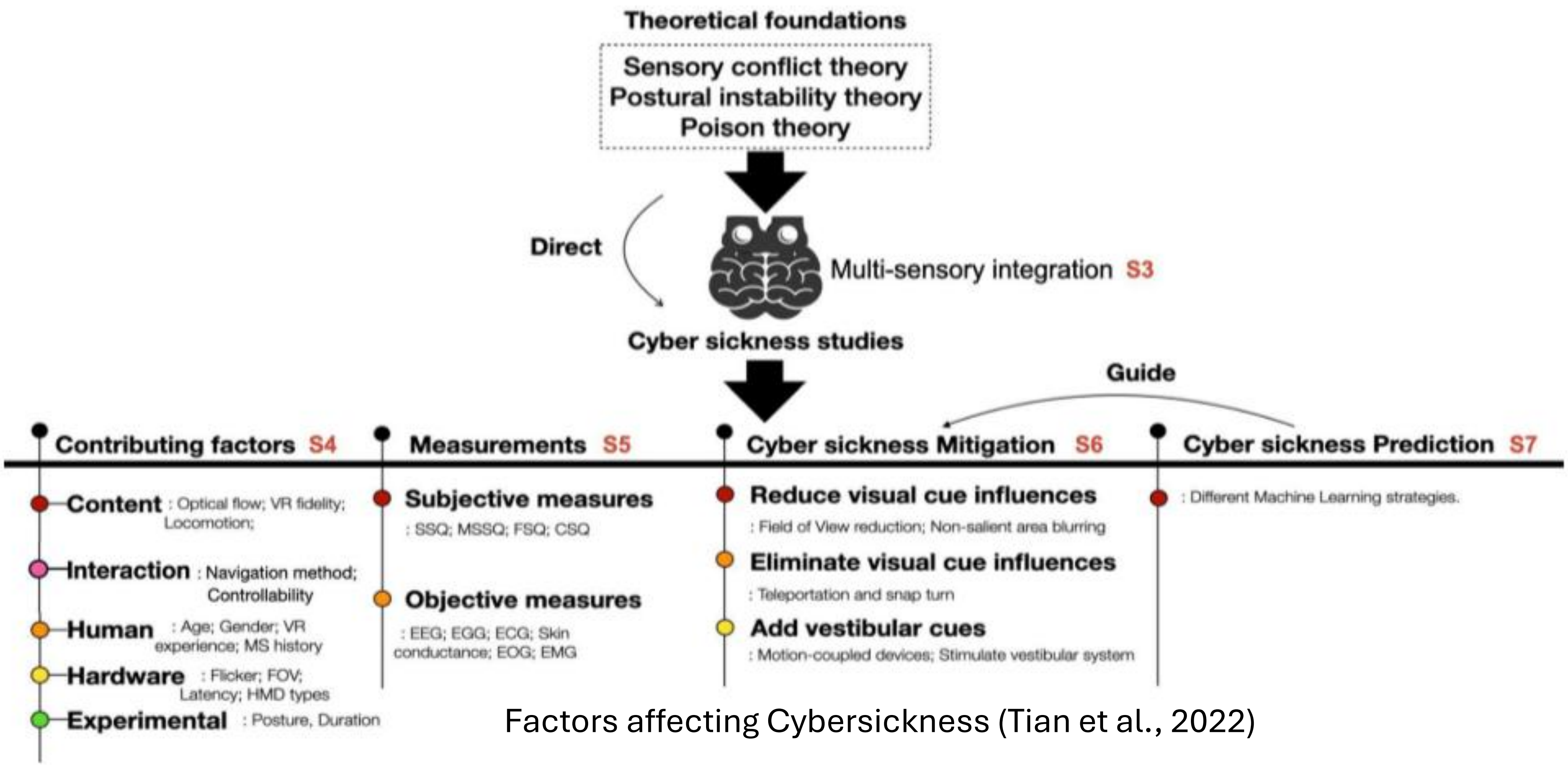
Cybersickness - Factors

- Human
  - Intrinsic factors
    - Demographic characteristics (age, gender)
      - women are generally more sensitive to cybersickness than men (Gonçalves et al. 2018; Al Zayer et al. 2019; Hildebrandt et al. 2018; Rangelova et al. 2020)
      - no significant difference between genders in the susceptibility to cybersickness (So and Yuen 2007; Sagnier et al. 2019; Weech et al. 2019; Williams and Peck 2019; Melo et al. 2019; Hsiao et al. 2019; Curry et al. 2020).
      - elderly often showed more severe discomfort than younger ones (Rebenitsch and Owen 2014; Hildebrandt et al. 2018).
    - Susceptibility to motion sickeness and cybersickness
    - Health-related characteristics (e.g., illness or poor vision)
  - Extrinsic factors
    - video game experience,
      - experienced users have a lower tendency to suffer from cybersickness (Weech et al. 2019; Hunt and Potter 2018; Weech et al. 2020; Grassini et al. 2021).
    - VR experience,
    - simulation experiences.

Cybersickness - Factors

- Experimental
  - Session duration
    - Between 10 and 20min
  - Posture
    - seated posture is generally less cybersickness inducing than the standing one (Davis et al. 2014; Hu et al. 2021).

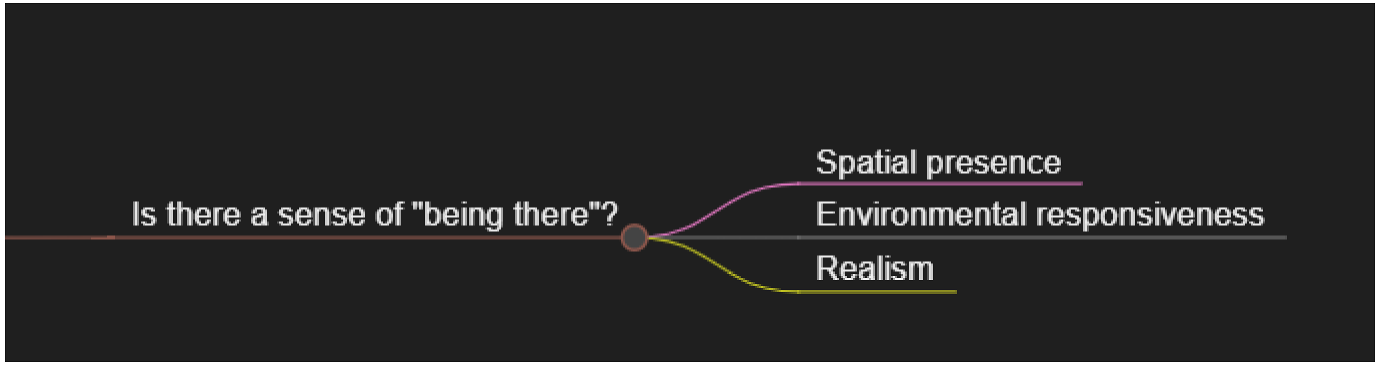
Cybersickness - Summary

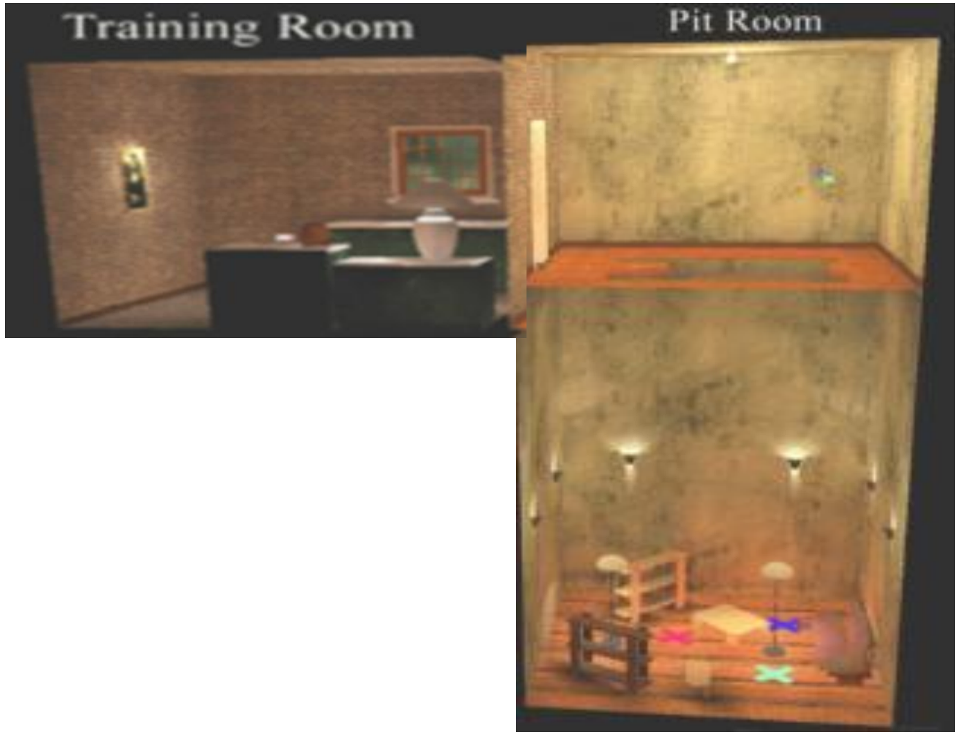


Factors affecting Cybersickness (Tian et al., 2022)

Presence

- User knows is not physically in the virtual environment but he/she feels there





Meehan et al., 2002

Presence

- Several definitions

Wilkinson et al., 2021

Table 1.
Definitions of presence related to virtual reality.

Study	Definition
Roettl & Terlutter (2018)	Sense of being in a virtually mediated location instead of being in a real location.
Triberti & Riva (2016)	Cognitive process with the purpose to locate the Self in a physical space or situation, based on the perceived possibility to act in it.
Zahorik & Jenison (1998)	Tantamount to successfully supported action in the environment.
Lombard & Ditton (1997)	Perceptual illusion of non-mediation.
Slater (2018)	Illusion of being there, notwithstanding that you know for sure that you are not. It is a perceptual but not a cognitive illusion.
Pan & Hamilton (2018)	Making you feel like you are somewhere else.
Cooper et al. (2018)	Subjective feeling of being present in the virtual environment, rather than the real space.
Makransky & Lilleholt (2018)	A psychological state in which the virtuality of the experience goes unnoticed.
Kisker et al. (2019).	The subjective feeling of being there in a virtual environment while the awareness of the physical environment and technical equipment diminishes.
Slater (2003)	The extent to which the unification of simulated sensory data and perceptual processing produces a coherent place that you are in and where there may be a potential for you to act.
Diemer (2015)	The perceptual distance between the actual experience and the simulated experience.

Presence and Immersion

- Presence is related to the experience of feeling being in a place
- Immersion is related to the technical aspects

Wilkinson et al., 2021

Table 2.
Definitions of immersion related to virtual reality.

Study	Definition
Slater (2018)	Objective property of the system, to the extent to which a VR system can support natural sensorimotor contingencies for perception including the response to a perceptual action.
Witmer & Singer (1998, 2005)	A subjective experience: the psychological state where one perceives oneself as being included in and interacting with an environment that provides a continuous stream of stimuli and experience.
Kisker et al. (2019) Slater & Wilbur (1997)	The degree to which a technical system generates an inclusive, extensive, surrounding, and vivid illusion of reality.
Slater et al. (1996)	A quantifiable description of technology, which includes the extent to which the computer displays are extensive, surrounding, inclusive, vivid, and matching.
Shu et al. (2019)	The result of a good gaming experience that includes disconnection from the real world and real time, and involvement in the task environment.
Slater & Wilbur (1997)	To be shut out of physical reality, offering high fidelity simulations through multiple sensory modalities, finely maps a user's virtual bodily actions to the physical counterparts, and removes the participant from the external world through self-contained plots and narratives.

Presence

- « *It is interesting to note that one participant rated the situation as 'not threatening at all'. There are two potential explanations: first, the participant did not recognize, or underestimated the risks of a tunnel fire. Second, the participant did not experience enough presence and was always completely aware that what he/she saw was a simulation. This is supported by the participant's low self-reported involvement (a subscale of the IPQ) in the virtual environment."* Kinateder et al., 2015

Fig. 1. Screenshot of the virtual tunnel emergency situation in the dangerous goods condition (left) and the control condition with a regular heavy goods vehicle (right). The emergency situation was exactly the same in both conditions. Brightness and contrast of the screenshots were increased in this figure by 40% for improved illustration. Screenshots were taken at slightly different timings. Flame and smoke development were exactly the same in the two experimental conditions.

Kisner et al. (2019)

Presence

- Increase with
  - Immersion
  - Multi-sensory feedback
    - Haptic
    - Auditory
    - Emotions

Height condition

Ground condition

Plank

- Height condition :
  - Behavioral: walk slower
  - Physiological: HR higher
  - Subjective: felt more present

Video : https://link-springer-com.proxybib-pp.cnam.fr/article/10.1007/s00426-019-01244-9#additional-information

L’utilisabilité

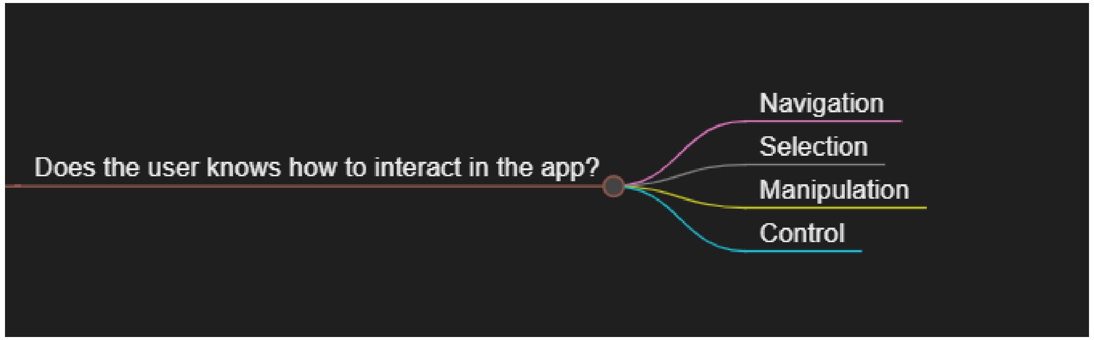
L’**utilisabilité** est la qualité de l’interface d’utilisation (Stanney et al., 2002)

Comprend les aspects suivants (Hix & Hartson 1993; Shneiderman, 1992) :

Efficiency : efficacité et précision de l’accomplissement de la tâche

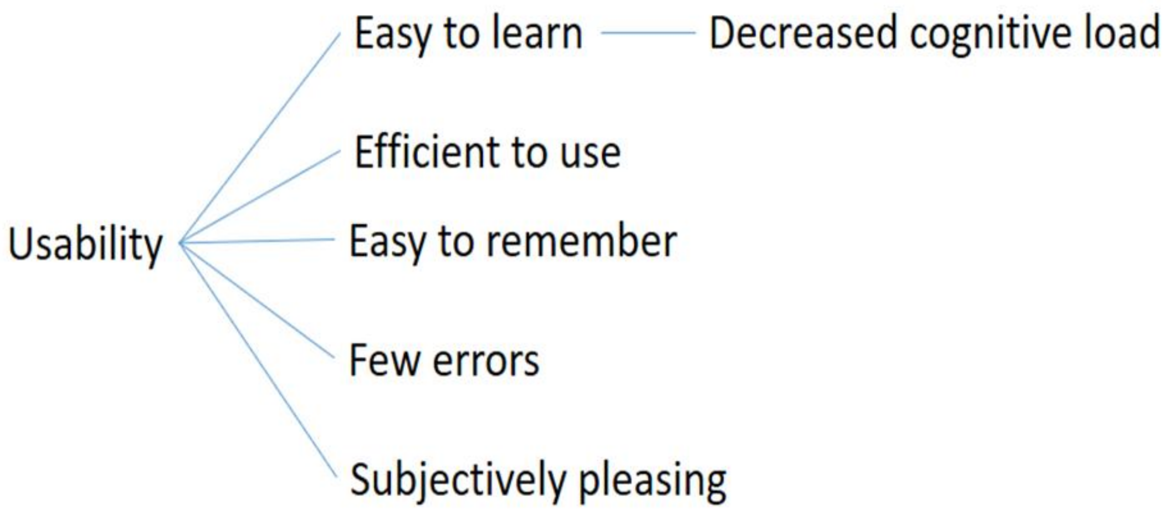
Effectiveness : ressources dépensées par l’utilisateur pour réaliser la tâche

Learnability : confort et acceptance de l’interface



L’utilisabilité

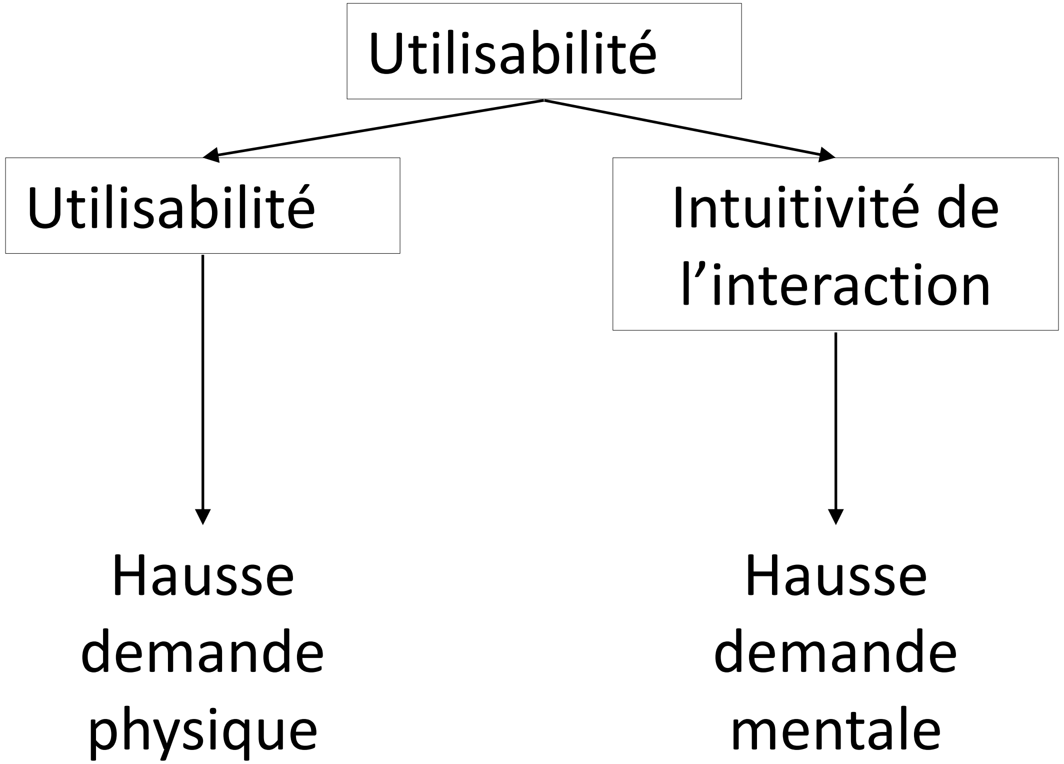
L’**utilisabilité** est la qualité de l’interface d’utilisation (Stanney et al., 2002)



Taxonomie des IHM, centré sur l’utilisabilité (Pinciroli, 2016)

L’utilisabilité

L’**utilisabilité** est la qualité de l’interface d’utilisation (Stanney et al., 2002)

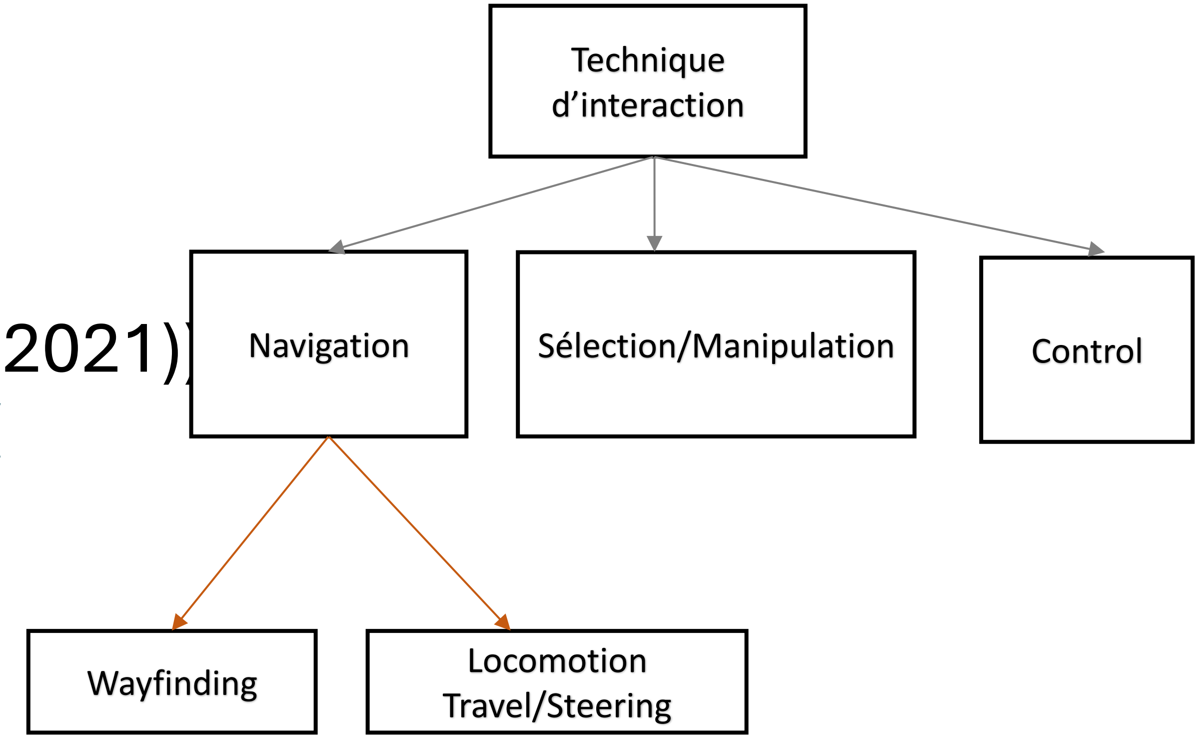


Reinhardt & Hurtienne (2017)

Interaction technique

- Interaction techniques is the combination of an hardware and a software (Tucker, 2004)

- Many are existing
- Locomotion Vault (Di Lucas et al., 2021)) https://locomotionvault.github.io/
  - Which one to choose? (comparison)
  - How to classify them?
  - Which one are the most used?



Taxonomy of interaction technique (Jankowski & Hachet, 2013)

Interaction techniques

- Steering/Translation - Continuous movments

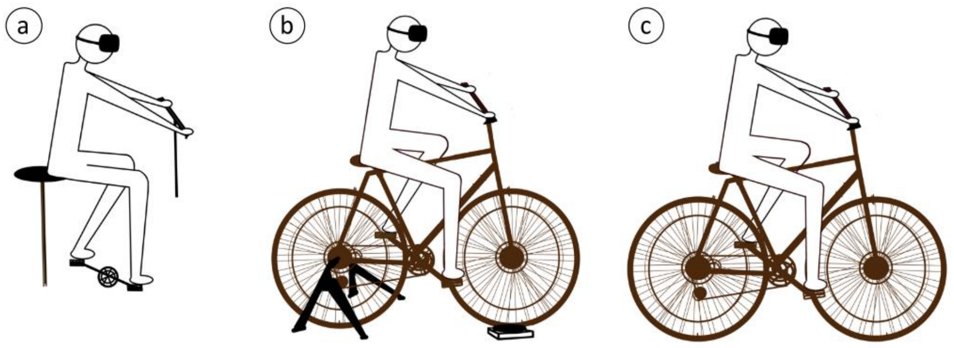
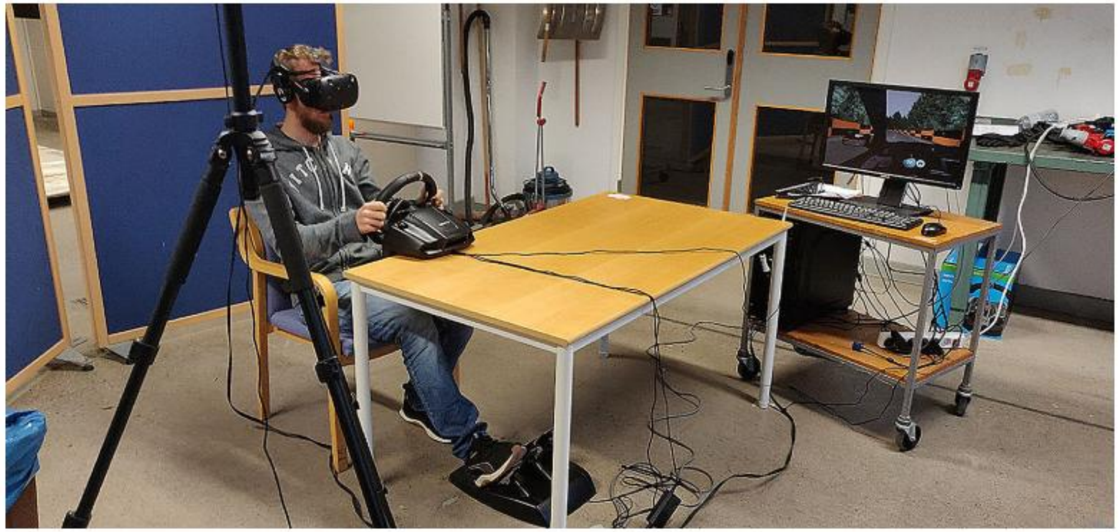


Figure 1: Overview of three levels of VR cycling fidelity: (a) cycling without a bicycle while sitting on a chair with a handlebar and pedals, (b) cycling on a stationary bicycle placed on the fixed platform, and (c) cycling on a dynamic bicycle moving through space.

Matviienko et al., 2023



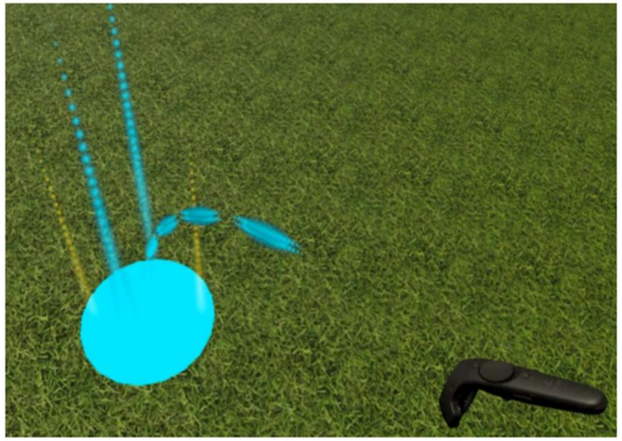
Driving simulator during wild fire
(Wetterberg et al., 2021)

Locomotion

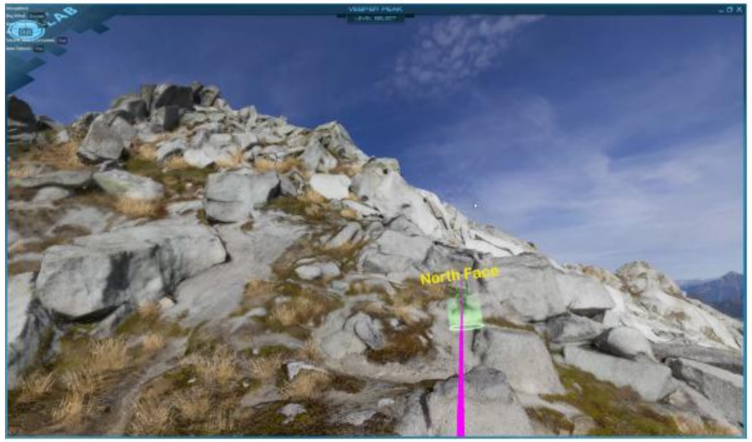
Surv1v3 (Candymakers, 2021)

Interaction techniques

- Teleportation - Discrete movments



Free teleportation (Frommel et al., 2017)



Gaze directed teleportation (Linn et al., 2017)

Interaction technique - Locomotion

- Teleportation type :
  - Free
  - Gaze-based
  - Fixed point

Fixed point teleportation (Frommel et al., 2017)

The Room VR: A dark matter

Interaction technique - Locomotion

- Teleportation type :
  - Free
  - Fixed point
  - Gaze-directed
  - Automatic

Driftwatch VR (AirshipFX, 2016)

Interaction technique - Locomotion

- Teleportation type :
  - Free
  - Fixed point
  - Gaze-directed
  - Automatic
  - Shooting-based

Sólfar Studios ehf. 2018. In Death. http://www.solfar.com

Figure 1: The concept of Shooting-based technique

Li et al., 2023

Interactions

- Teleportation
- Problème : Comprendre les déplacements des autres utilisateurs (environnement collaboratif) lorsque la locomotion est discontinue

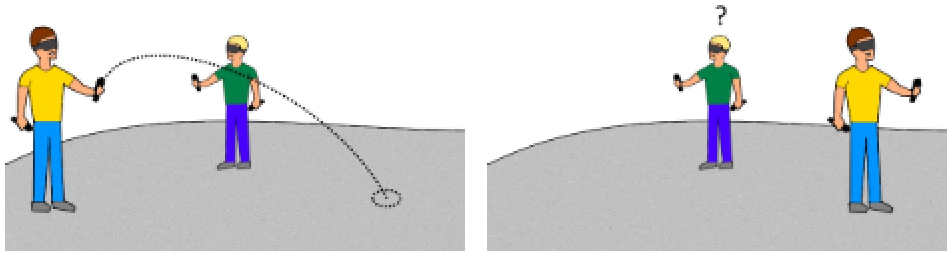


Figure 2: Depiction of the possibly confusing teleport locomotion in multi-user VR. Left: User teleports to a new location. Right: After the instantaneous, discontinuous teleport, the observing user lost track and is confused.

Fischer et al., 2023

Interactions

- Teleportation
- Solution : continuous visualization (walking) tend to better perform

Fischer et al.,

Particule
trace

Bea
m

Porta
l

Dash

Walking

Technique d'interaction

Naviguer dans un EV avec ou sans obstacles

Méthode :

- marche redirigée
- Wip
- stepper machine
- Teleporation
- Joystick
- Tackball
- arm swinging

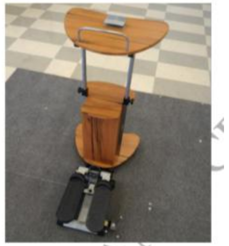
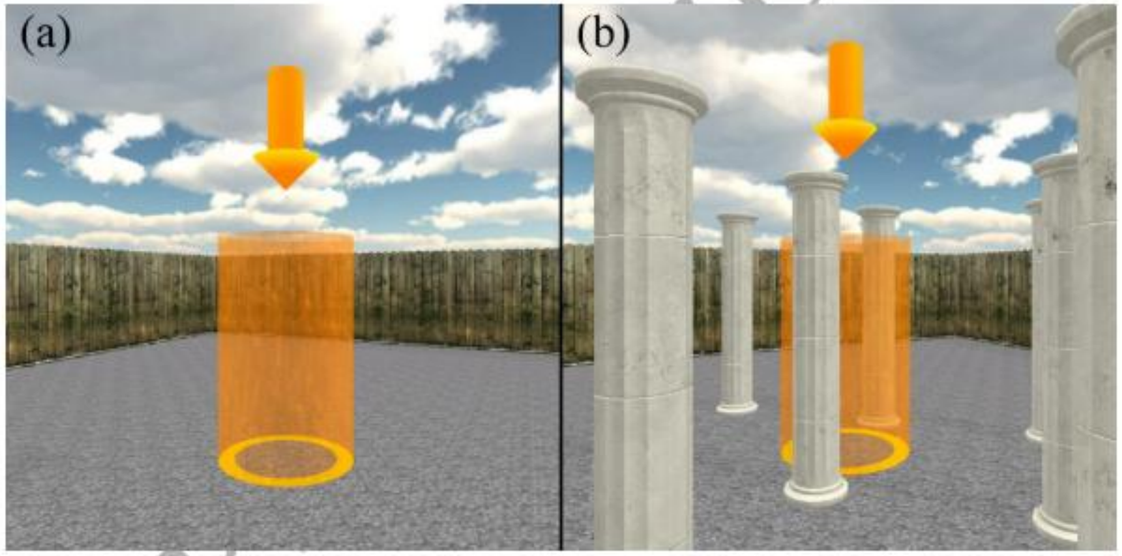


Figure 4. **The virtual environment and a destination point (a) without, (b) with obstacles.**

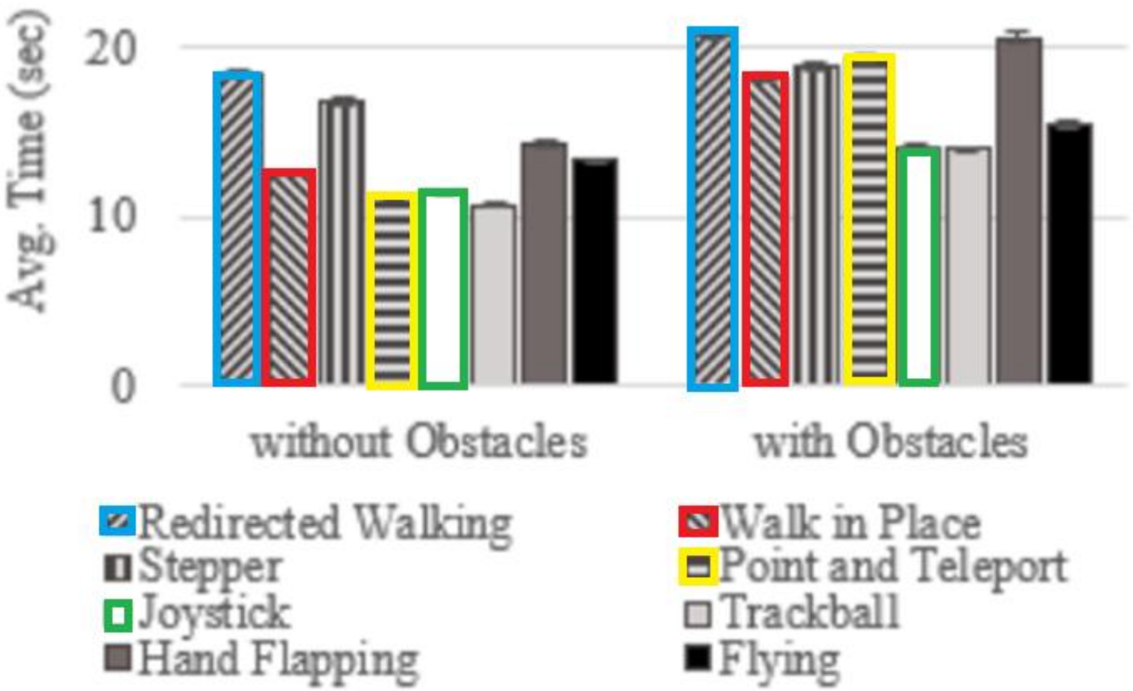


Technique d'interaction

Naviguer dans un EV avec ou sans obstacles

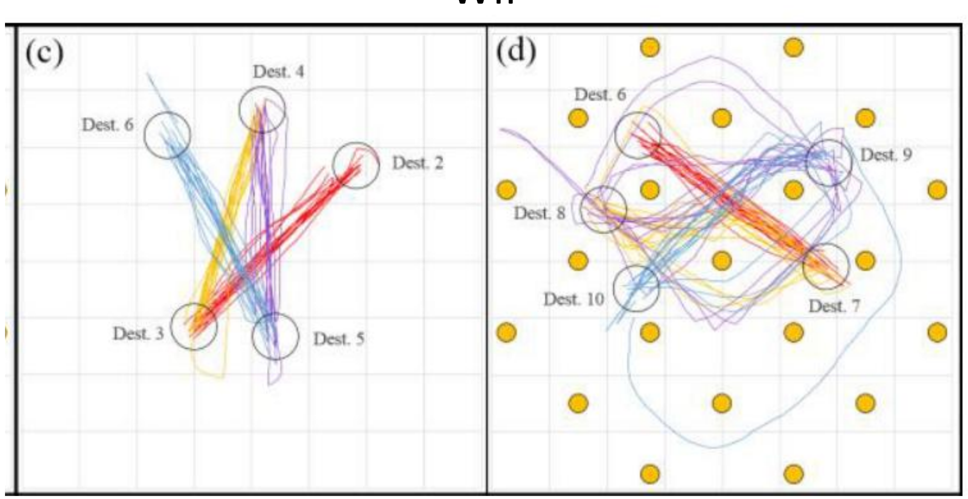
Méthode :

- Plus rapide avec joystick
- Plus de collision avec téléportation
- Réaction plus lente en marche

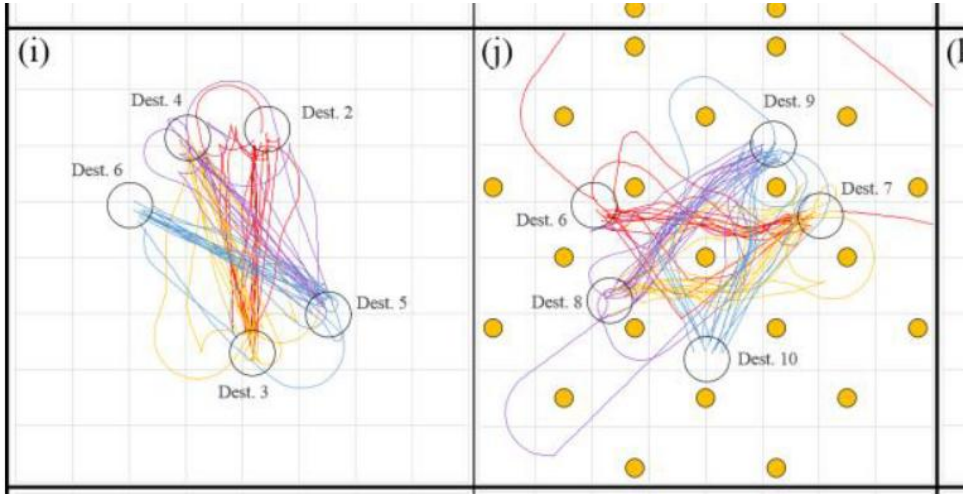


Technique d'interaction

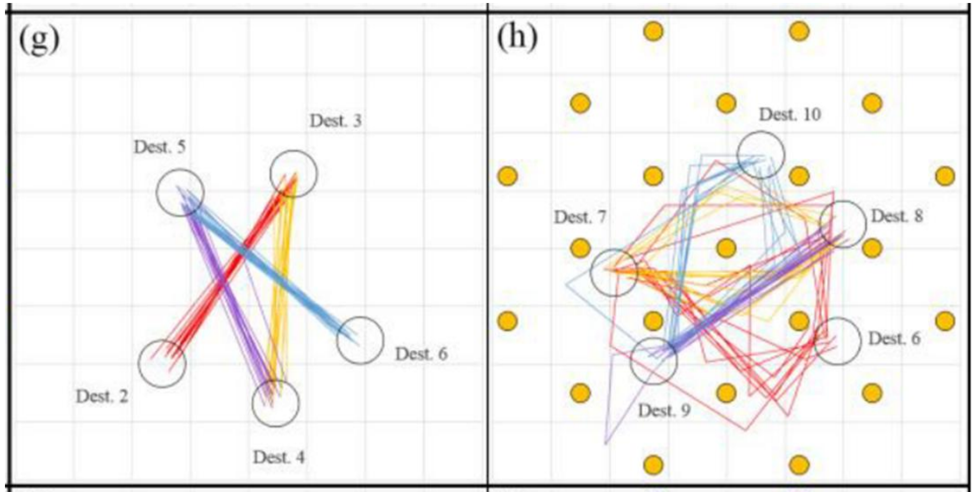
WIP



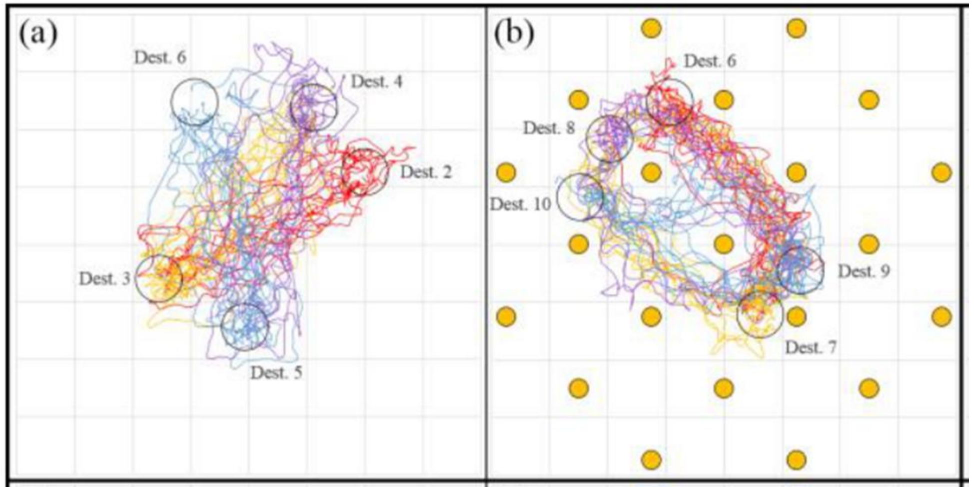
joystick



téléportation



Marche redirigée



Interaction technique - Locomotion

- Teleportation vs steering in game

Fig. 1. Left: Birdseye view of the virtual environment used in our experiment featuring an industrial look with open areas. Center: teleportation arch shown as well as kill counter. Right: visual feedback when a player is getting hit by bullets.

Prithul et al., 2024

Interaction techniques

- Natural Walking techniques
- User executing a movment pattern to move

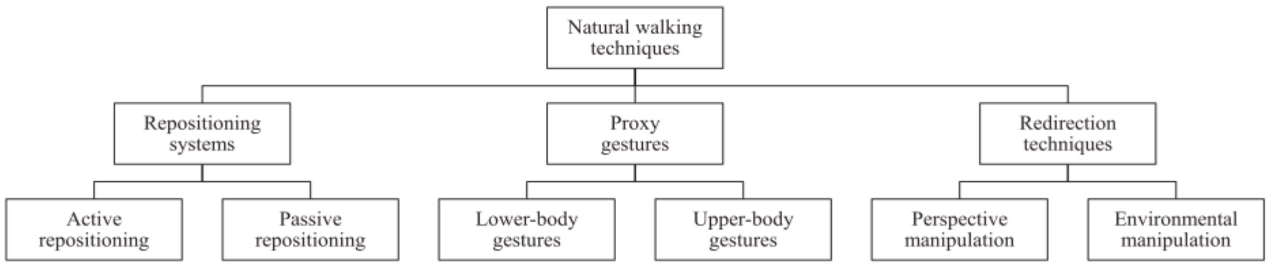
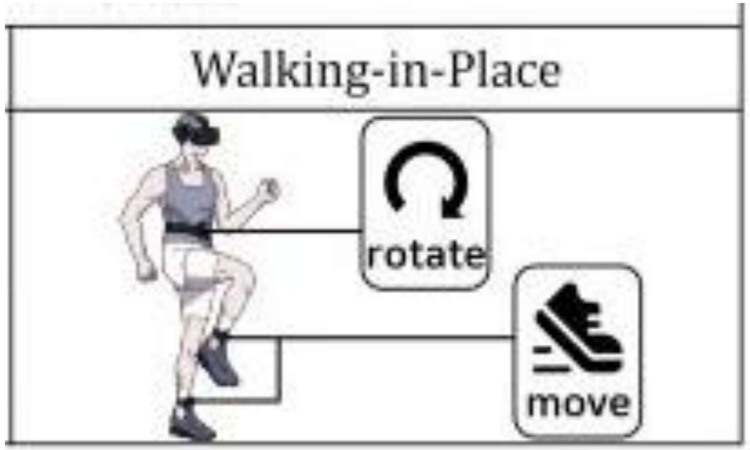


Fig. 2. Three general categories of walking techniques that provide users with relatively natural walking experiences when the virtual environment is smaller than the physical space: repositioning systems, proxy gestures, and redirected walking. It is possible to further distinguish between repositioning systems that are either active or passive, proxy gestures that are based on movement of the legs or upper body, and redirected walking that is based on application of gains or manipulation of the virtual architecture.

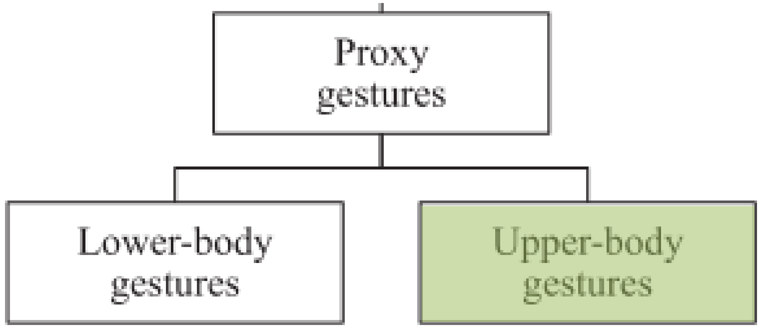
Natural Walking Techniques Taxonomy of Nilsson et al., (2018)

Walking in place (Bruno et al., 2017)

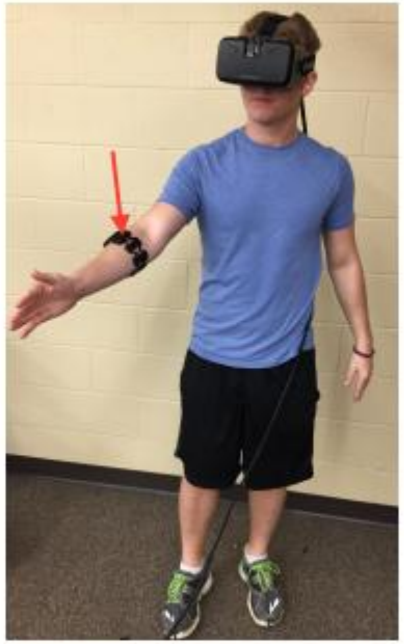


Walking-in-place (Park et al., 2023)

Interaction technique



Arm swinging (McCullough et al., 2015)



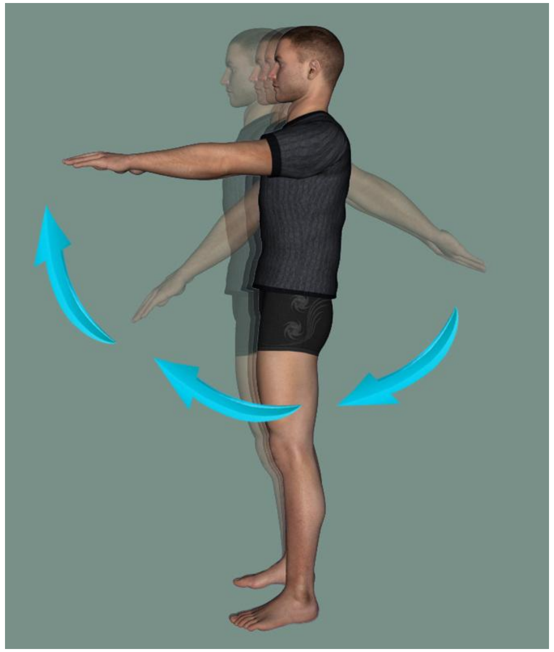
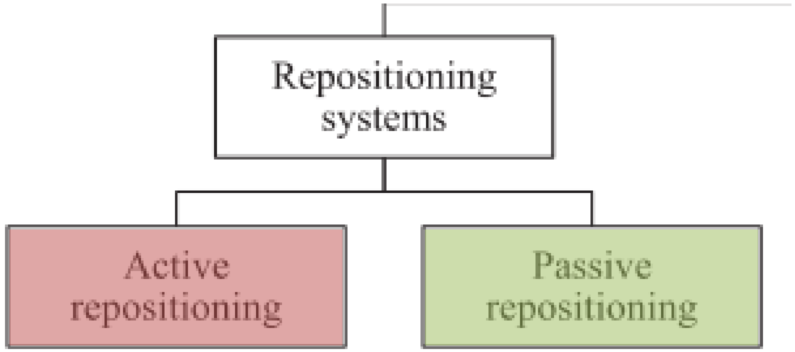


Figure 1: *This picture shows a user using the Myo armbands while wearing an Oculus DK2 HMD. The arrow indicates where the Myo logo should be situated with respect to the forearm.*

Vindicta VR (Game Cook, 2017)
See also Sprint Vector (Survios, 2018)

Interactions – Natural Walking



Repositionning system : utilisateur stationnaire

- Active
- Passive

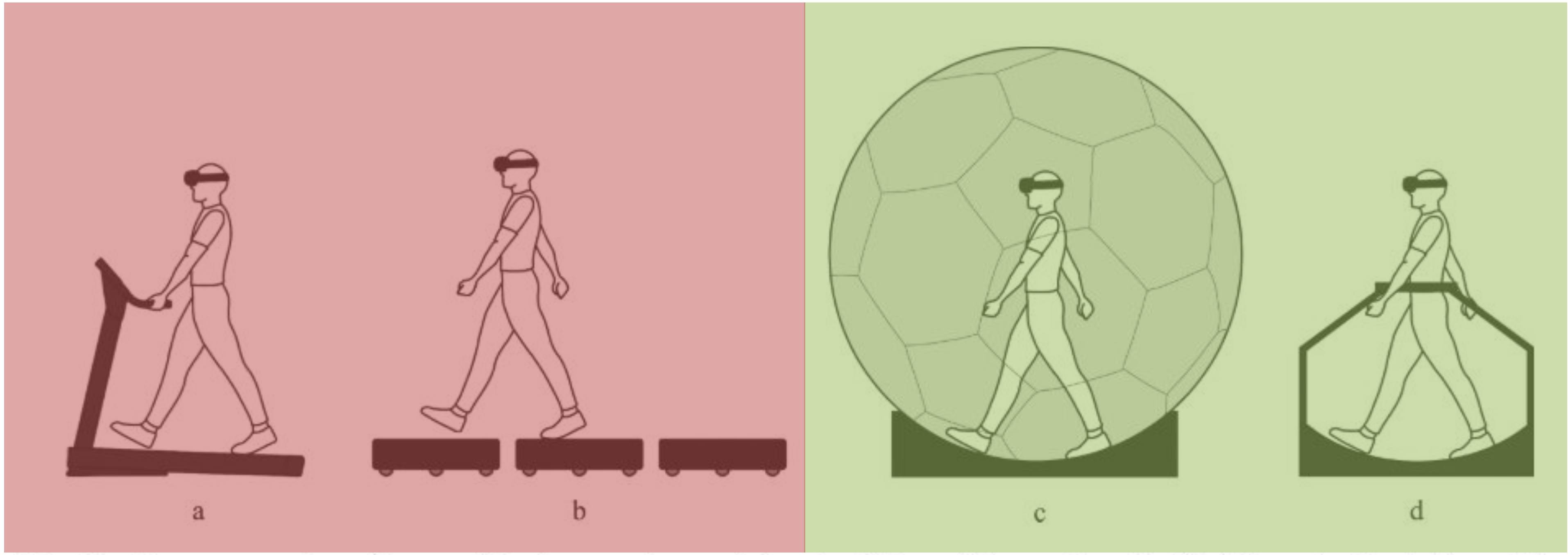


Fig. 3. Four examples of repositioning systems: (a) a traditional linear treadmill, (b) motorized floor tiles, (c) a human-sized hamster ball, and (d) a friction-free platform.

Nilsson et al., 2018

Interaction Techniques – Natural Walking

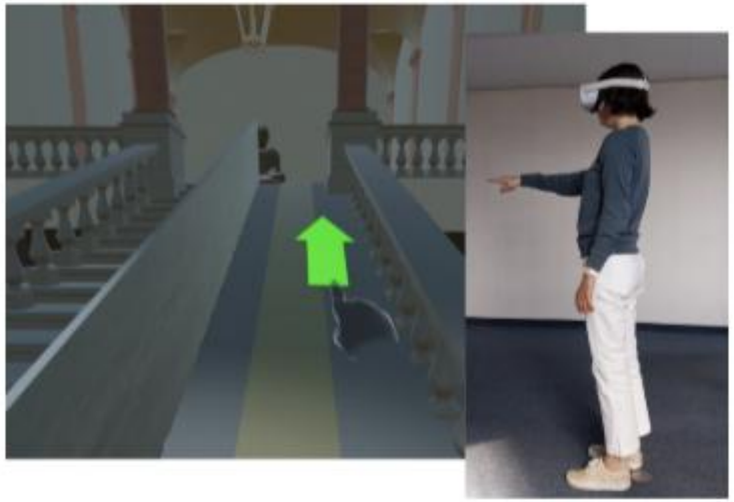
- Comparison of treadmill, natural walking and steering (Wang et al., 2024)
- Results:
  - More inconfort with treadmill

Figure 1: The user study for investigating users' walking performance and experience with various walking methods in different levels of fidelity VR. (a) shows the high-fidelity virtual scenario with a triangle walking trajectory, (b) shows a low-fidelity virtual scenario with a rectangle walking trajectory, (c) shows the participant walking with the Real Walking method, (d) shows the participant walking on the omnidirectional treadmill, (e) shows the participant walking with controller method.

Interaction Techniques – Natural Walking

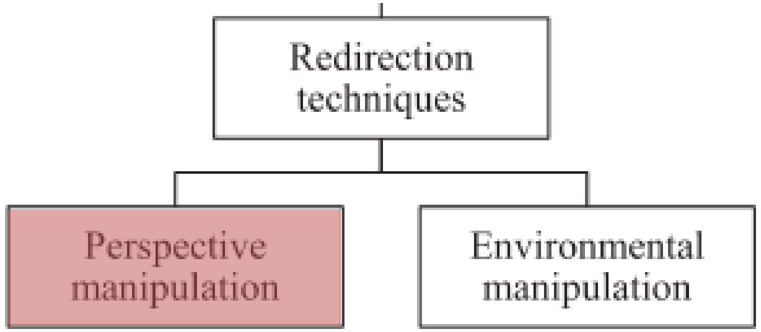
- Comparison natural walking and steering (Bonino et al., 2024)
- Results:
  - Better usability for steering
  - No diff for cyberscineckness
  - Move faster with steering

(a) Fully natural technique



(b) Semi-natural technique

Interactions – Natural Walking



Redirected walking

- Perspective manipulation : modifier le point de vue de l'utilisateur en virtuel en appliquant un gain
- Différents types de gains

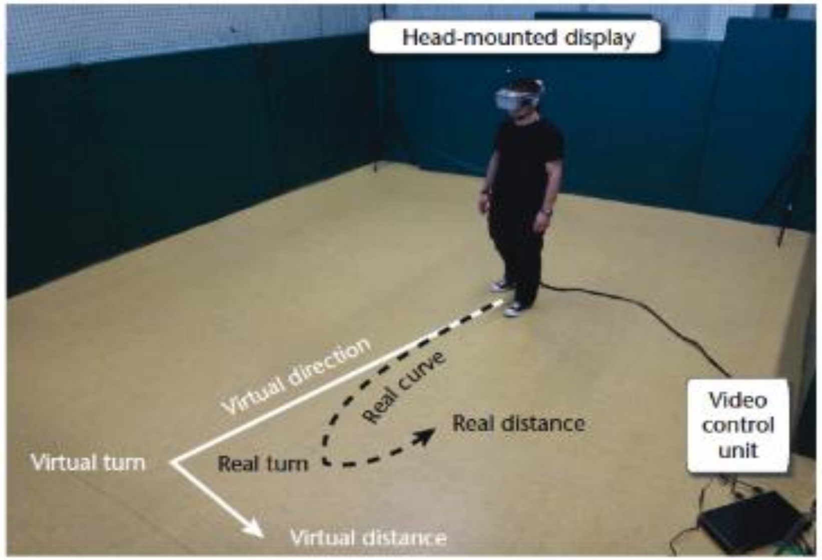
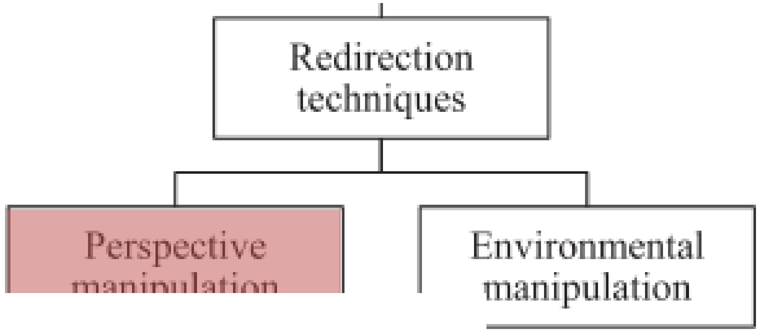


Figure 4: An illustration of redirected walking from Steinicke et al. [16]

Interactions – Natural Walking



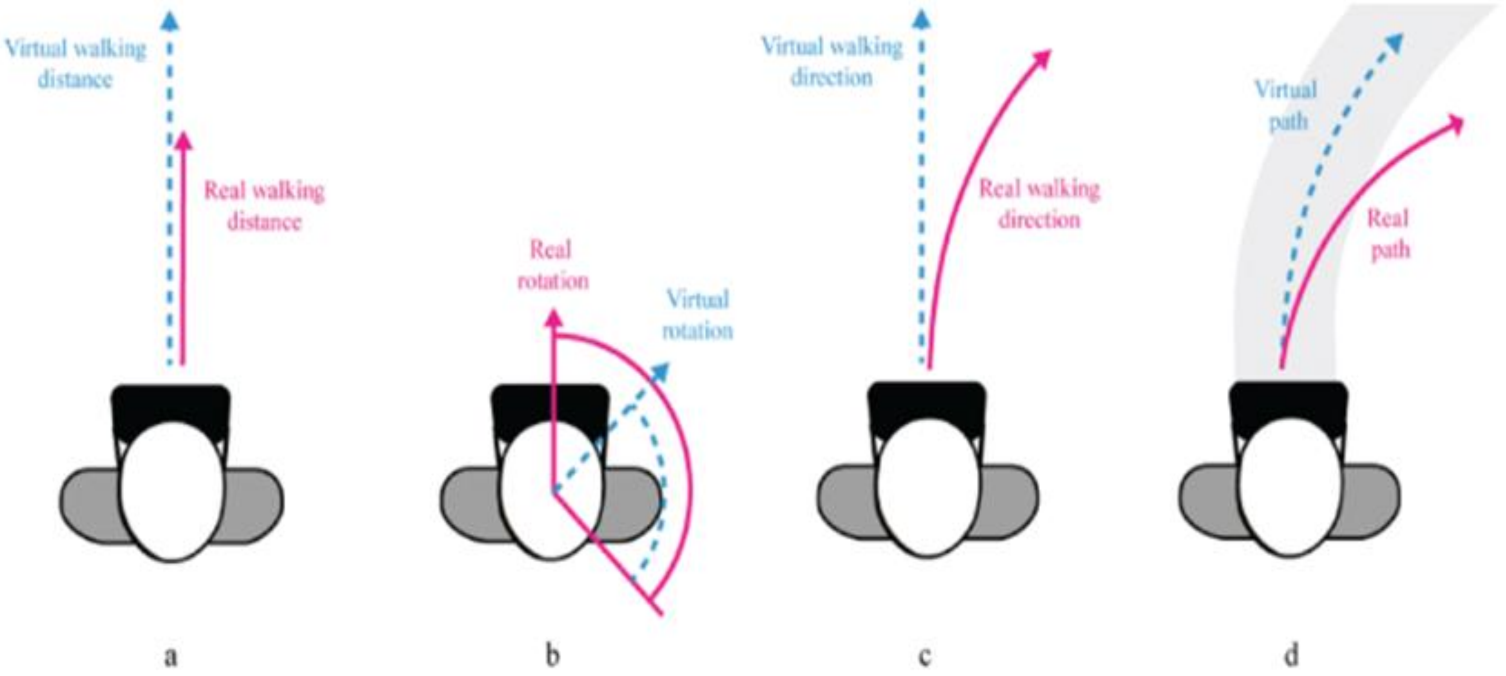
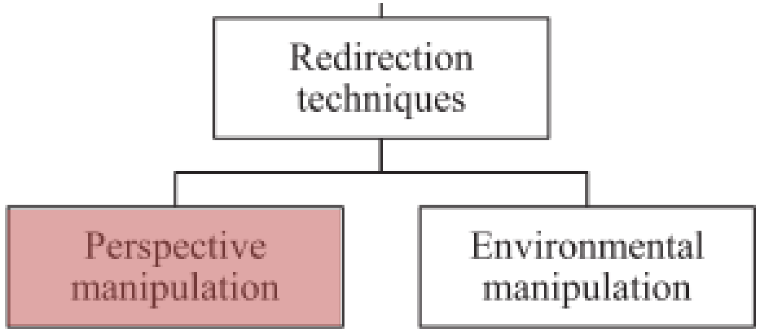


Fig. 5. The four types of gains used for perspective manipulation: (a) translation gain, (b) rotation gain, (c) curvature gain, and (d) bending gain. Purple and blue lines indicate the real and virtual transformations, respectively.

Nilsson et al., 2018



- Un gain perceptible génère de l'inconfort.
- Adaptation du seuil de détection grâce au flux optique (optical flow)

Fig. 1 Concept of redirected walking technique integrated with optical flow overlaid with lines (invisible to the user). In a virtual space, objects moving independently of the background can create optical flows to manipulate the user's walking trajectory

Lee et al., 2024

Interaction technique

- RedirectedDoors technique. This technique subtly manipulates the user's orientation by rotating the entire VE by a specific angular ratio (i.e., gain) of the door being opened by the user.

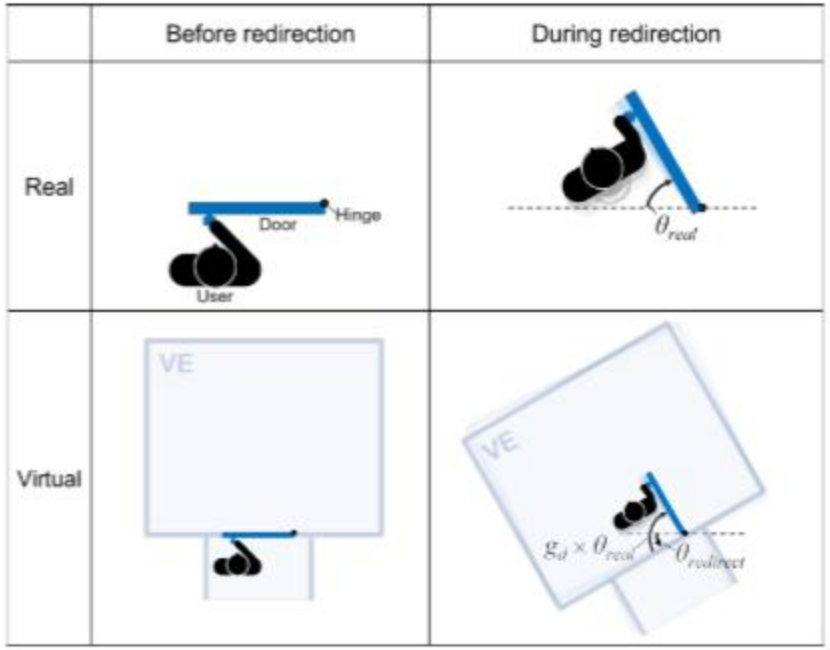


Fig. 2: Overview of RedirectedDoors mechanism [18]

Oshikawa et al., (2022)

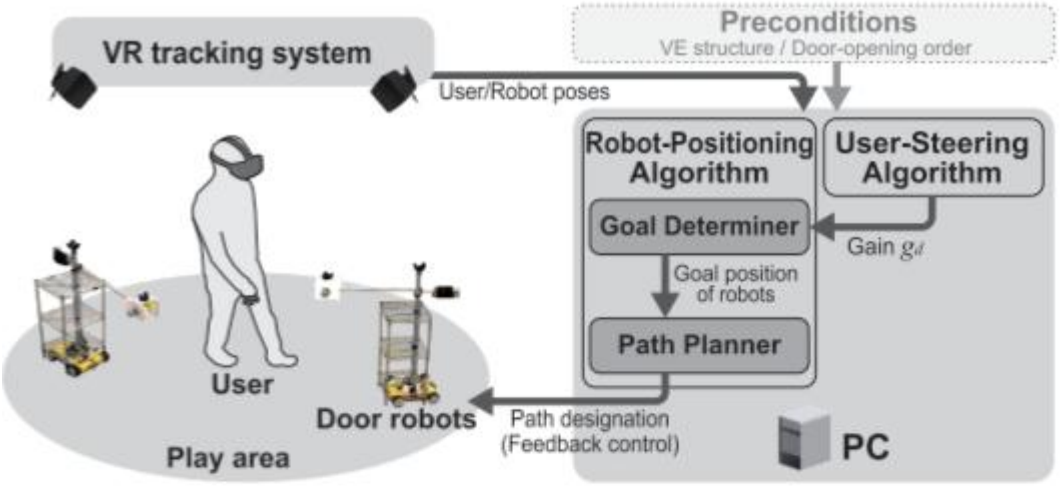
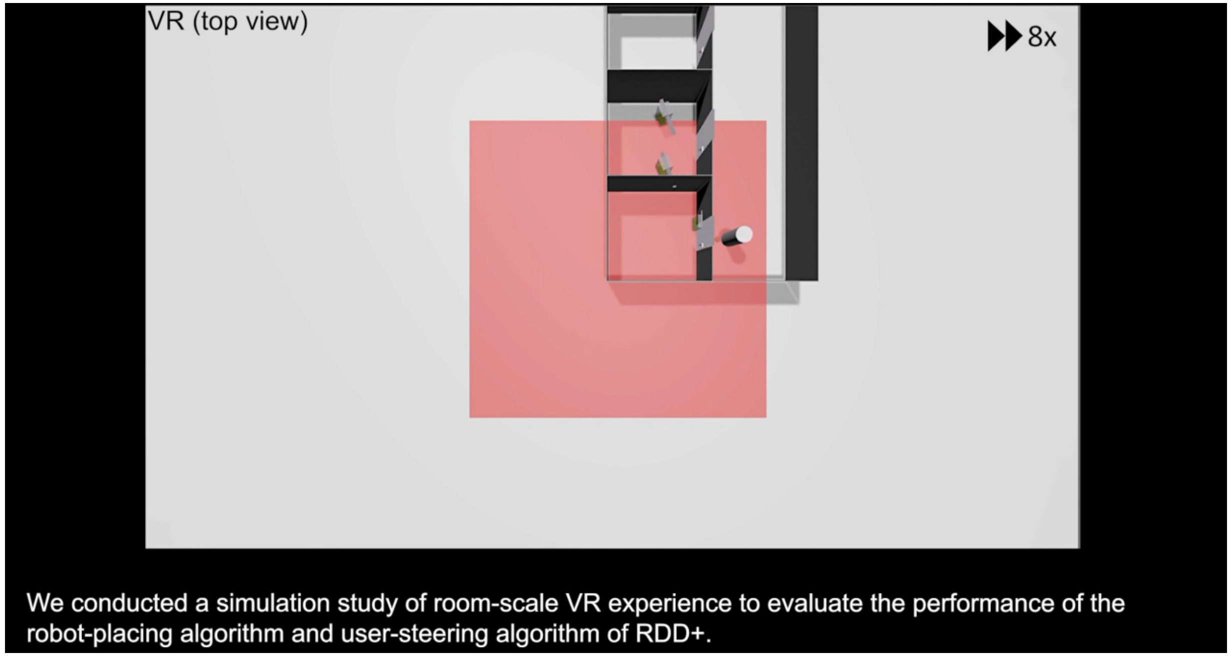


Fig. 4: Overview of RDD+ system workflow

Add haptic feedback (Oshikawa et al., (2024)

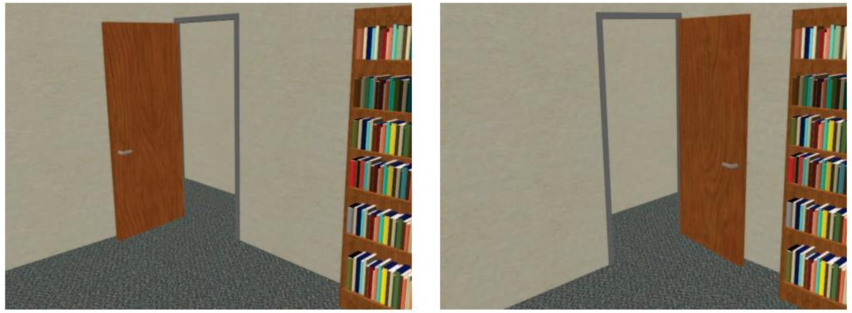
Interaction technique

- RedirectedDoor+ (Oshikawa et al., 2024)

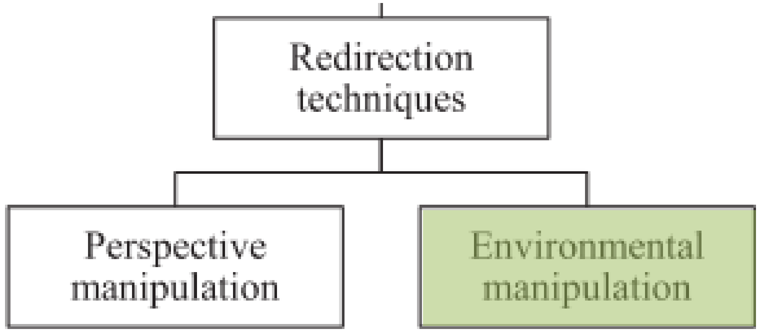


Interaction technique

Tea for gods (Void Room, 2023)

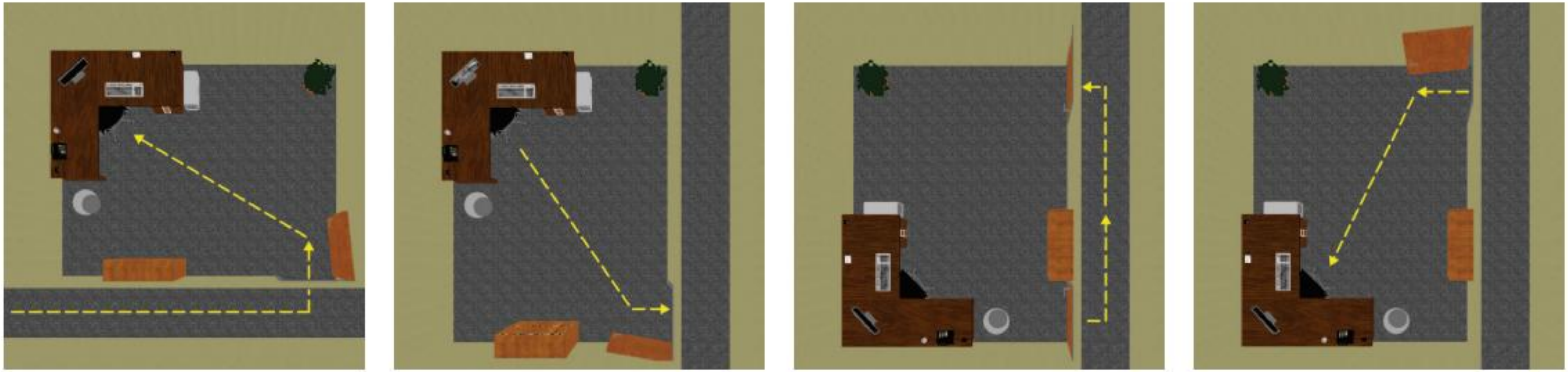


(a) Before Scene Change (b) After Scene Change



Redirected walking

- Environmental manipulation : modification de l'environnement virtuel en fonction des mouvements de l'utilisateur



(a) The user enters a 14’ x 11’ room and walks towards a desk to view the computer monitor.

(b) When the user approaches the monitor, the corridor and the door to exit the room are instantaneously rotated by 90 degrees.

(c) When the user enters the hallway, the second doorway is added, and the contents of the room are swapped with the next room.

(d) The first door is removed as the user enters the second room. The process can then be repeated.

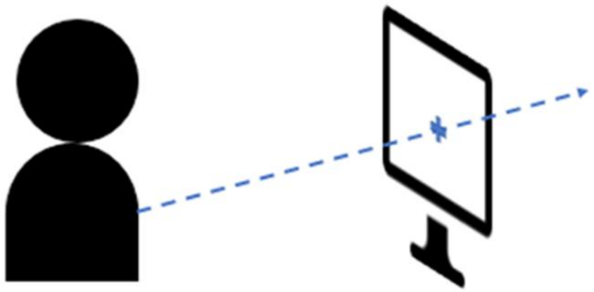
Interaction technique - Locomotion

- Conclusion
  - A lot of different locomotion techniques
  - Most used are
    - teleportation, steering and natural walking
    - Natural walking get more and more interest

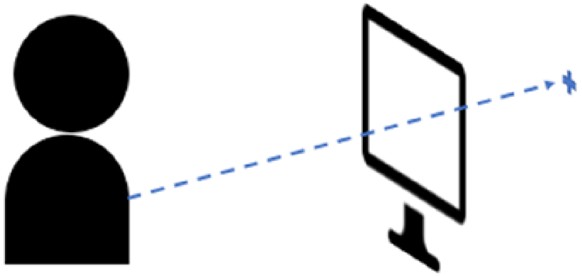
	Pro	Con
joystick	rapide	Cybermalaise en RV Moins appréciée en RV (Langbhen et al., 2018)
Téléportation	Rapide (Christou et al., 2017)	Désorientation spatiale (Bowman et al., 1997) Manquer information (christou et al., 2017)
WIP	Technique naturelle (Ferracani et al., 2016) Facile à apprendre (Verhulst et al., 2016) Peu couteux (Feasel et al., 2008) Présence ++ (Bozgeyikli et al., 2019) Moins cybermalaises ressentie (Park et al., 2023)	Fatigue physique (Verhulst et al., 2016)
Arm-swinging	Moins fatiguant que le WIP (nilsson et al., 2013)	Lors de la navigation, pas d'autres input par bras
Marche réele	Présence ++ (Bozgeyikli et al., 2019) Meilleure mémorisation des informations spatiales (Langbhen et al., 2018)	Long temps de réaction (Bozgeyikli et al., 2019)

Interaction Technique – Selection

- Selection
  - Raycasting
  - Direct selection
  - Natural gesture interface



Sélection en
2D



Sélection en
3D

Interactions

- Selection
- Fitt’s law et Throughput

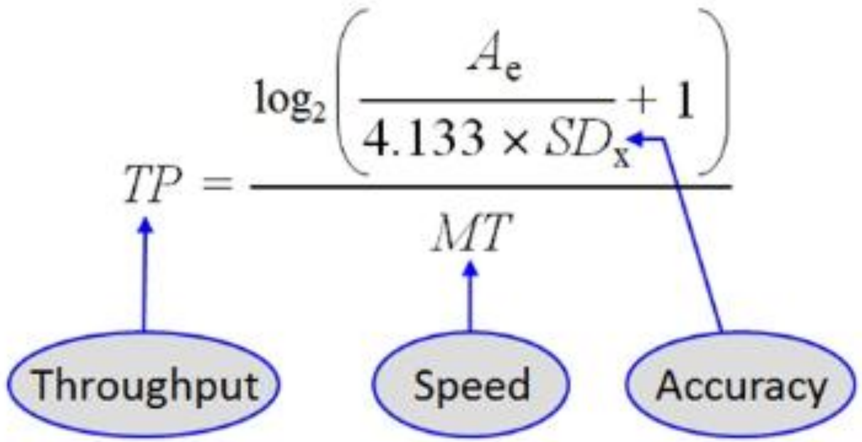


Fig. 2. The speed-accuracy trade-off in the calculation of Fitts' throughput

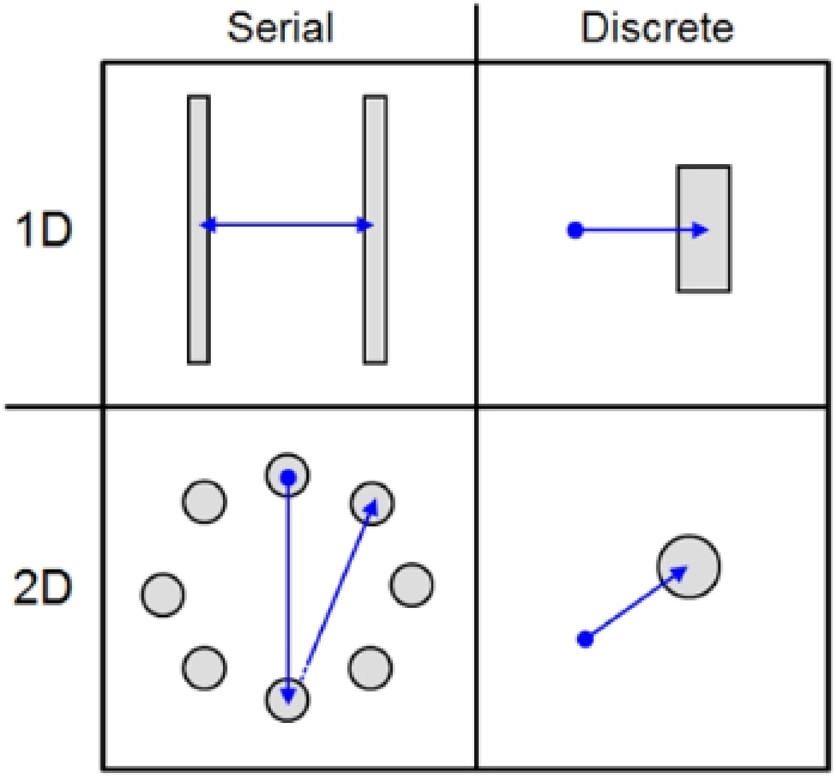


Fig. 3. Fitts' law tasks: 1D vs. 2D. Serial vs. discrete

Technique d'interaction

Tâche de sélection

Méthode :

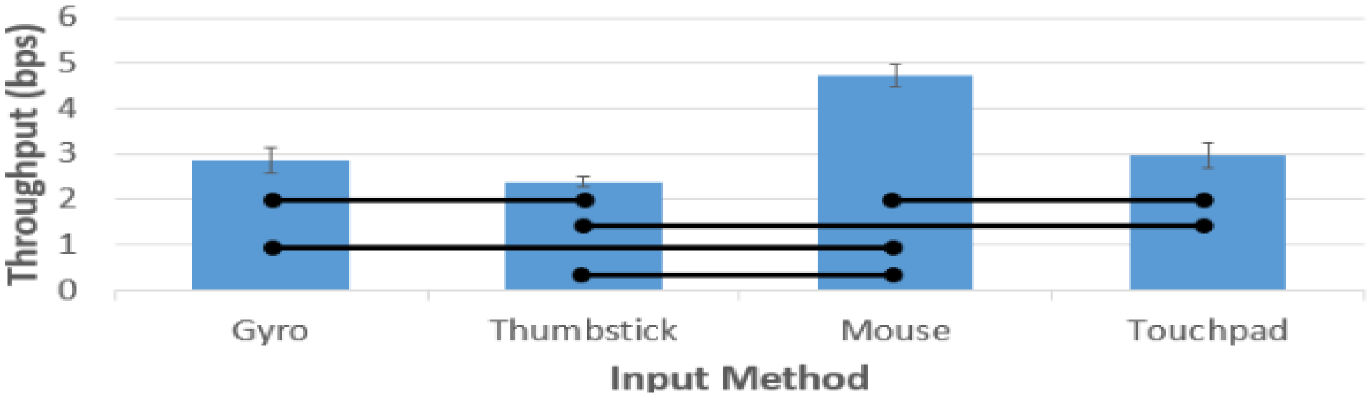
- Joystick
- Touchpad
- Gyro
- souris

Ramcharitar et al., 2017

Technique d’interaction

Tâche de sélection

Résultats :
- Souris à le meilleur througput
- Joystick le moins bon



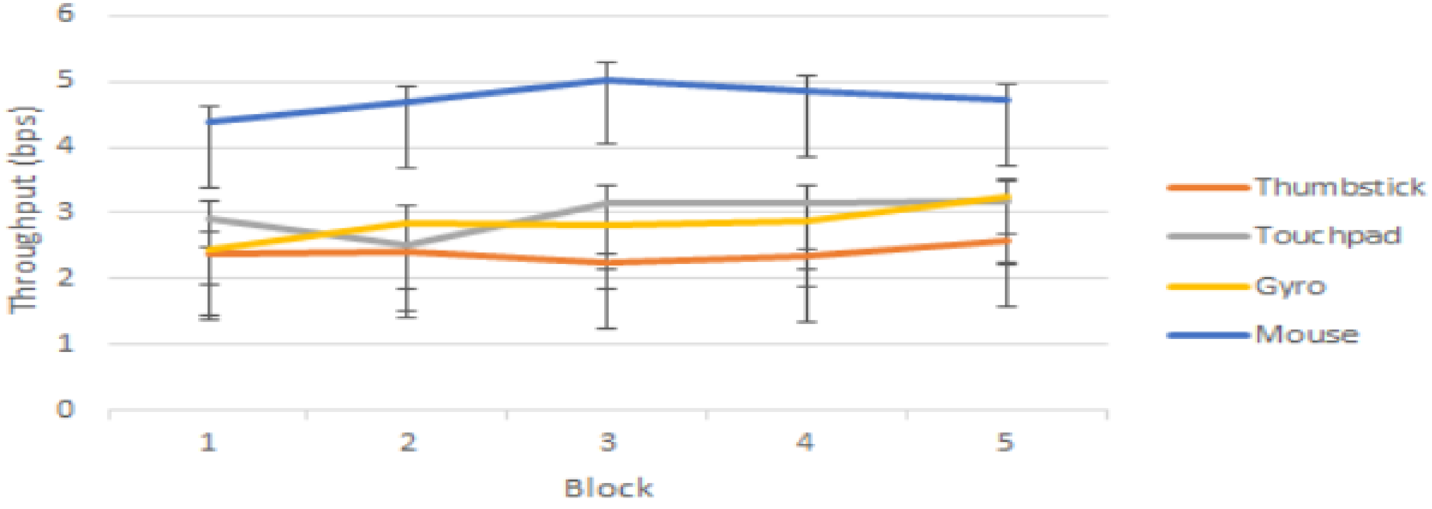


Figure 5: Throughput by block. Error bars show ±1 *SD*.

Ramcharitar et al., 2017

Technique d'interaction

Tâche de sélection

Méthode :

- Joystick
- Move de Playstation
- kinect
- souris

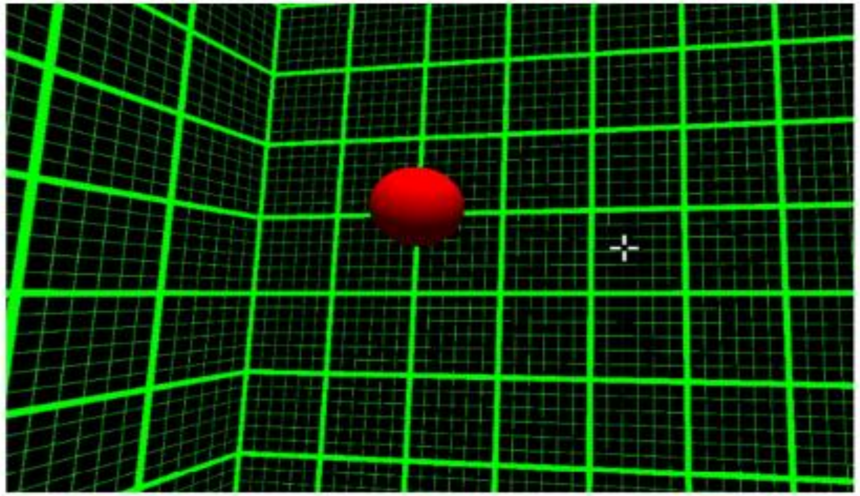


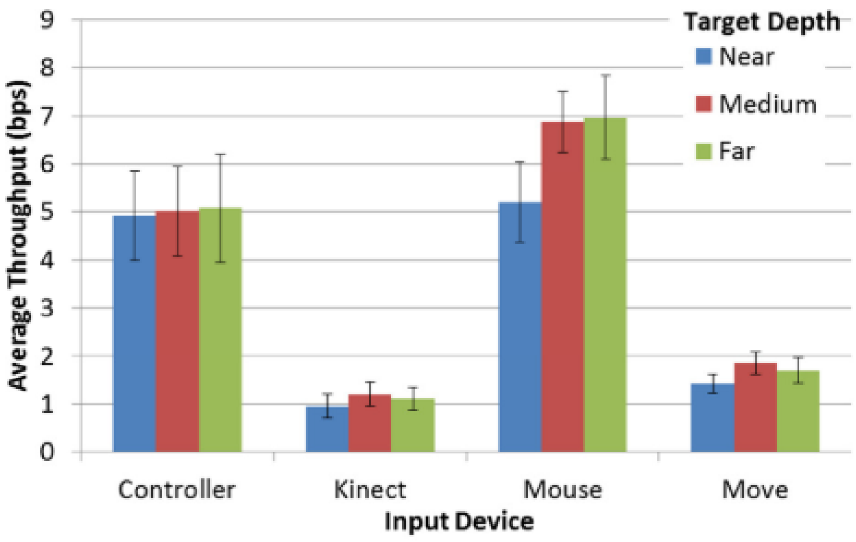
Figure 2. Software used in the experiment. The red sphere is a target, and the white crosshair is the pointer. Orientation information is provided to the viewer by way of the grid lines depicted in the background.

Zaraneck et al., 2014

Technique d'interaction

Tâche de sélection

Résultats :
- Souris a le meilleur throughput
- Kinect et move ont les moins bons



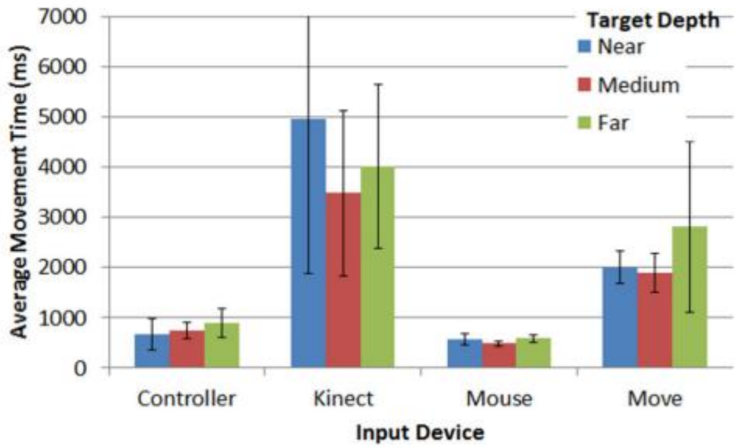
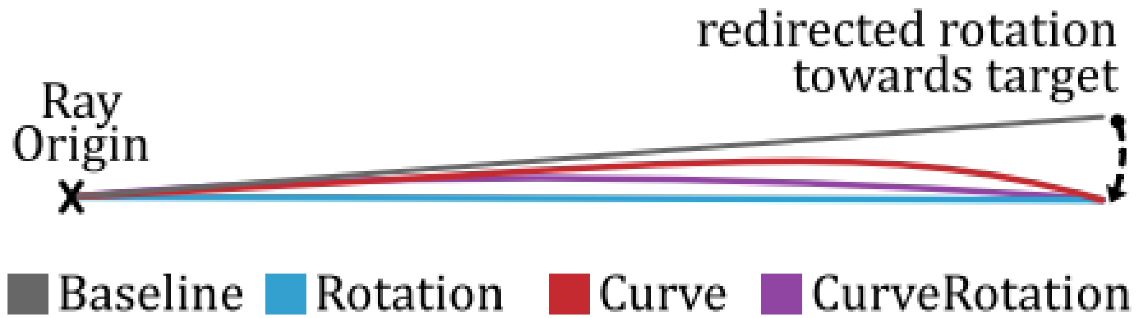


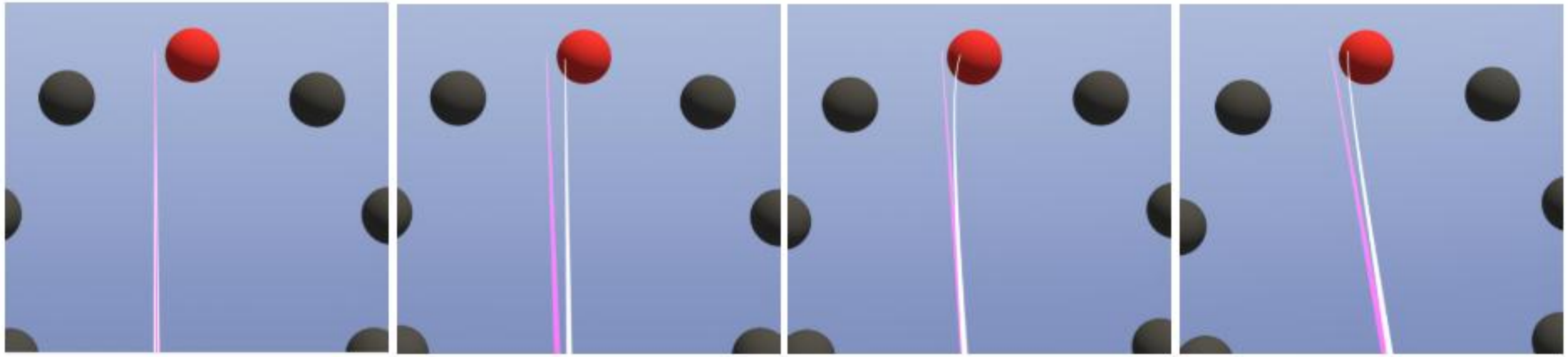
Figure 3. Mean movement time by input device and target depth. Error bars show ±1 *SD*.

Zaraneck et al., 2014

Interactions



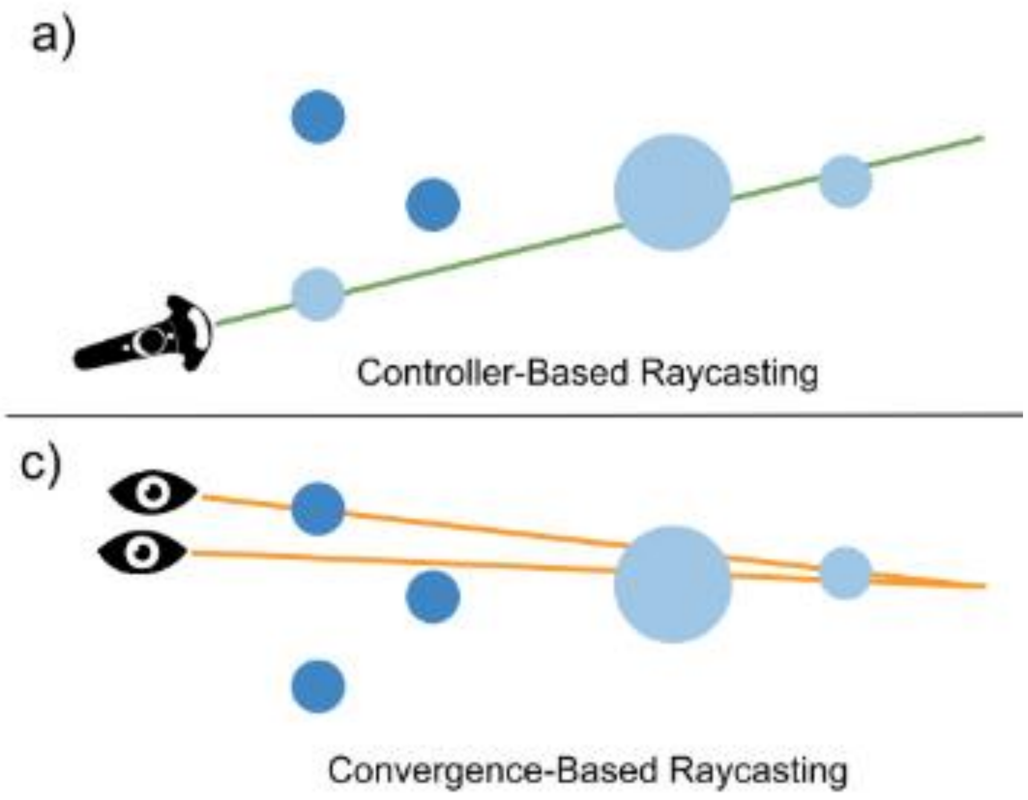
- Selection
- Ray casting and assistive selection technique (Gabel et al., 2023)



(a) Baseline (b) RayRotation (c) RayCurve (d) RayCurveRotation

Interactions

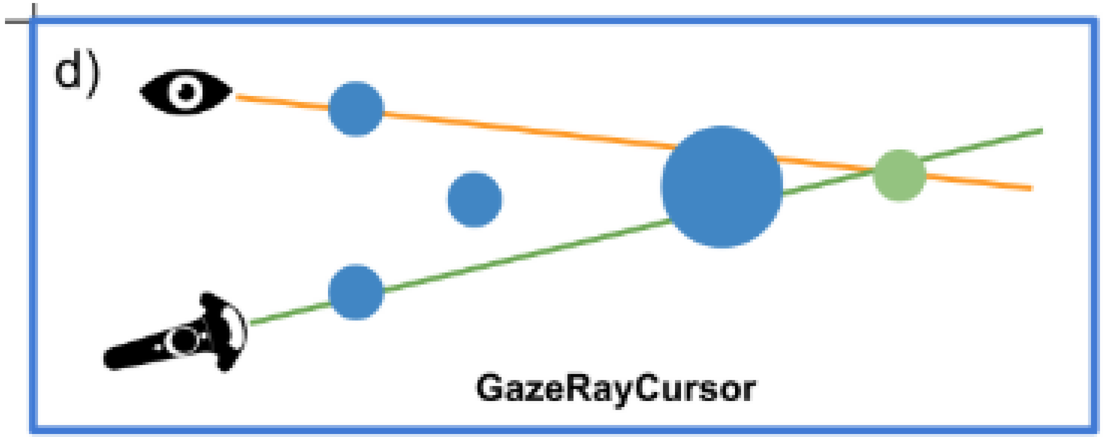
- Problème : Difficulté à sélectionner une cible lorsque d’autres objets sélectionnables sont à proximité



Chen et al., 2023

Interactions

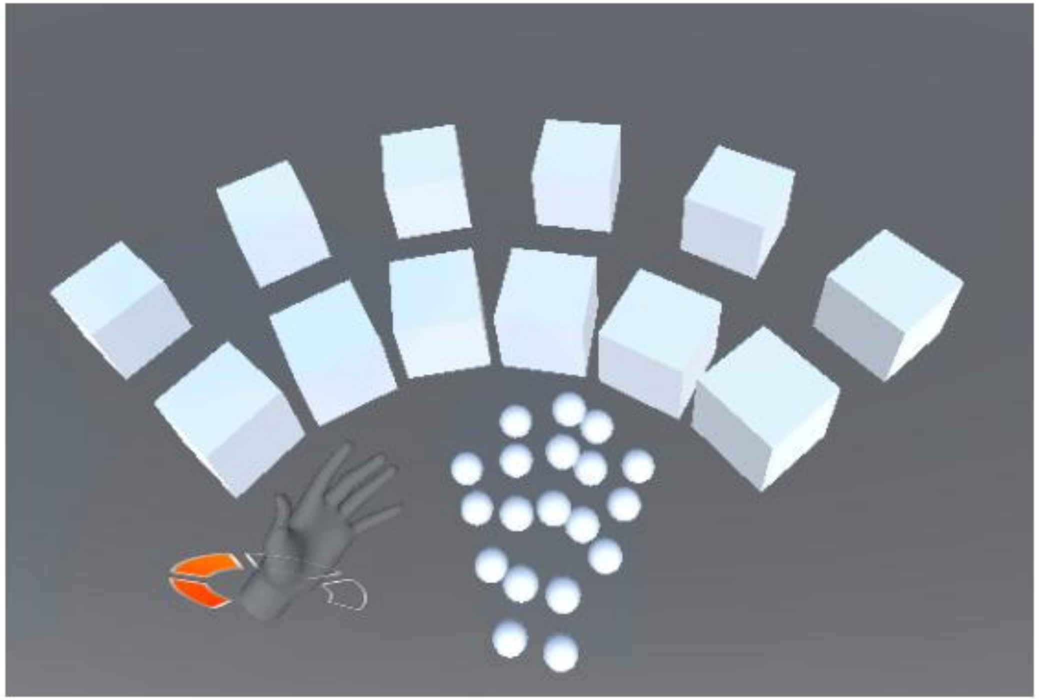
- Selection
- Solution : GazeRayCursor
- Résultats
  - Moins d’erreurs de sélection
  - Temps de sélection plus court



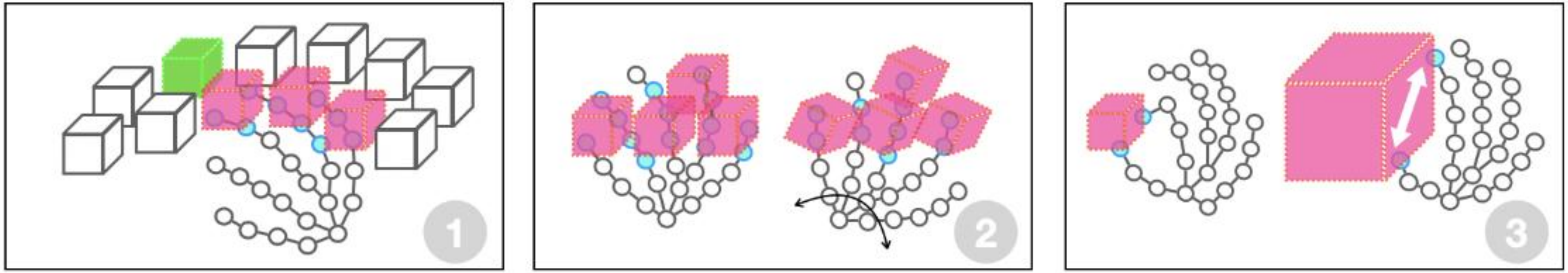
Chen et al., 2023

Interactions

- Manipulation
  - Swarm control : manipuler plusieurs entités
    - Dominant hand
    - Non-dominant hand



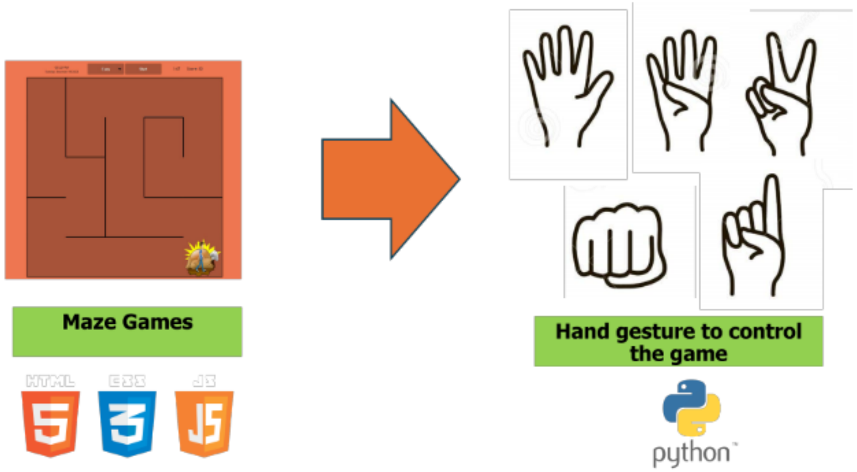
Li et al., 2023



Li et al., 2023

Introduction

- Body and Hand tracking in Virtual Reality applications
- Hand Tracking: detect and follow hands position and rotation of a user. These data can then be apply in a 3D environnement.



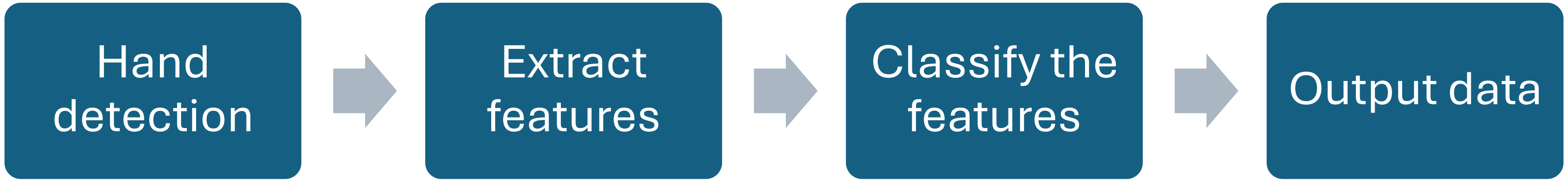
To assess and to design new interaction (Husna et al., 2025)

Add them in concret application like games

Hand tracking

- Computer vision algorithms to extract informations from images or video to get hand gestures

Gestures recognition steps



Hand tracking

- Computer vision algorithms to extract informations from images or video to get hand gestures

Gestures recognition steps

Get informations in real time

- Depth camera
- RGB camera

Leap motion

Kinect

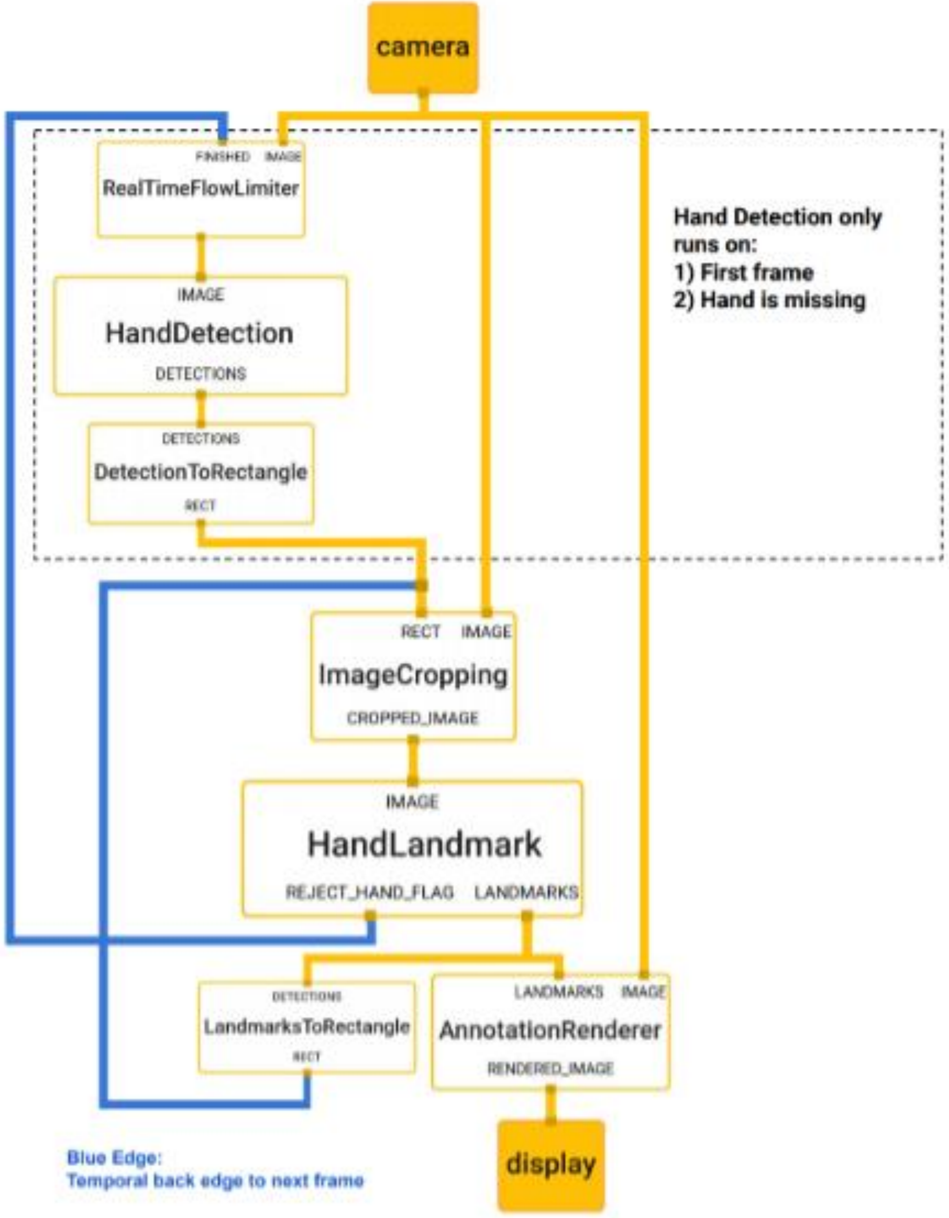
Hand tracking

- Computer vision algorithms to extract informations from images or video to get hand gestures

Gestures recognition steps

Extract features

- skin tones,
- textures,
- hand sizes,
- camera model, and
- hand movement parameters, (Zhang et al., 2020)



hand landmark models (Zhang et al.,2020)

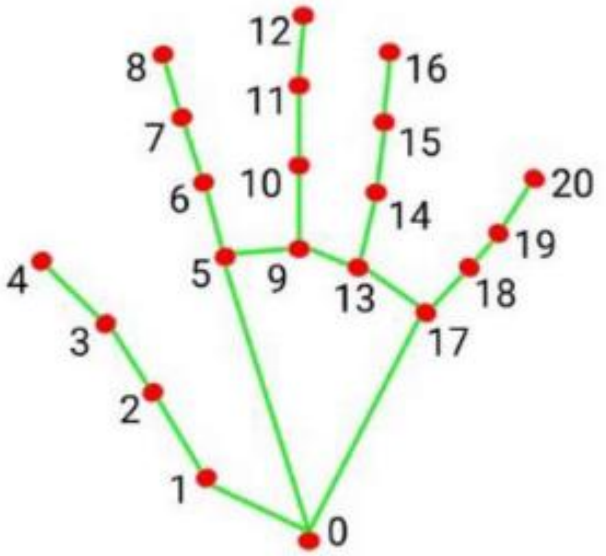
Hand tracking

- Computer vision algorithms to extract informations from images or video to get hand gestures

Gestures recognition steps

Classify Features
- CNN

Output data



Mediapipe hand skeleton

Hand tracking in Virtual Reality

- multi-stage process to estimate hand pose and finger angles in real time (Han et al., 2020)
- Hand detection
  - Convert the RGB image into gray scale (ex extracting the green channel)
  - Identifying whether a hand is present and its location,
  - Separating the hand from the surrounding objects and background.
  - Draw a bounding box around the hand
- Hand keypoints
  - key points are identified and labeled on the hand and fingers
- Model-based Tracking
  - Use keypoints to create an inverse kinematic model of the hand
  - Hand pose and finger joint angles are comp
- User application
  - Apply the hand pose to a virtual one

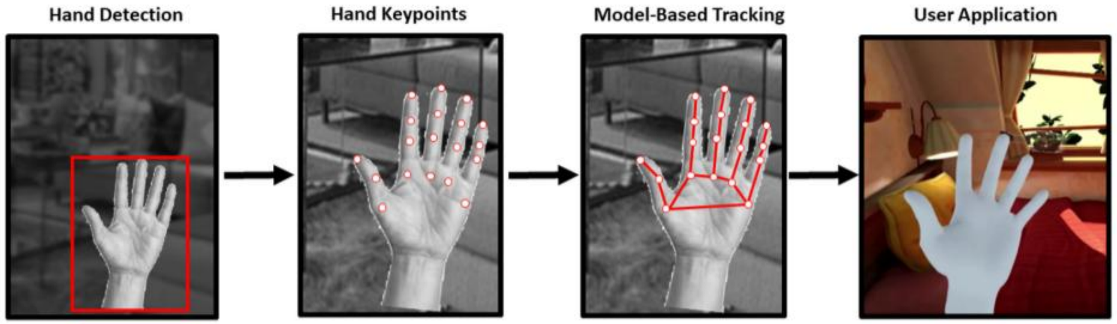


Fig. 1 Meta Quest 2 has a multi-stage process for hand-tracking, which includes separate stages for hand detection, key-point identification, and tracking

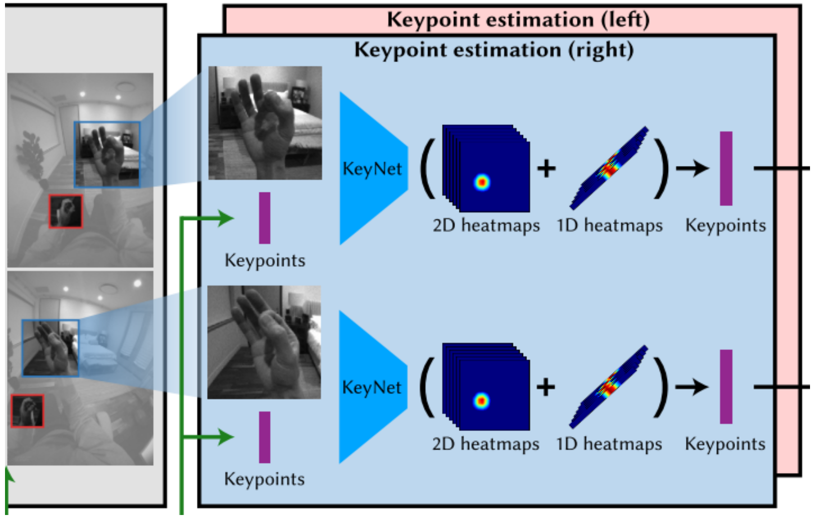
Hand tracking in Virtual Reality

- multi-stage process to estimate hand pose and finger angles in real time, Fig. 1, see (Han et al., 2020)f
- Hand detection
  - Identifying whether a hand is present and its location,
    - Make a bounding box around each hand at each image input
    - Automatic labelisation using dataset and CNN
    - Run algo on all 4 images (from the 4 cameras)
  - Separating the hand from the surrounding objects and background.

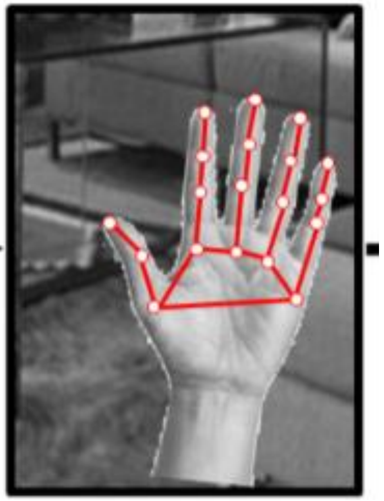
Hand Detection

Hand tracking in Virtual Reality

- multi-stage process to estimate hand pose and finger a real time, Fig. 1, see (Han et al., 2020)f
- Hand detection
- Hand keypoints
  - key points are identified and labeled on the hand and fingers
  - Looking for the 21 keypoints in 3D



Model-Based Tracking



Hand tracking in Virtual Reality

- multi-stage process to estimate hand pose and finger angle real time, Fig. 1, see (Han et al., 2020)f
- Hand detection
- Hand keypoints
- Model-based Tracking
  - Use keypoints to create an inverse kinematic model of the hand
  - Hand pose and finger joint angles are computed
  - prior 3D model of the hand, a user's hand pose can be reconstructed by fitting the model with images from either multiple cameras

Hand tracking in Virtual Reality

- Look at the study, how the paper is structured?
- Look at the abstract, and answer the questions :
  - What's the performance of Hand tracking in Virtual Reality?
  - Which metrics?

Behavior Research Methods
https://doi.org/10.3758/s13428-022-02051-8

COMMENT

A methodological framework to assess the accuracy of virtual reality hand-tracking systems: A case study with the Meta Quest 2

Diar Abdlkarim[1] · Massimiliano Di Luca[1] · Poppy Aves[1] · Mohamed Maaroufi[1] · Sang-Hoon Yeo[1] · R. Chris Miall[1] · Peter Holland[1,2] · Joeseph M. Galea[1]

Accepted: 9 December 2022

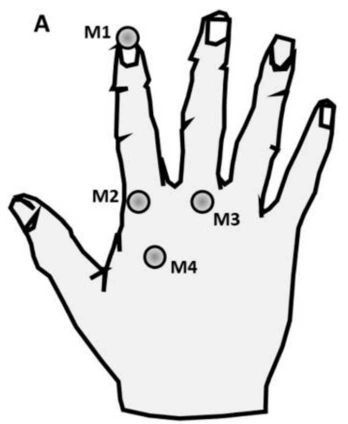
Abstract
Optical markerless hand-tracking systems incorporated into virtual reality (VR) headsets are transforming the ability to assess fine motor skills in VR. This promises to have far-reaching implications for the increased applicability of VR across scientific, industrial, and clinical settings. However, so far, there are little data regarding the accuracy, delay, and overall performance of these types of hand-tracking systems. Here we present a novel methodological framework based on a fixed grid of targets, which can be easily applied to measure these systems' absolute positional error and delay. We also demonstrate a method to assess finger joint-angle accuracy. We used this framework to evaluate the Meta Quest 2 hand-tracking system. Our results showed an average fingertip positional error of $1.1 cm$, an average finger joint angle error of $9.6°$ and an average temporal delay of $45.0\ ms$. This methodological framework provides a powerful tool to ensure the reliability and validity of data originating from VR-based, markerless hand-tracking systems.

Keywords Hand-tracking · Virtual reality · Metaverse · Tracking precision · VR delay

Abdlkarim et al., 2023

Performance of VR Hand tracking

- Comparison of
  - Markers hand tracking (Qualisys)
  - Markerless hand tracking (Quest 2)



Marker on hand for Qualisys

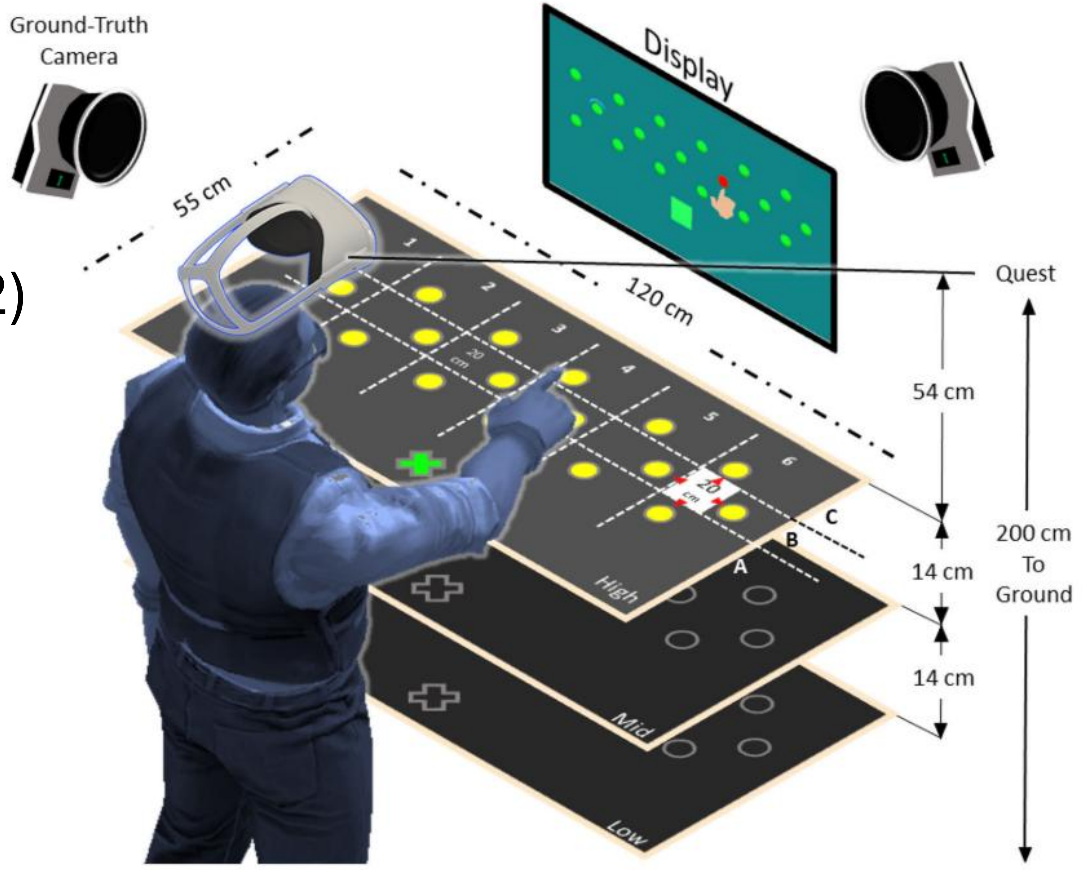
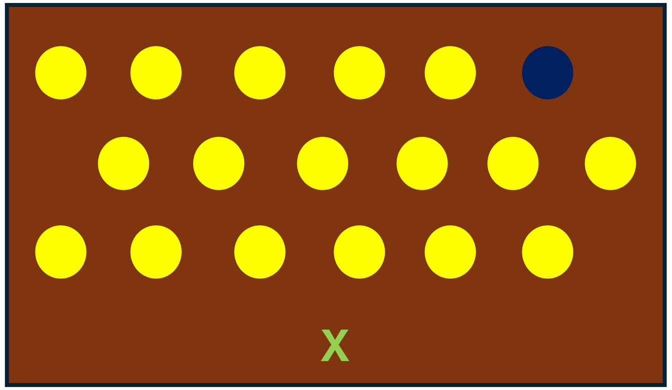


Fig. 2 Experimental setup with the target panel, display, ground-truth cameras, and user standing under the Meta Quest 2 HMD. The targets (*yellow circles*) are separated into rows A, B, and C, and columns 1 to 6 with a total of 18 targets per each height. The *green cross* is the starting position

Abdlkarim et al., 2024

Performance of VR Hand tracking



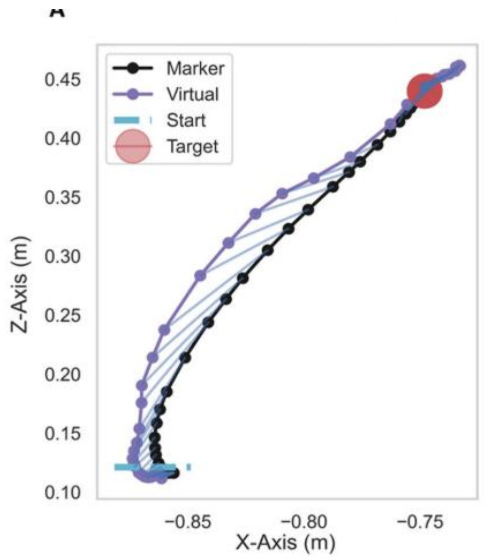
- 2 tasks:
  - Target-reaching task at a specific tempo
    - Pose the finger on the green cross
    - Touch the target for 1 seconde
    - Return the finger on the green cross
  - Hand opening-and-closing task : open and close the hand at a specific tempo :
    - 80,
    - 120,
    - 160 bpm

Abdlkarim et al., 2024

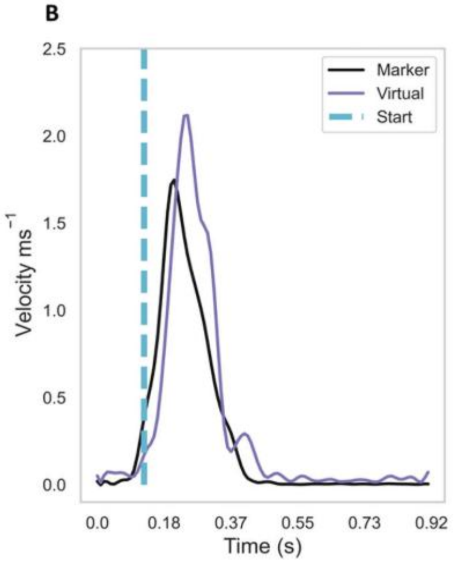
Accuracy of VR Hand tracking

Abdlkarim et al., 2024

- Analysis:
    - max fingertip velocity,
    - positionnal accuracy (i.e., error)
    - path offset between real and virtual
    - time delay (lag) between real and virtual



Fingertip trajectory from the target-reaching task



Fingertip velocity from the target-reaching task

Accuracy of VR Hand tracking

Abdlkarim et al., 2024

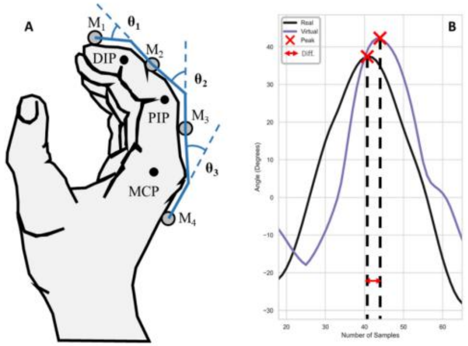


Fig. 5 Hand opening-and-closing. A: Joint rotations showing the Distal (DIP), Proximal (PIP) and Metacarpo-phalangeal (MCP) joints of the index finger. B: Computing temporal delay between the virtual and real MCP joint angles using the peak angle (red crosses) as a metric for temporal alignment

- Analysis:
  - max fingertip velocity,
  - positionnal accuracy (i.e., error)
  - time delay (lag) between real and virtual (ms)

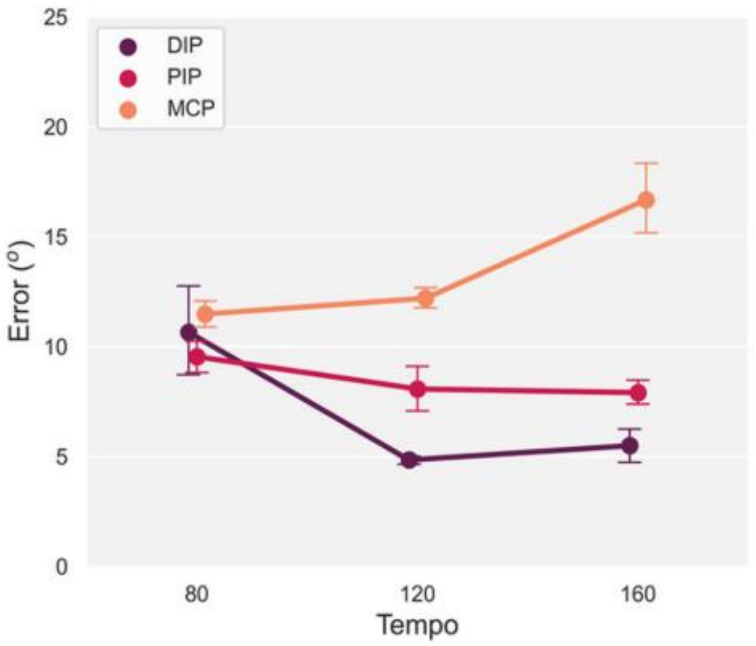
Fingertip trajectory from the target-reaching task

Fingertip velocity from the target-reaching task

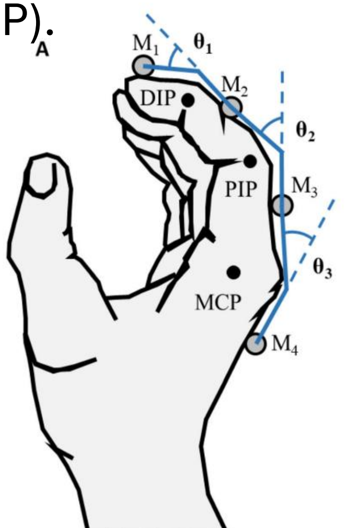
Accuracy of VR Hand tracking

Abdlkarim et al., 2024

- Results:
  - Positionnal accuracy:
    - average fingertip positional error of 1.1cm
    - average finger joint angle error of 9.6◦
  - Delay: average temporal delay of 45.0 ms



Angular error ± standard error of the mean, between ground-truth marker and Meta Quest averaged across the three joints (DIP, PIP and MCP).



Accuracy of VR Hand tracking

Abdlkarim et al., 2024

- Discussion:
  - Add a lense correction algorithm
  - Better performance in foveal view

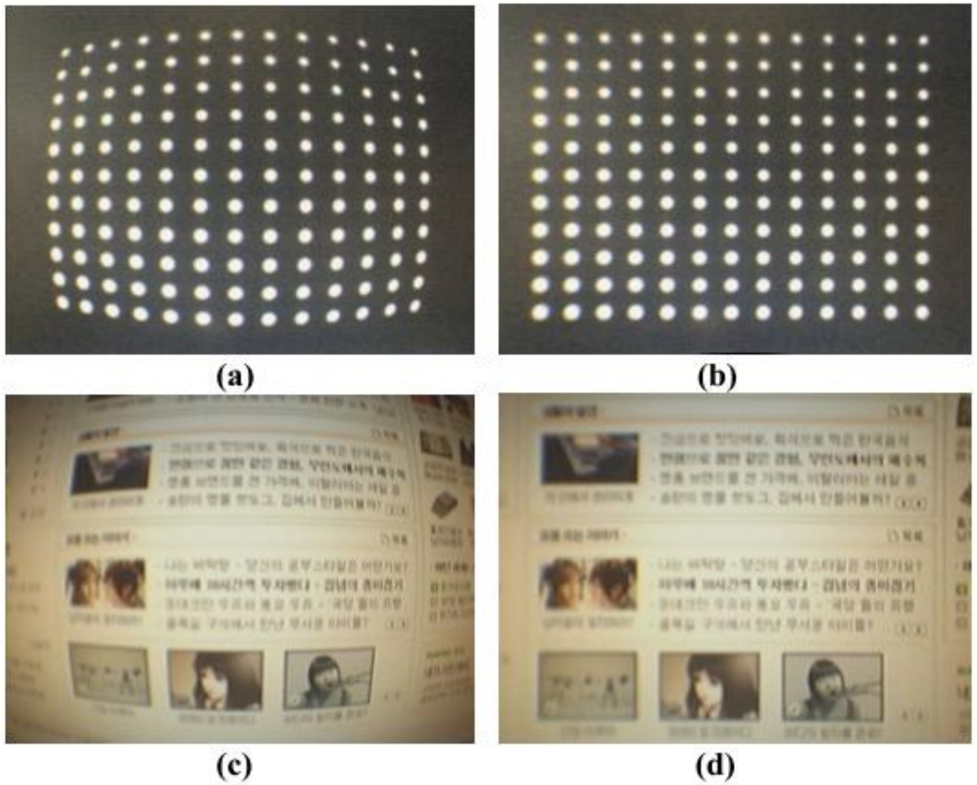


Fig. 7. Experimental results. (a) distorted feature image, (b) compensated image of (a) using model (8), (c) real image (d) compensated image of (c) using model (8).

Park et al., (2009)

Interaction technique – Application Control

- Application control allow user to interact with menus
  - Not a lot of menu
  - First UI was only responding to mouse input

Interaction technique – Application Control

- Linear menu displayed éléments on a list
  - Most common type
- Radial display éléments on a circle

Direct linear menu, Lone Echo (2020)

Radial menu, Population: One (Big Box VR, 2020)

Interaction technique – Application Control

- Comparison of radial and linear menu (Santos et al., 2017)
- Better selection time for radial menu
- No significant error difference
- No significatn difference on usability

Figure 3. Spatial linear menu

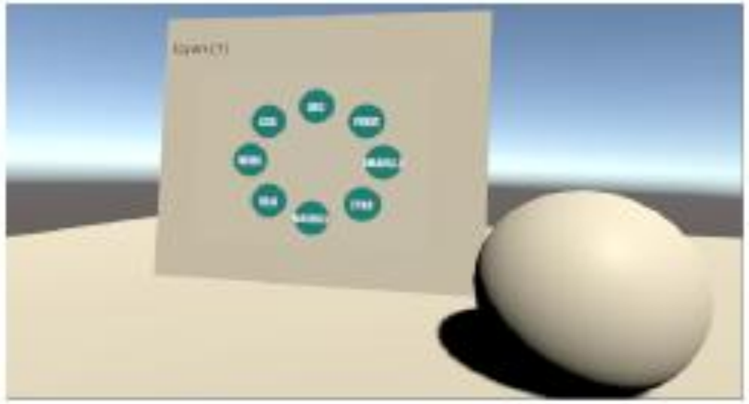


Figure 4. Spatial radial menu

Interaction technique – Application Control

- Menu anchoring. Where the menu is positionned
  - World or spatial
  - Hand
  - Arm

Interaction technique – Application Control

- Comparison of world and hand menu anchoring

And comparison of linear and radial

(Monteiro et al., 2019)

- Results
  - All menu get good performance
  - World anchoring is prefered (better overview)
  - Linear menu is prefered

FIGURE 1. VE used for the experiment trials. The VE consisted of a virtual living room of a smart house, where object states could be remotely controlled.

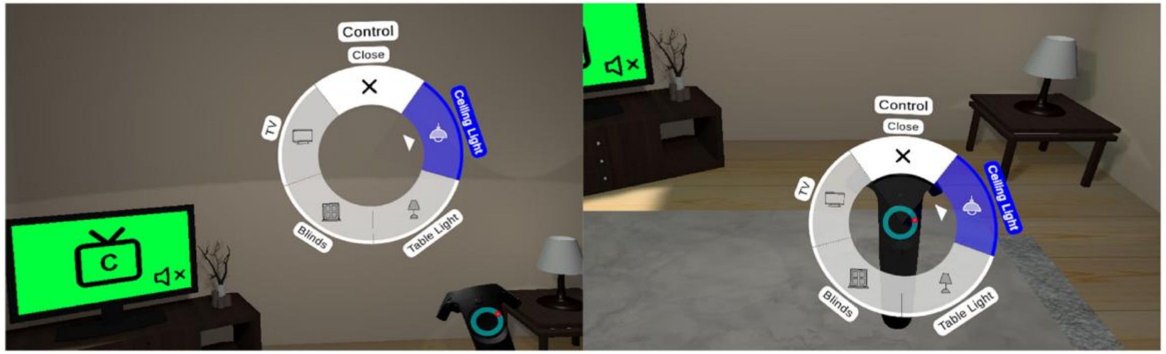


FIGURE 3. Radial menu type with the main menu options and the "Ceiling Light" option selected. The selection was made by placing the finger in the circular touchpad on the controller (red dot). On the left is the wall placement and on the right is the hand placement.

Interaction technique – Application Control

- Comparison of menu anchoring (Lediaeva et al., 2020)
- Results
  - Longer selection time for arm anchoring
  - World anchoring is prefered

Spatial menu

Arm menu

Hand menu

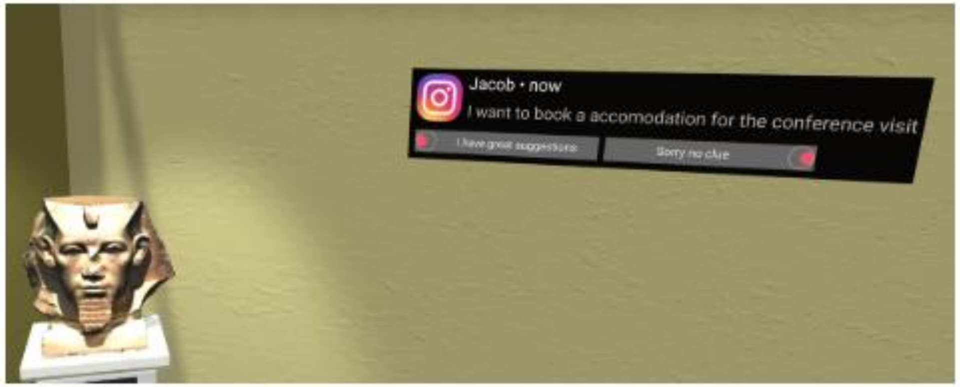

Waist menu

Interaction technique – Application Control

- Comparison of notification anchoring (Rzayev et al., 2019)
- Results – place notifications based on importance
  - Urgent : *Head-up placement*
  - Importance faible : *in-situ placement*
  - Importance moyenne : *on-body or floating placement*

(b) *On-Body* - Notification attached to the controller

(a) *Head-Up Display* - Notification attached to the headset

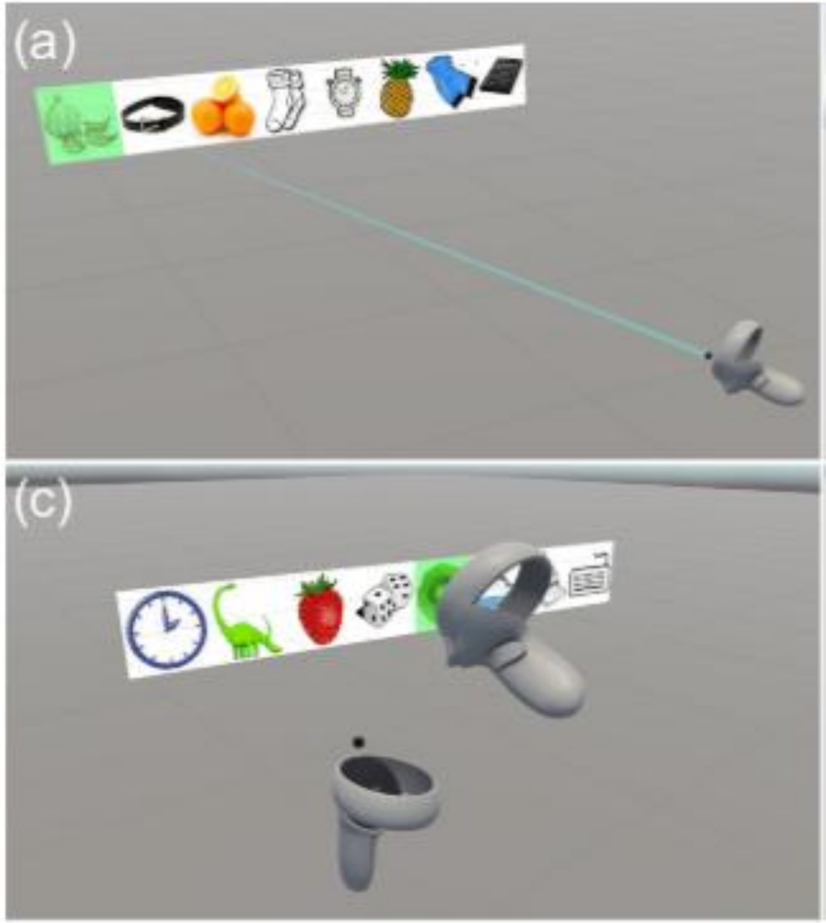


(d) *In-Situ* - Notification at the wall

Interaction technique – Application Control

- Type of selection:
  - Raycasting
  - direct input

- Results
  - Direct input is faster than raycasting
  - SUS has better results with raycasting



(Wentzle et al., 2024)

Interaction technique – Application Control

- UI position (front vs far)
- and complexity (digital vs gamified)
- during exergame (Kojic et al., 2019)

- Results
  - Digital UI is more readable
  - Users felts more support with the far UI

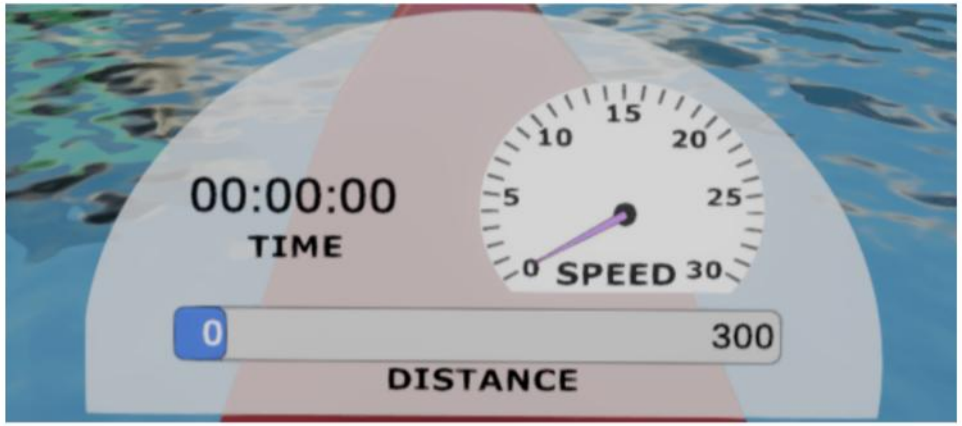


Figure 1: Players view on cockpit at the front of the rowing scull with gamified visualization of metrics.

Figure 2: Players view on a coach boat that follows the player with digital visualization of metrics with countdown screen for beginning of the workout.

Interaction technique – Application Control

- Conclusion:

TABLE II
COUNTS AND PROPORTIONS OF VARIATIONS IN DESIGN CHARACTERISTICS FOR 108 SPATIAL MENUS USED IN POPULAR VR APPLICATIONS.

Characteristic	Variation with Count (N = 108)				
Item Layout Spatial arrangement of menu items. $\kappa = 0.68$	*Linear* (single horizontal or vertical row) 45 (42%)	*Grid* (multiple rows) 23 (21%)	*Radial* (circular layout) 10 (9%)	*Scatter* (non-uniform, e.g. scattered desk) 3 (3%)	*Mixed* (compound with linear and grid parts) 27 (25%)
Interaction Technique Method for invoking menu and highlighting items. $\kappa = 0.67$	*Raycast* (controller direction intersects distant item) 66 (61%)	*Direct* (controller position intersects with item) 26 (24%)	*Hardware* (controller button or joystick) 10 (9%)	*Mixed* (support both raycast and direct) 6 (6%)	
Selection Technique Method to confirm item and dismiss menu. $\kappa = 0.69$	*Hardware Button* (button press) 84 (78%)	*Immediate* (as item highlighted with interaction tech.) 23 (21%)	*Dwell* (hold still for time period) 1 (1%)		
Number of Items Items typically visible in first menu level. $\kappa = 0.57$	*1-5* 45 (42%)	*6-10* 39 (36%)	*11-20* 22 (20%)	*21 or more* 2 (2%)	
Anchoring Where menu is positioned. $\kappa = 0.69$	*World* (independent of user) 80 (74%)	*Hand* (relative to user's hand) 23 (21%)	*Body* (relative to user's arm, head, hips, etc.) 5 (5%)		
Hierarchy Number of nested layouts of items. $\kappa = 0.83$	*1 level* 44 (41%)	*2 levels* 50 (46%)	*3 or more levels* 14 (13%)		
Hand Usage Number of hands required. $\kappa = 0.64$	*Unimanual* (one hand) 90 (83%)	*Bimanual* (both hands) 18 (17%)			

Wentzel et al., (2024)

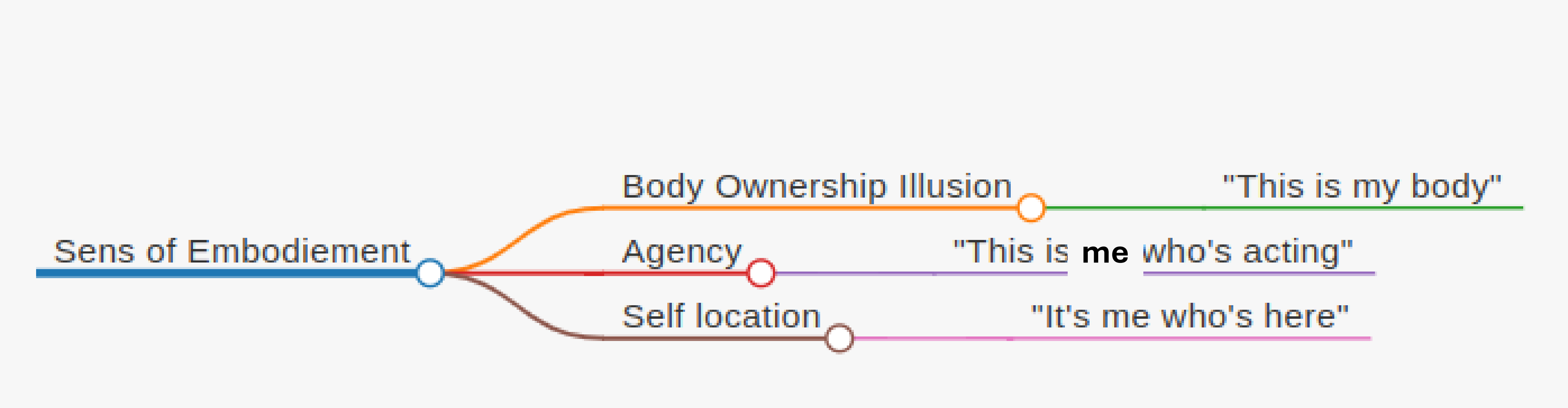
Sense of embodiment

- Current definition (Kilteni et al., 2012)

"*The term Sense of Embodiment (SoE) will be used to refer to the ensemble of sensations that arise in conjunction with being inside, having, and controlling a body*"

Sense of embodiment

- Sense of Embodiment is modelized by 3 dimensions

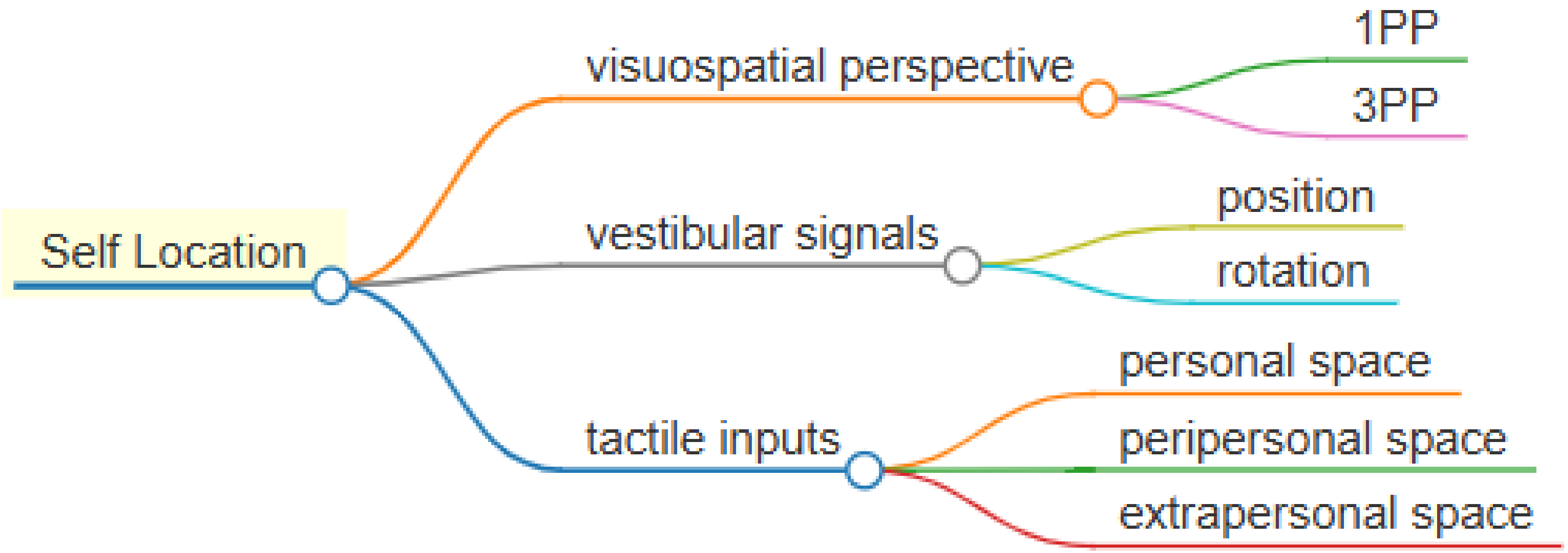


Body Ownership Illusion (BOI)

- BOI is the feeling of having your body replaced by a virtual one.
- Is evoked by visuo-tactil or visuomotor synchronies (perceptive feedback)
- Paradigme The Rubber-hand Illusion (Botvinick & Cohen, 1998)

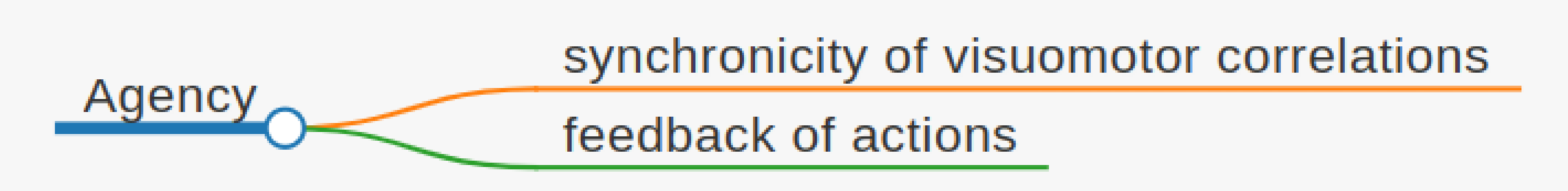
Sense of embodiment

- Self location



Sense of embodiment

- Agency
  - motion is mapped to the virtual body in real-time or near real-time



Proteus Effect

- The avatar-related character-istics influences the gamer in terms of both attitudes and behavior

« sous l'action de sa représentation virtuelle, le sujet va donc s'auto-influencer et rationaliser ses comportements dans le sens de la nouvelle identité constituée par l'avatar »

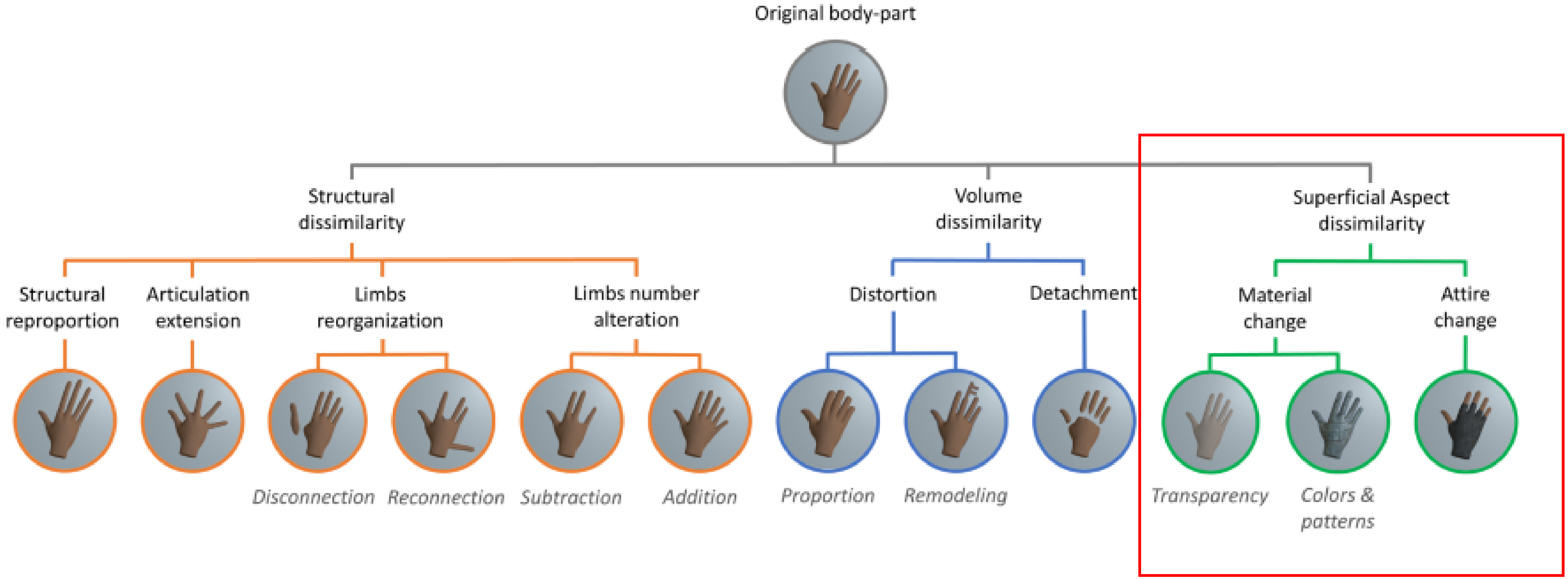
(Guegan & Michinov, 2011)

Protée

Nintendo Wii Sports Resort Swordplay

Taxonomy of the avatar

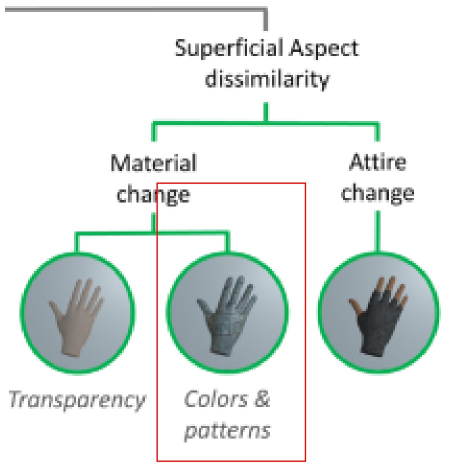
Cheymol et al., 2023



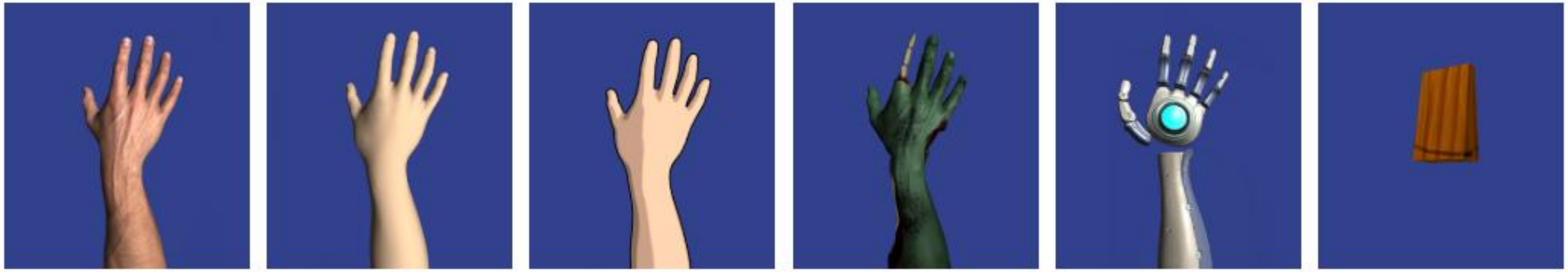
Do we need a realistic hand?

Embodiment in VR

- Do we need a realistic hand model? (Lin & Jörg, 2016)



Cheymol et al., 2023



Embodiment in VR

- Do we need a realistic hand model? (Lin & Jörg, 2016)
- Task: Ball game - catching objects

DK2 + Leap Motion

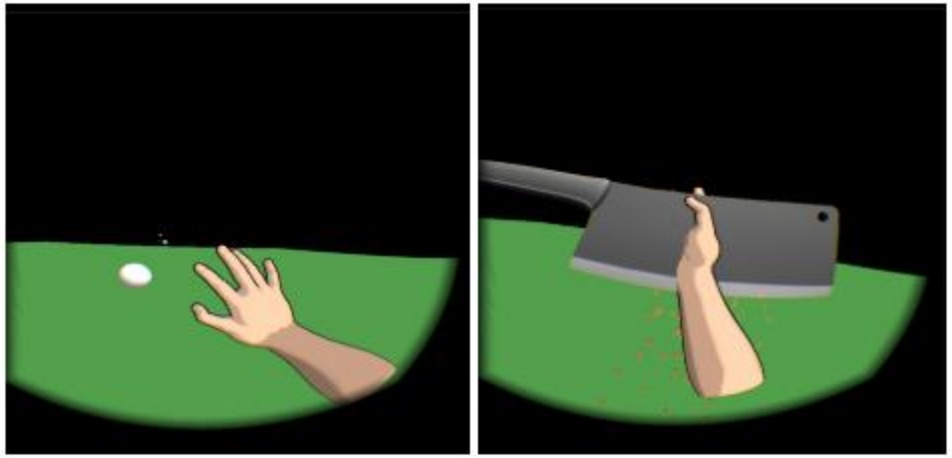


Figure 4: *The ball game (left) serves as the conditioning phase of the study. The knife (right) hits the model.*

Embodiment in VR

- Do we need a realistic hand model? (Lin & Jörg, 2016)
- Task: catching objects
- Result: Illusion worked with all hands

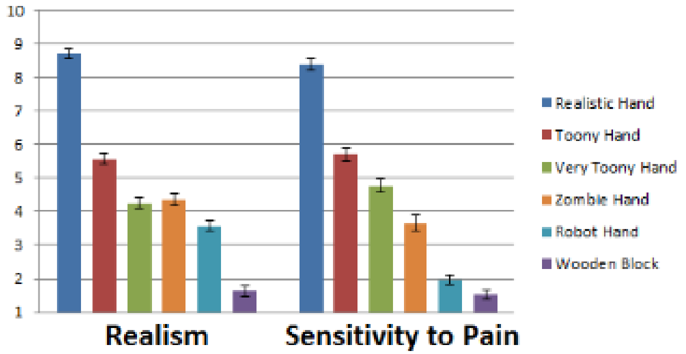
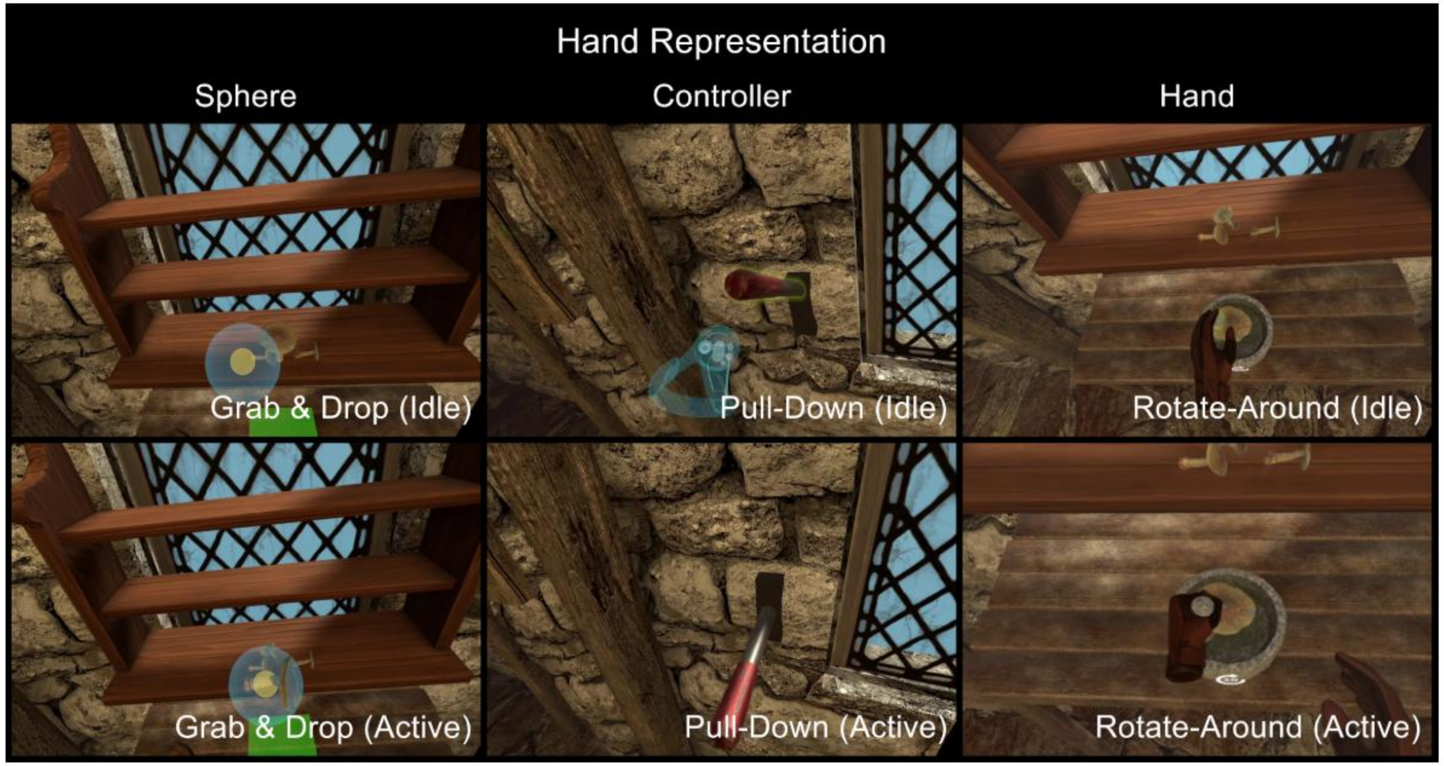


Figure 2: *Perceived realism and sensitivity to pain of the hand models. The error bars are standard deviations of the mean.*

Embodiment in VR

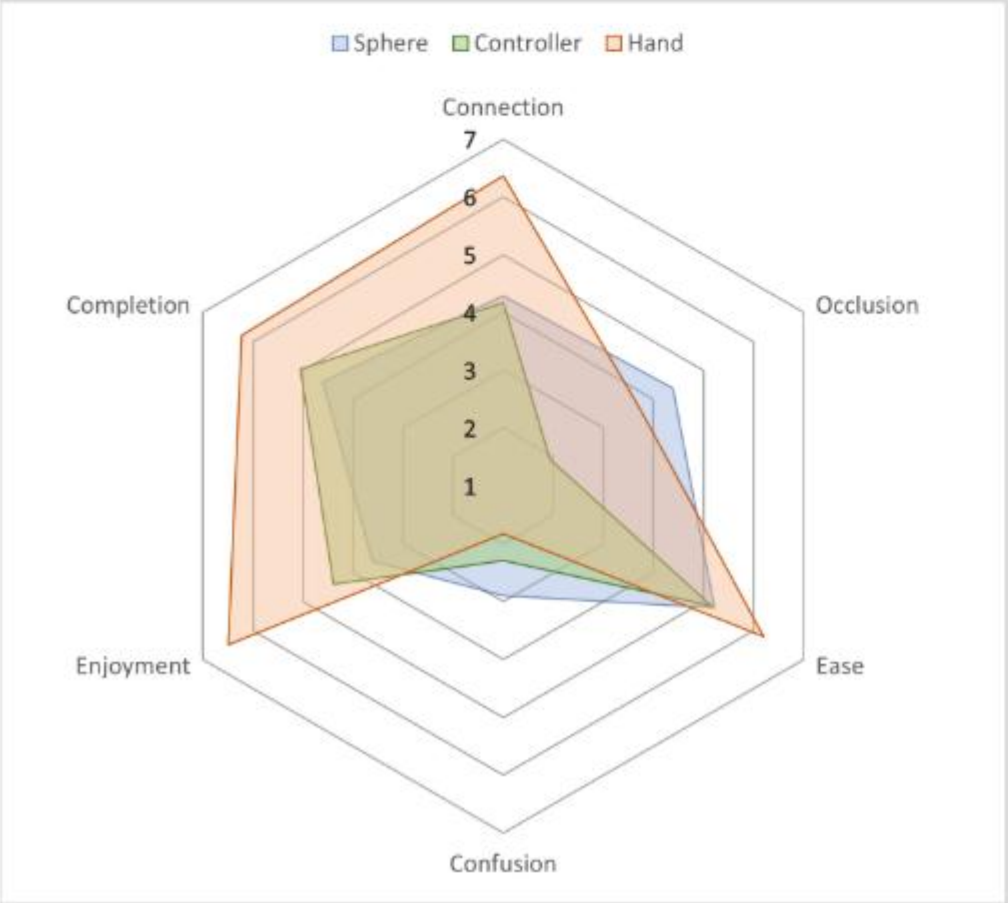
- Do we need a hand? (Balcomb *et al.*, 2023)
- Method
  - 12 interactions



Balcomb et al., 2023

Embodiment in VR

- Objective : to compare hand representation in VR game
- Résultats
  - No diff in completion time
  - More enjoyale with realistic hand

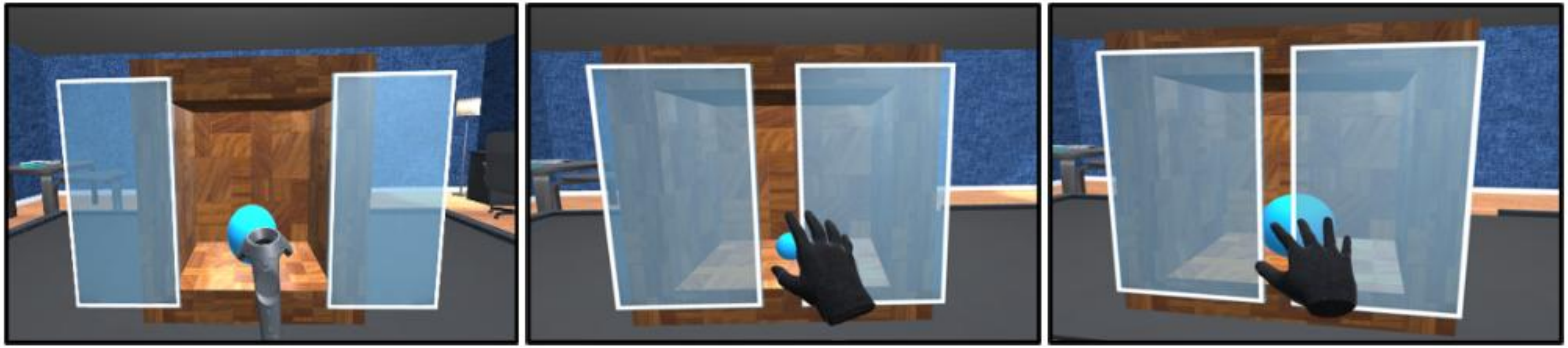


Balcomb et al., 2023

Interactions

- Hand representation and performance
- Method
  - 3 hands visualisation
  - Grasp object and avoid collision

Noitom’s Hi5 VR glove

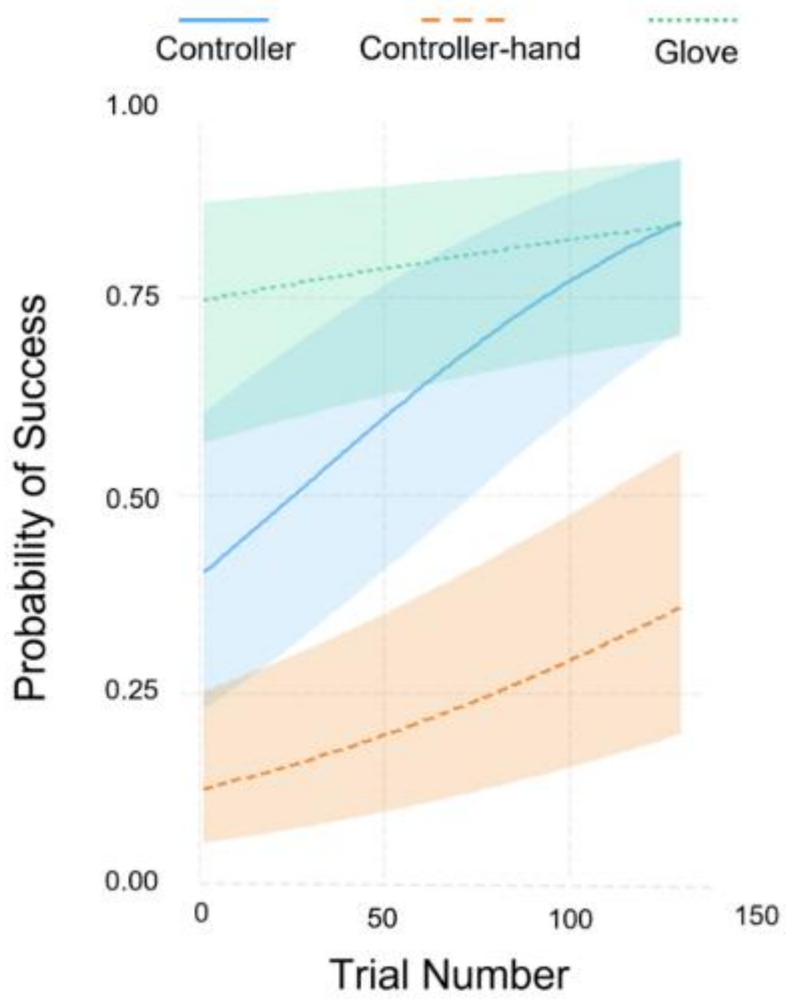


(a) Controller (b) Controller-hand (c) Glove

Venkatakrishnan et al., 2023

Interactions

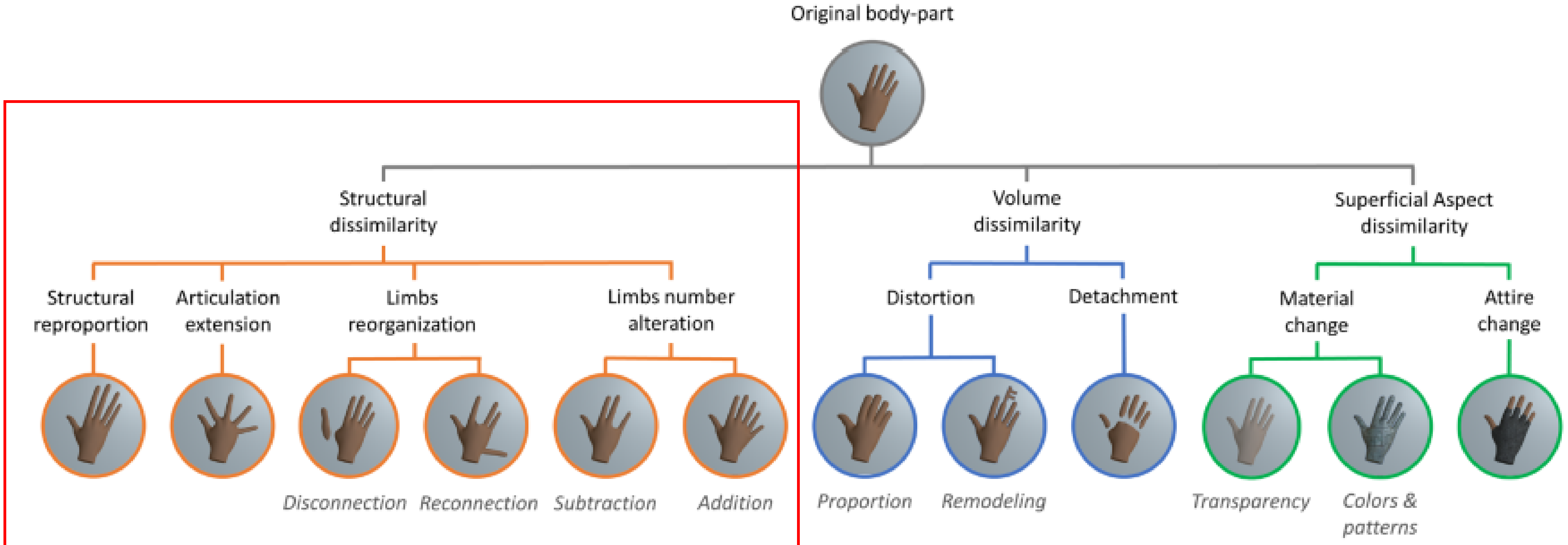
- Method
  - 3 hands visualisation
  - Grasp object and avoid collision
- Results
  - Worse with controller-hand



Venkatakrishnan et al., 2023

Taxonomy of the avatar

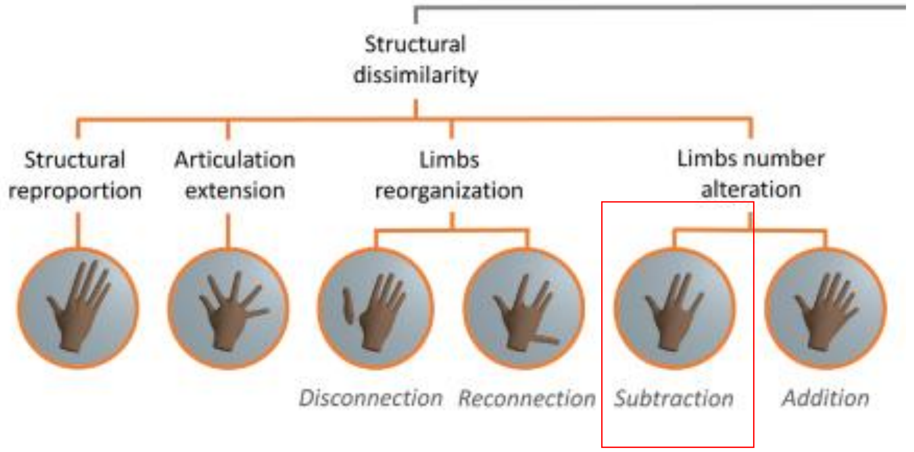
Cheymol et al., 2023



How much information of the avatar should we have?

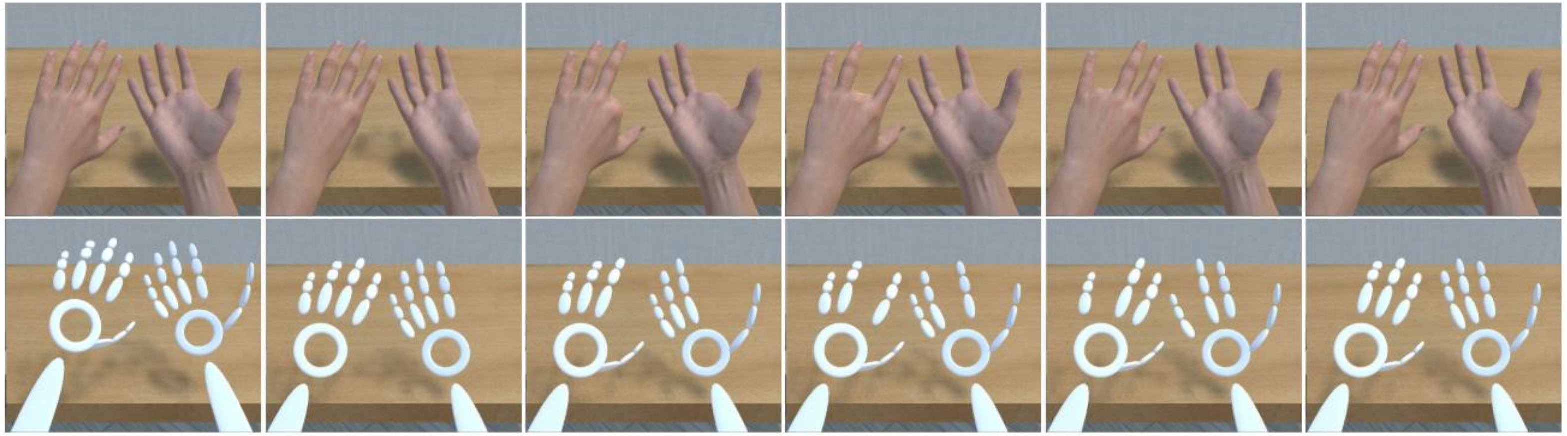
Do we need a realistic hand?

Virtual representation of the u



Cheymol et al., 2023

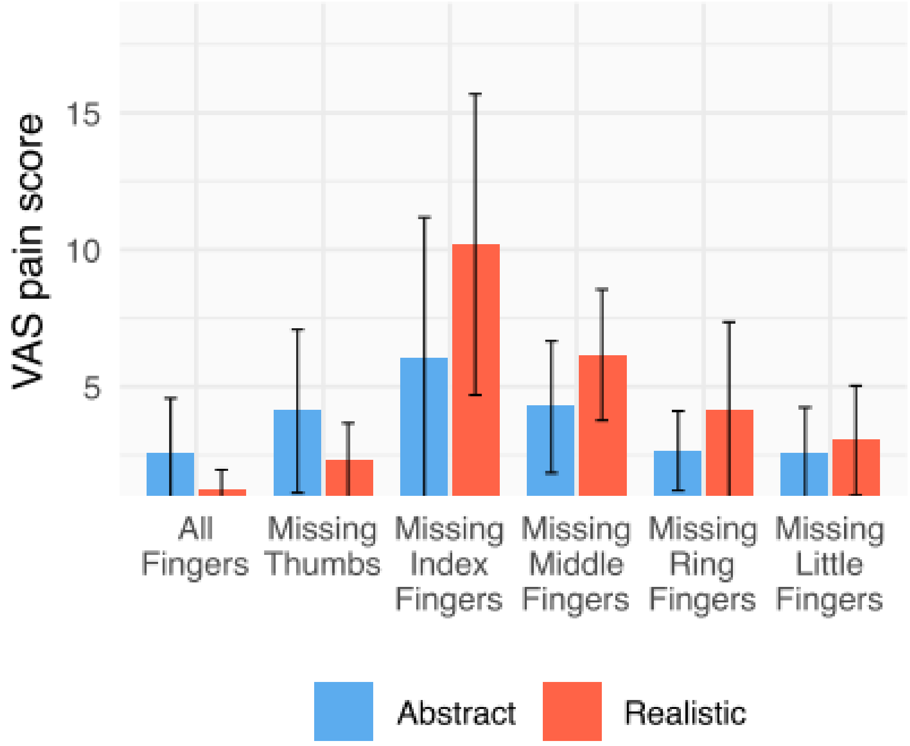
- Objective : investigate the effect of missing fingers
- Method
  - Real world item manipulation



Kocur et al., 2020

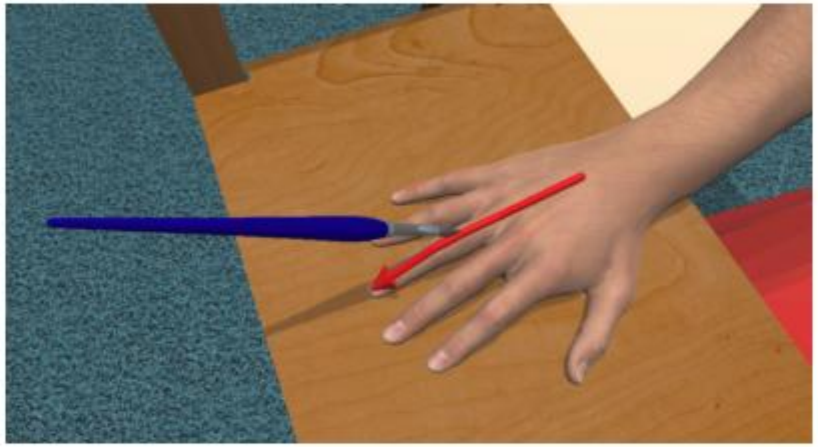
Virtual representation of the user body

- Objective : investigate the effect of missing fingers
- Result
  - phantom pain with missing fingers

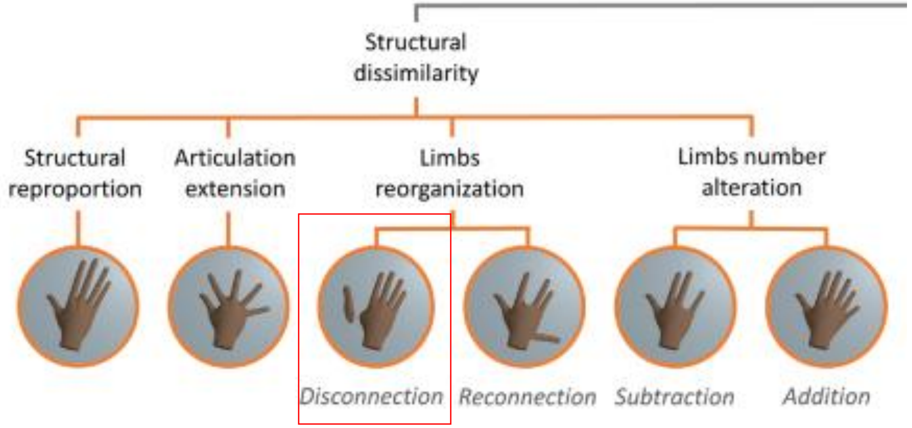


Kocur et al., 2020

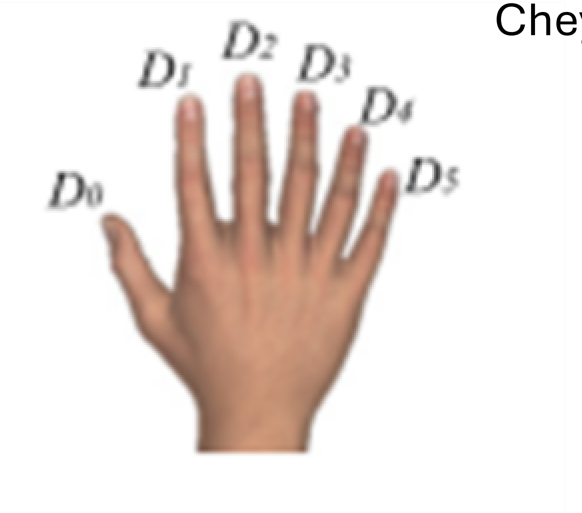
Exemple



Hoyet et al., 2016



Cheymol et al., 2023



Résultats :

- Les participants considèrent le 6eme doigt comme faisant partie de leur main
- Ils ne sont pas gêné d'avoir 6 doigts

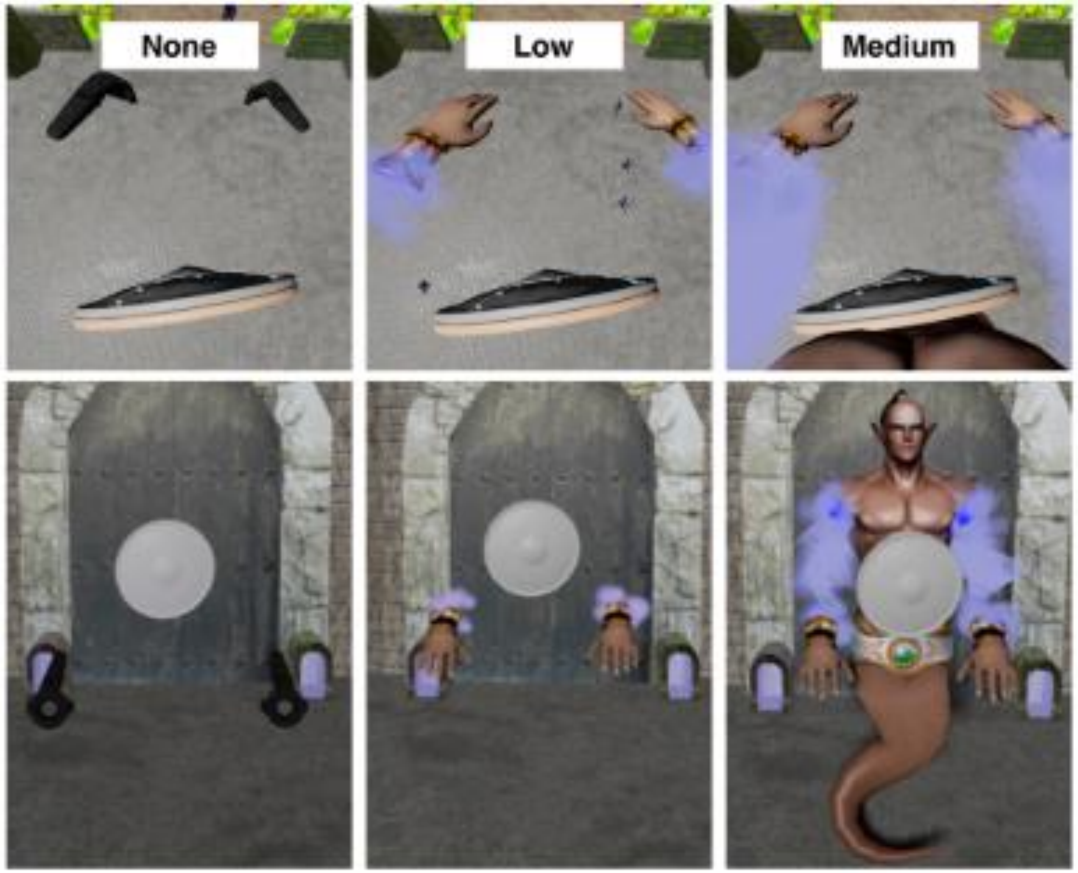
TABLE 1 | Animations of the virtual digits were driven in real-time using the corresponding mapping.

Virtual digit	D_0	D_1	D_2	D_3	D_4	D_5
Driven by	Thumb	Index	Middle	Ring	$k \times D_3 + (1 - k) \times D_5$	Pinky

We used a value of $k = 0.6$ in our experiment, which provided the most natural looking animations of the six-digit hand as a whole.

Virtual representation of the user body

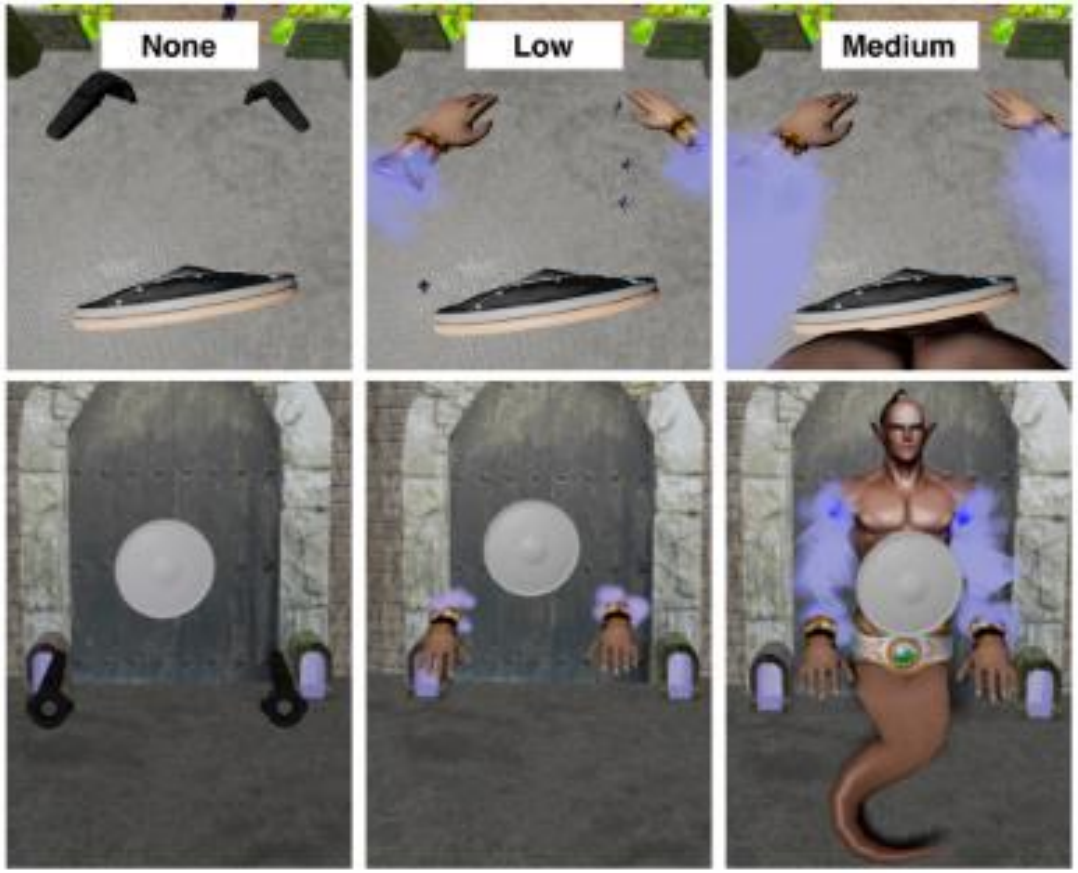
- Objective: investigate the effect of varying the number of visible body parts of an avatar on player experience and performance.
- Task: VR game



Lugrin et al., 2018

Virtual representation of the user body

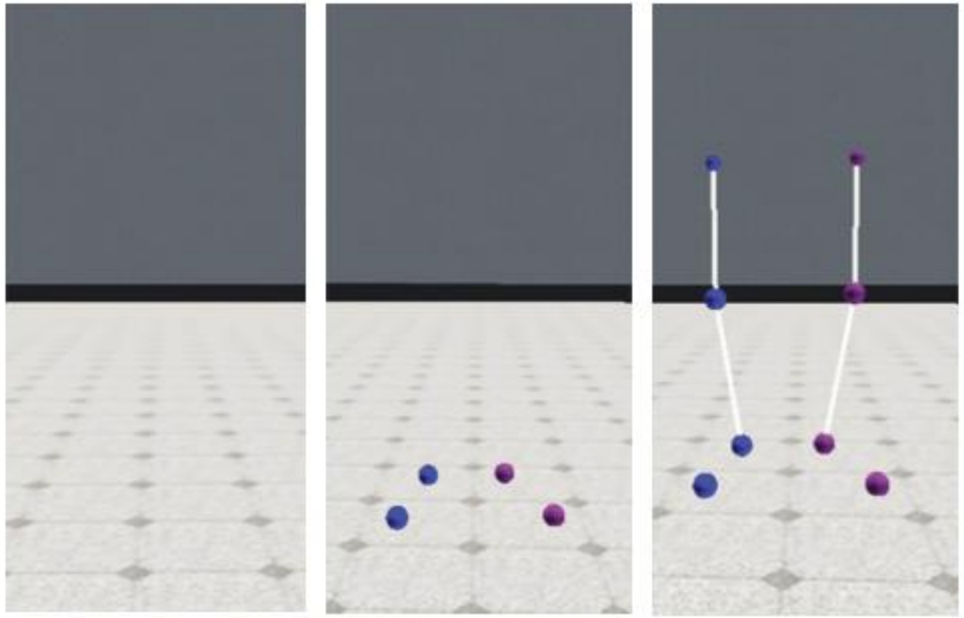
- Objective: investigate the effect of varying the number of visible body parts of an avatar on player experience and performance.
- Task: VR game
- Result: no advantage of visual representation

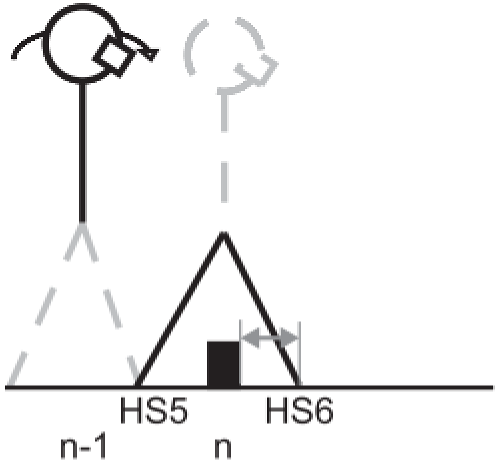


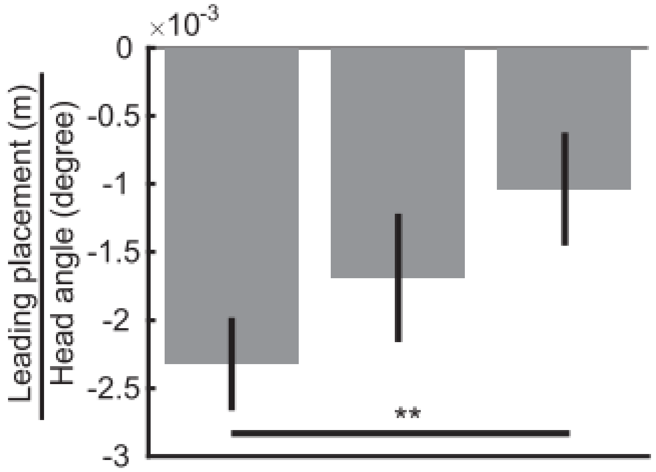
Lugrin et al., 2018

Virtual representation of the user body

- Task: avoid collision with items
- Result: better feet placements with more visual informations







Kim et al., 2018

Virtual representation of the user body

- Objective : to investigate the effect of gender on the perception of six different hands

- Method :
    - Keyboard typing
    - Drawing
    - Manipulation cube

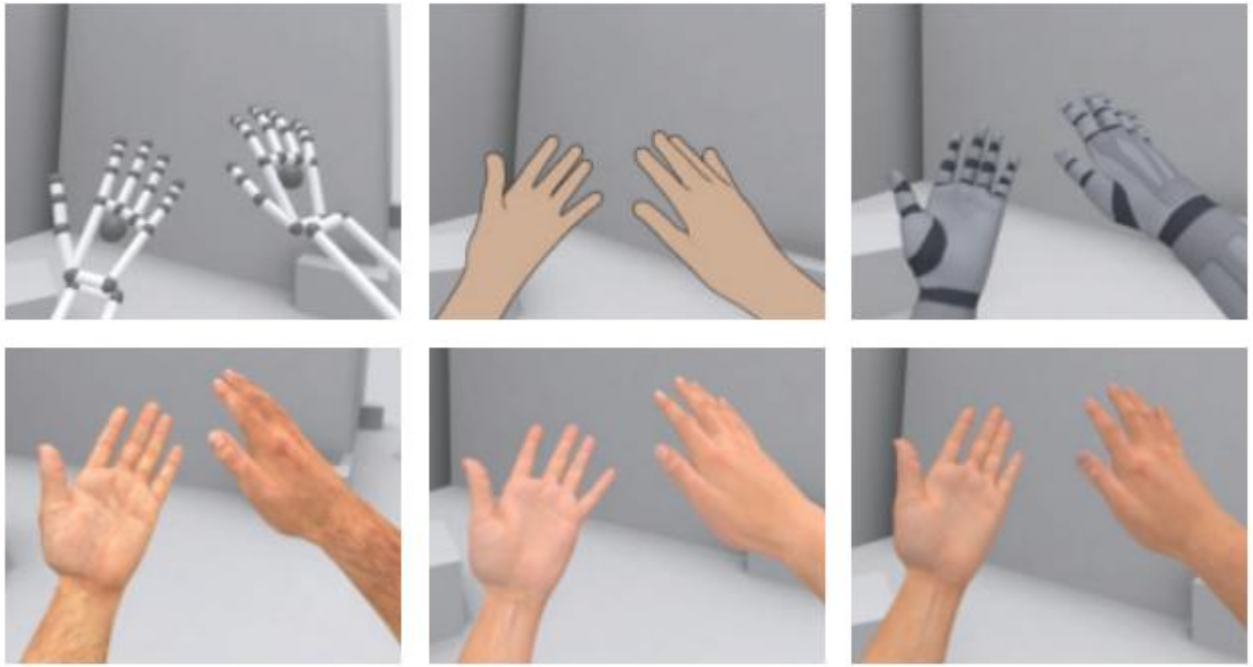


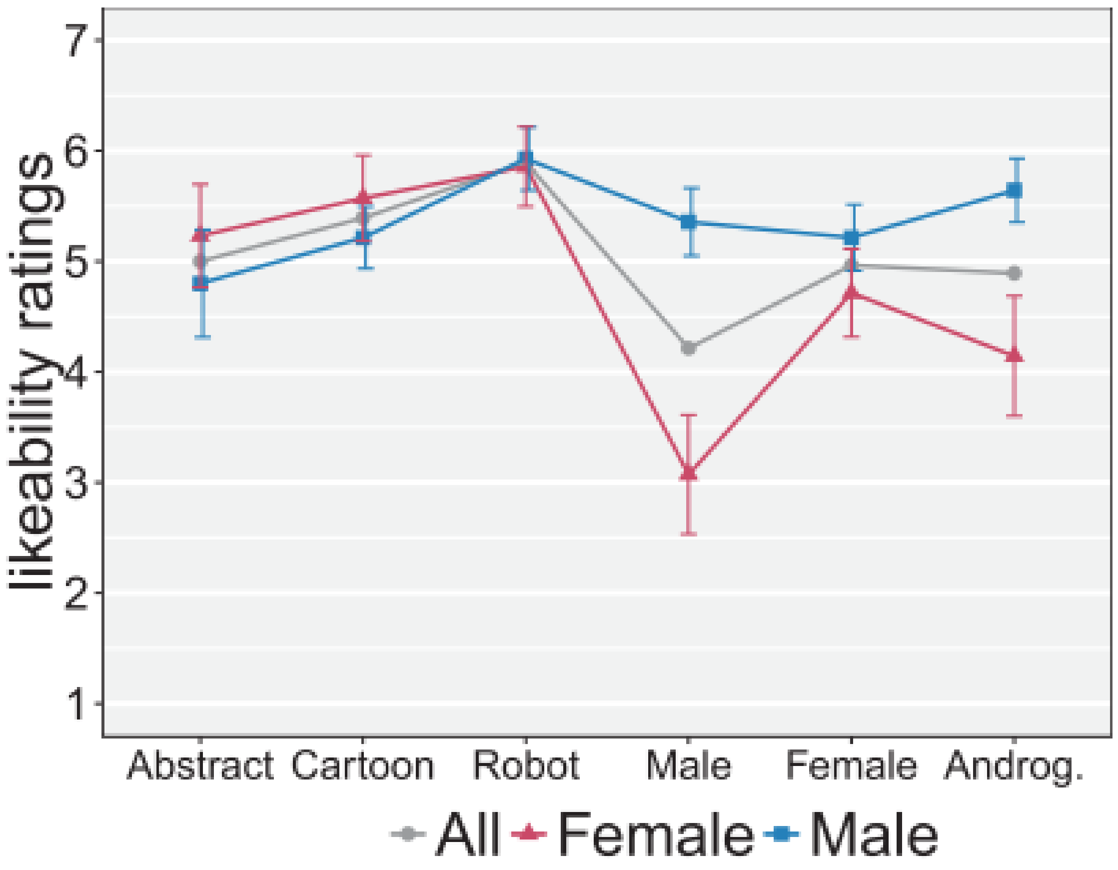
Figure 2. 1st row: screenshots of non-human hands: abstract, cartoon, robot; 2nd row: human hands: male, female, androgynous

Schwind et al., 2017

Virtual representation of the user body

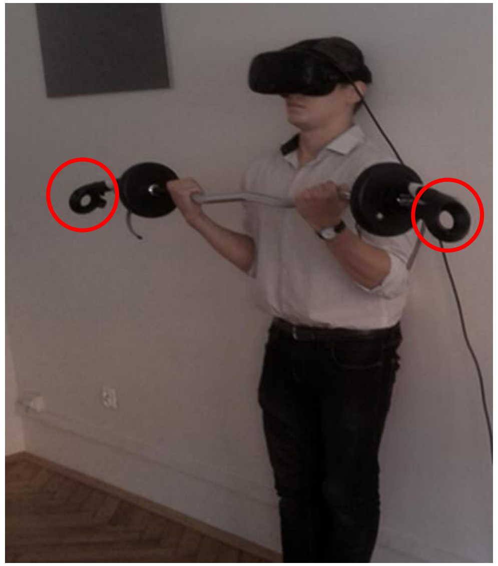
- Objective : to investigate the effect of gender on the perception of six different hands

- Result :
    - Wowen dislike male hand



Schwind et al., 2017

Proteus Effect Example



- Objective: Is the avatar changing the strength exercice?

- Method
  - Borg scale
  - Barbell weight perception
  - Biceps curl repetition

- Procedure
  - Repeated-measure
  - VR and no VR

EXERTION: how do you feel?

0	No effort at all (REST)
1	Very Easy
2	Somewhat Easy
3	Moderate
4	Somewhat Hard
5	Hard
6	
7	Very Hard
8	
9	
10	Very Very Hard

Czub et al 2021

Proteus Effect Examples

Table 1. *Repeated Measure Analysis Summary*.

	VR	Control	*Z*
Number of repetitions	59.48 (35.12)	56.03 (32.62)	-2.05*
Borg's scale	13.83 (3.06)	14.14 (1.32)	-1.56
Perceived mass of the curl bar	10.56 (3.98)	11.586 (5.36)	1.24
Blood glucose	101.8 (11.8)	106.7 (12.1)	1.17

Note. *$p < .05$. VR and Control columns contain mean values and standard deviations (*SD* in parentheses).

Czub et al 2021

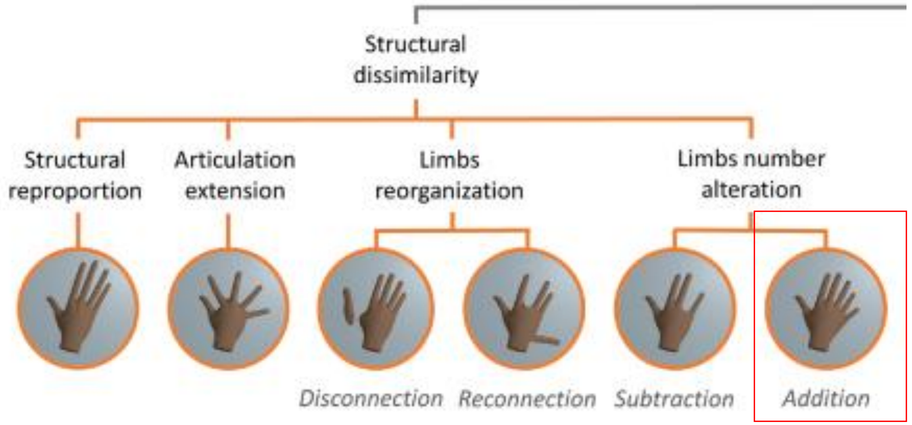
- Result
  - More biceps curl in VR
  - No difference with the Borg's scale
  - No difference in the perceived mass of the barbell

Extented avatars

- Can we embodied non-humanoïd avatar?
- *But what if, instead ofsimply,extending our morphology, a person could become something else- a bat perhaps or an animal so far removed from the human that it does not even have the same kind of skeleton an invertebrate, like a lobster? (Riva et al., 2014)*

Extend avatar

- Can we embodied extended avatar? (Steptoe et al., 2013)
- Task: catching targets.
  - Tail is moving randomly
  - Tail is controlled by hip movments



Cheymol et al., 2023

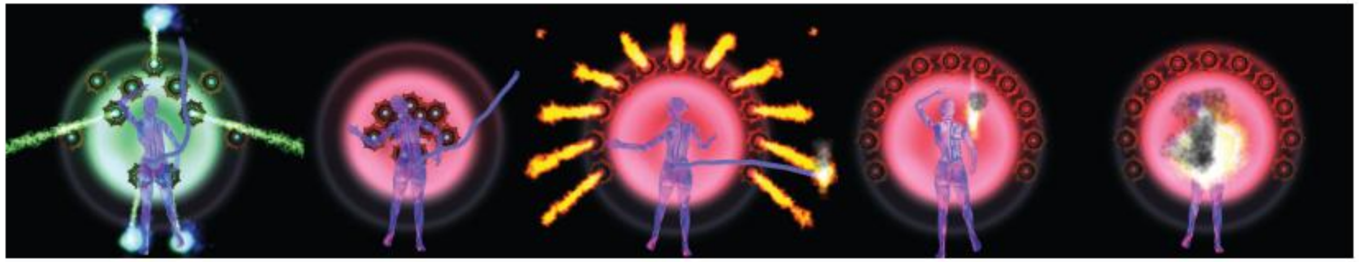
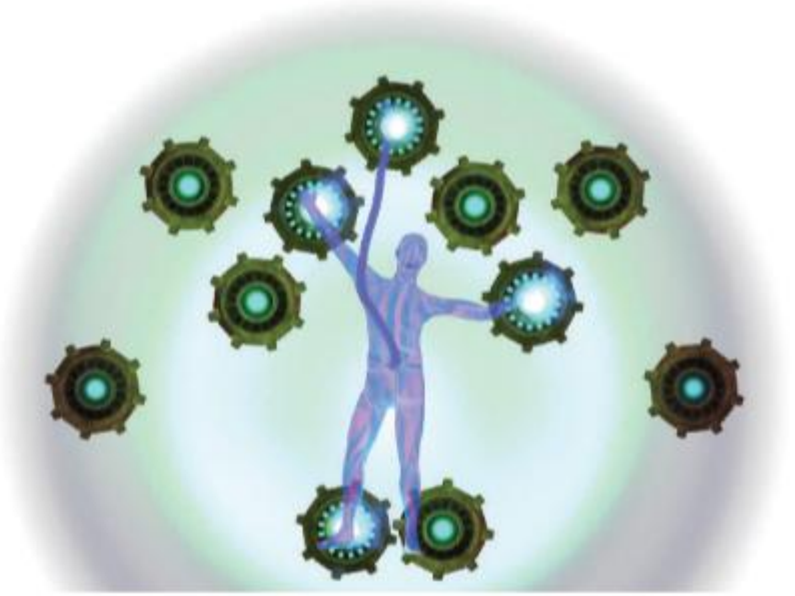


Fig. 4. Threat stage of the experiment. Left to right: the final moments of the game; the emitters fold to the center, an alarm sounds and the lighting changes to bright red; the emitters burst out to the perimeter shooting flames and the tail sets on fire; the tail burns down; the body sets on fire.



Steptoe et al., 2013

Extend avatar

- Can we embodied extended avatar? (Mie et al., 2016)
- Task: Avoid collision and controllings the wings

Figure 1: From top left: HMD, back-pocket-wrap, and rigid-body markers; breadboard with vibrators; participant geared up; placement of the rigid-body markers

Figure 2: The physical setup and virtual scene

Mie et al., 2016

Extend Avatar

- Objective: Investigate how to manipulate item embodied in a non-humanoid avatar

- Method:
    - Wolf – roll apple with fore foot
    - Snake – controller is mapped with the tail

(a) humanoid (b) wolf (c) Snake

Figure 1: Virtual avatars in different groups.

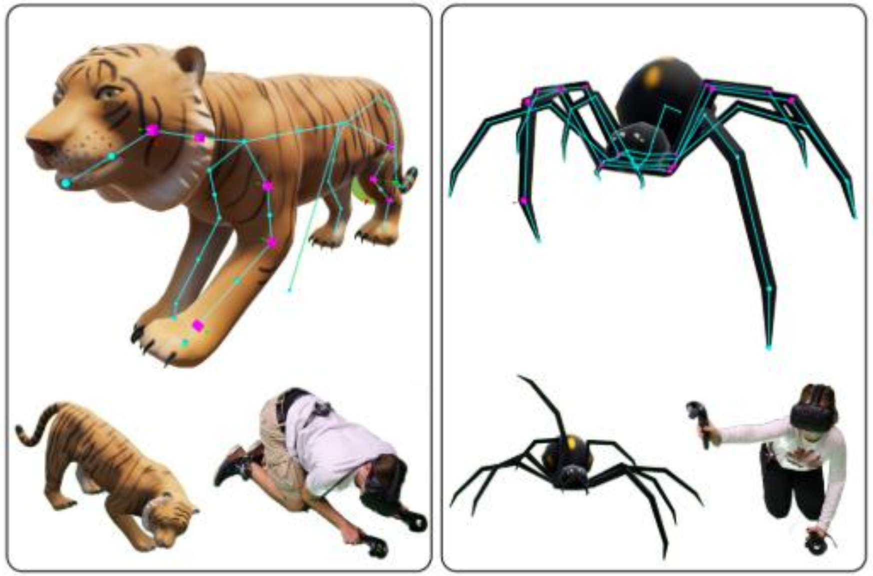
(a) humanoid (b) Wolf (c) Snake

Lee et al., 2018

Extend avatars

- Objective: Investigate to embodied a non-humanoid avatar

- Method :
    - Spider,
    - Bat,
    - Tiger,



Krekkov et al 2019

Krekhov et al., 2018, 2019

Extend avatars

- Objective: Investigate to embodied a non-humanoid avatar
  - Users can felt embodied into an animal

rather exhaustive, Disliked tiger paws that felt shorter than their actual limbs

“I could feel more like a giant bat if I could fly bymoving my arms andmaybe lean forward to accelerate”

Krekhov et al., 2018

Extend avatars

- Objective: Investigate to embodied a non-humanoid avatar

- Be a rhino, a bird or a scorpion and escape your cage

Krekhov et al., 2019

Extend avatars

- Objective: Investigate to embodied a non-humanoid avatar
- Rhino Room: manipulate a horn

Figure 3. *Rhino Room.* Players had to mimic the rhino posture (left) and escape from a burning zoo. The blue marked water tap (middle) had to be removed from the wall (right) to extinguish the fire. To open the yellow marked door, players had to use the horn and remove a lock bar (cf. Figure 1).

Krekhov et al., 2019

Extend avatars

- Objective: Investigate to embodied a non-humanoid avatar
- Scorpion Room: control tail and claws

Figure 4. *Scorpion Room.* Players remained in an upright posture (left) and used the controllers to open and close the claws and initiate a tail strike. To escape from the labyrinth, players had to cut away several branches (right). The exit-blocking emperor scorpion (middle) had to be pelted with poisoned fruits. The avatar tail was used to pick up these fruits. Aiming during the throwing process was done via a proper hip orientation.

Krekhov et al., 2019

Extend avatars

- Objective: Investigate to embodied a non-huma
- bird Room: control wings to fly or creating gust

Figure 2. *Bird Cage.* Players embodied a bird that was caught in a cage and had to escape through the top right door (marked yellow). The blue marked rods could be used for rests between the exhausting flights performed by full-body controls (bottom right). Finally, wind gusts had to be created to turn a lamp into a wrecking ball (top right).

Krekhov et al., 2019

Extend avatars

- Objective: Investigate to embodied a non-humanoid avatar

- a within-subjects design
- Familiarization step (2 minutes)

- Result:
  - All animals are well rated
  - Rhino easier to control than scorpion
  - Rhino is more tiring because of the knee posture
  - Correlation between embodiment and game enjoyment

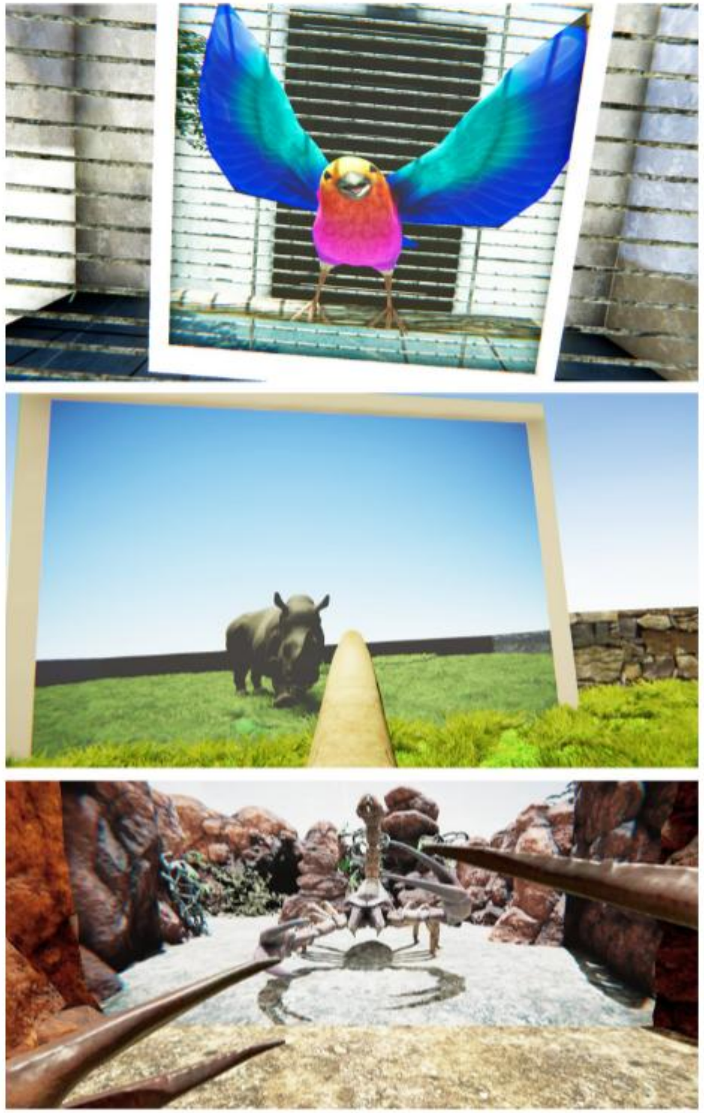


Figure 5. Before each game, players were asked to act in front of a wall-sized mirror for about two minutes to get familiar with their virtual representation and to answer the alpha IVBO questionnaire [49].

Krekhov et al., 2019

Conclusion

- Embodiment is affected by technologie, scenario, environnement
- Embodiment can change the user behaviour (Proteus Effect)
- Embodiment would lead to ethical questions in video games

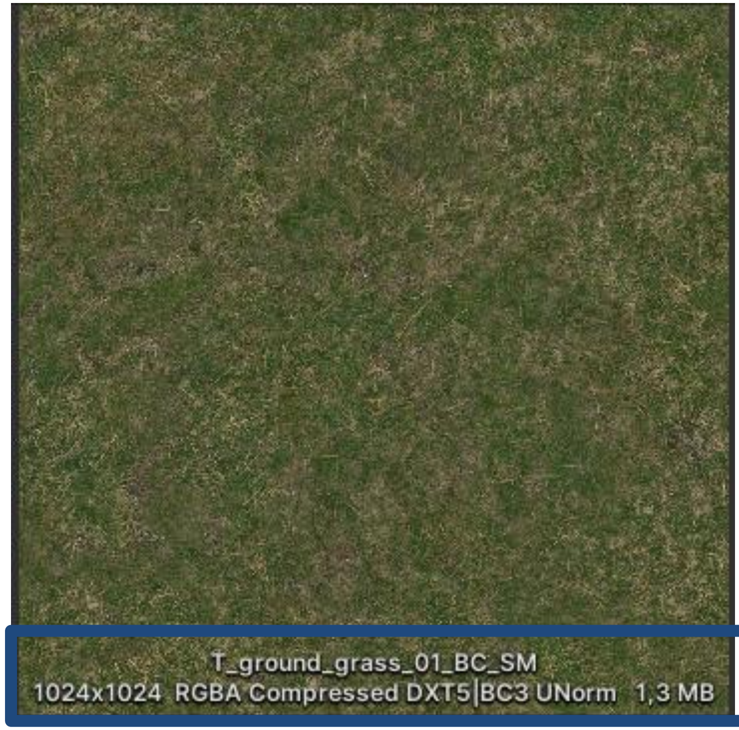
- -> The way how user is represented is a key element in VR games and applications

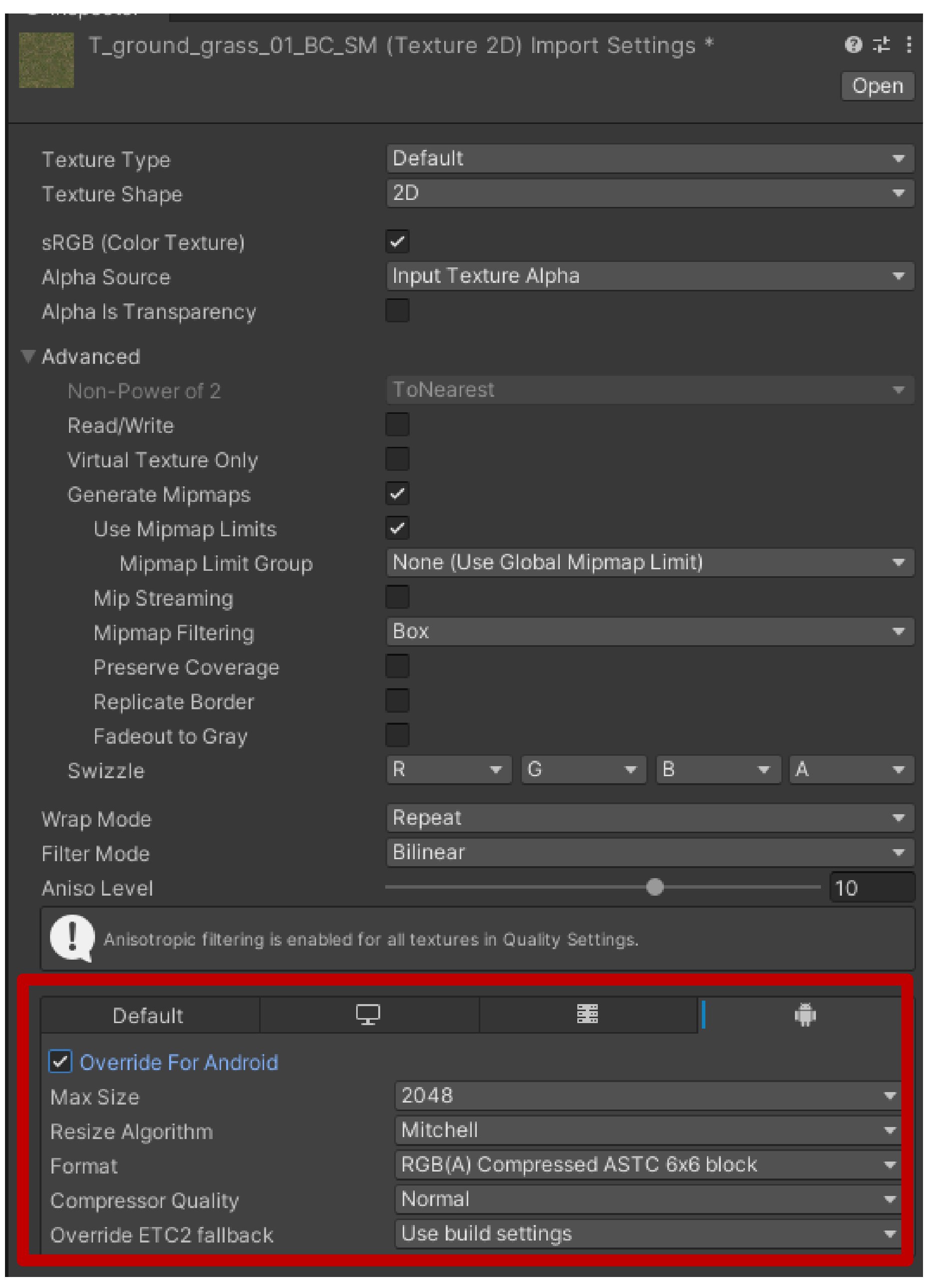
Unity tips - Worflow

- Break large scene
- Better to use prefab than add component
- Better to use AssetBundle
- Preset on Asset importation or AssetPostProcessor
- Texture guidelines
- Meshes guidelines

Unity tips – Worflow Texture

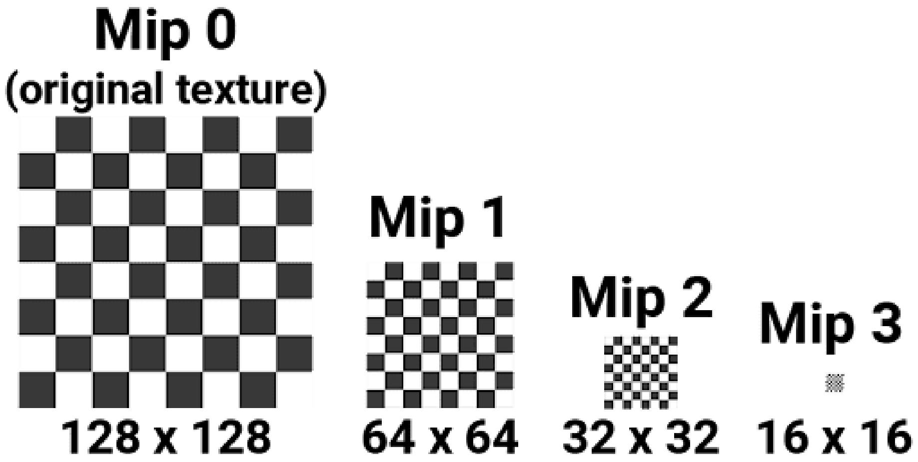
- Compress textures (ASTC for Android)
- Lower the max size

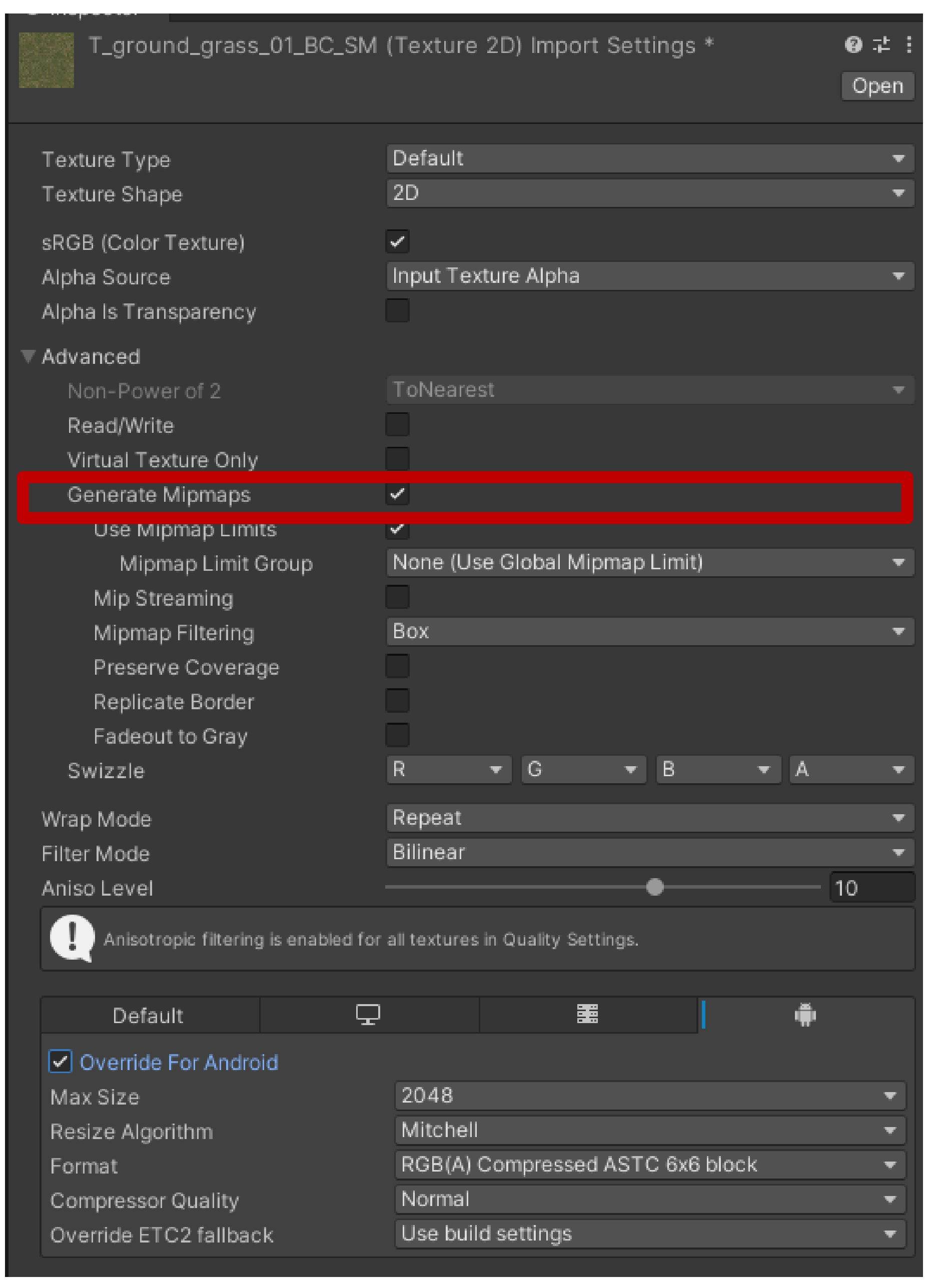




Unity tips – Worflow Texture

- Don't use mipmap for consistent size on screen texture (e.g., sprite, UI)



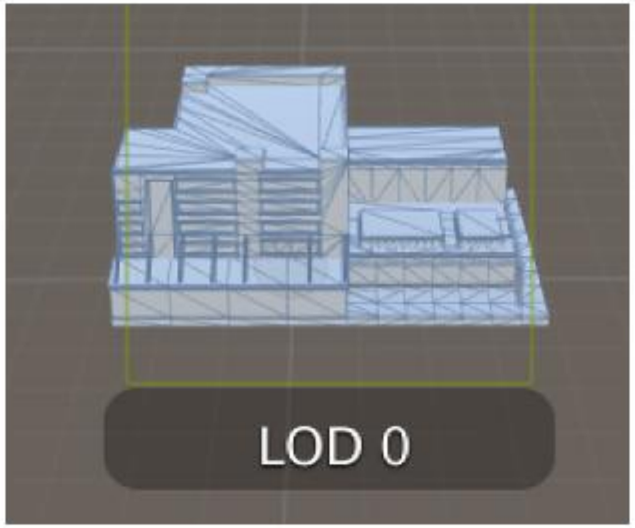


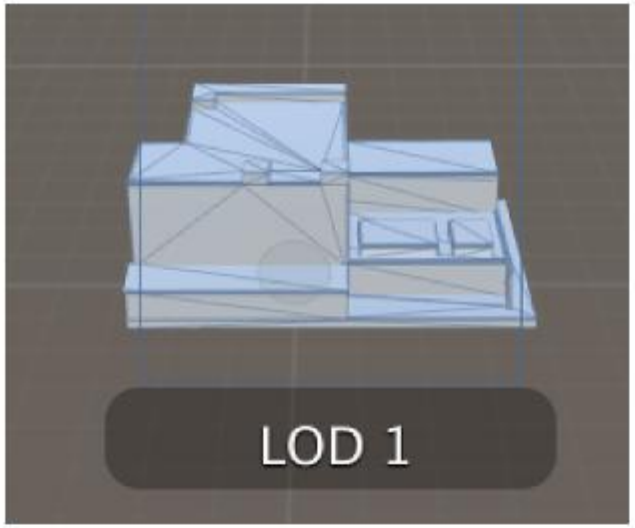
Unity Tips - workflow

- Trim sheet
  - Albedo
  - Normal map
  - Specular map

Unity tips – LOD

- Use [Level of Detail]





Unity tips – Light

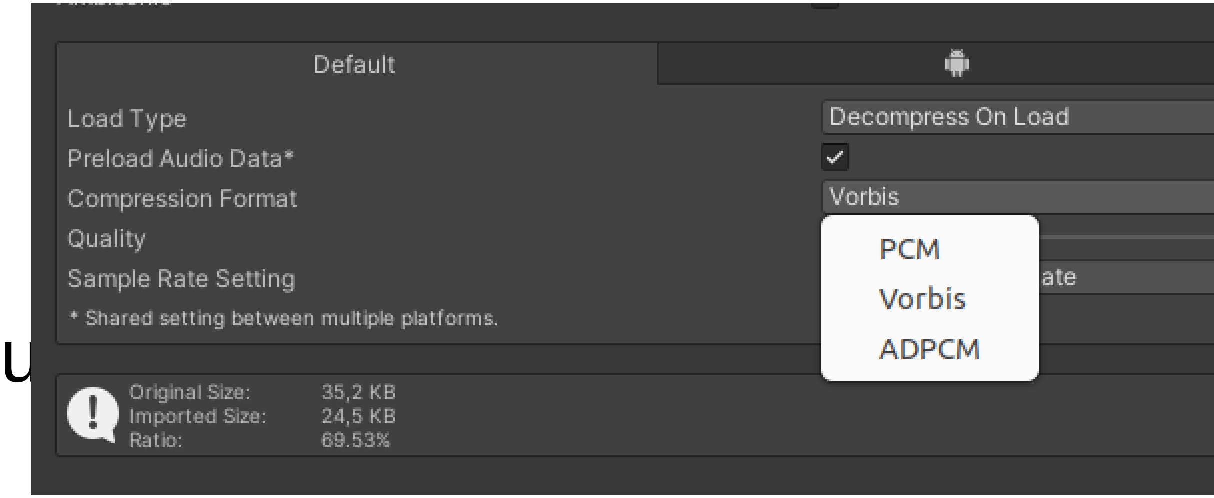
- Bake lightmap
- Minimize Reflection probes
- Use Lightprobes

Unity tips – Occlusion culling

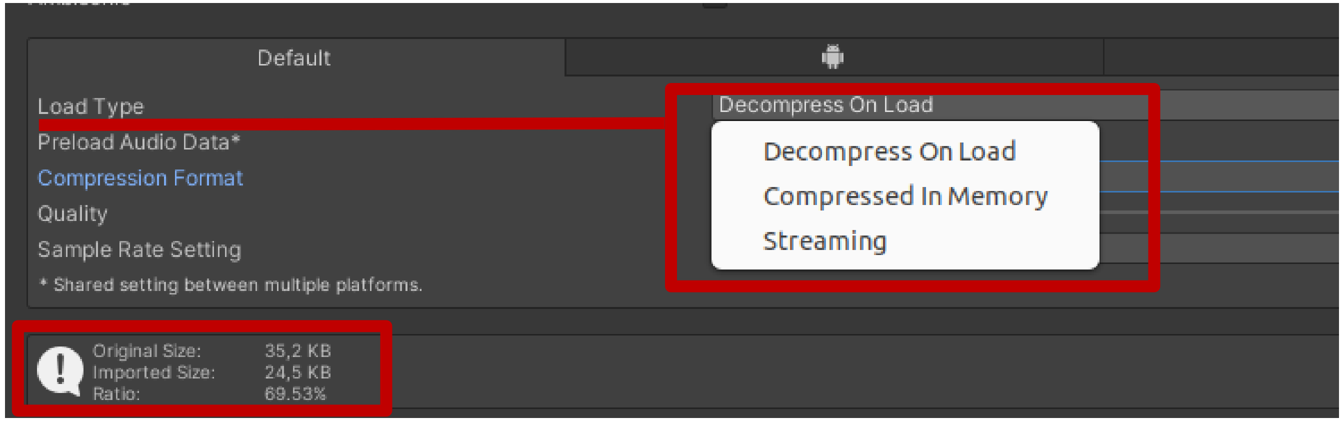
- Do not render GO that are not seen
- Window > Rendering > Occlusion Culling

Unity tips - Audio

- Keep clip mono (single channel)
- Use uncompressed wave file (mp3 are uncompressed and compressed)
- Unload unused AudioSource
- Set compression format
  - Vorbis for most sound
  - MP3 for unlopping sound
  - ADPCM for short and frequently u



Unity tips - Audio



- Choose proper load type according clip size

Clip size	Usage	Load setting
Small (< 200 KB)	Frequen short audio (Sound effect)	Decompress On Load
Medium (>200 KB)	Frequent medium audio (dialog, short music)	If reducing memory usage is the priority, select Compressed In Memory. If CPU usage is a concern, clips should be set to Decompress On Load.
Large (>350-400 KB)	Infrequent large audio (Ambiant sound, music)	Streaming

Conclusion générale

- Add usable interaction
- Reduce inconfort
- Add some immersion so the user can feel present