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Tactile Extended Reality: The Role of Haptics in Immersive Interactive Applications

Maria Torres Vega

April 22, 2026

Who Am I?

2003 2009 — **Master's degree in Telecommunication Engineering**
Polytechnic University Madrid (ETSIT-UPM), Madrid, Spain
Erasmus program at Technical University Hamburg-Harburg (TUHH), Hamburg, Germany

2010 2013 — **R&D Engineer at develogic GmbH** Hamburg, Germany

2013 2017 — **PhD in Electrical Engineering**
Eindhoven University of Technology, Eindhoven, The Netherlands

2017 2022 — **Postdoctoral researcher for immersive media delivery**
IDLab, Ghent University & imec, Belgium

Since 2022 — **Tenure Track Assistant Professor**
KU Leuven, Belgium
- *Human-centric Multimodal Interactive Extended Reality*

Research interests

- Multimodal eXtended Reality: content creation, analysis and perception
- Quality of Experience modelling
- Management and control of future immersive multimedia delivery

Past and present of eXtended Reality

What is Virtual Reality?

Pygmalion's Spectacles, Stanley G. Weinbaum (1935)
(First reference to a device capable of producing an immersive virtual experience)


PYGMALION'S SPECTACLES

By STANLEY G. WEINBAUM

Author of "The Black Flame," "A Martian Odyssey," etc.

The Sensorama, Morton Heilig (1957)
(First actual device to offer an immersive experience)

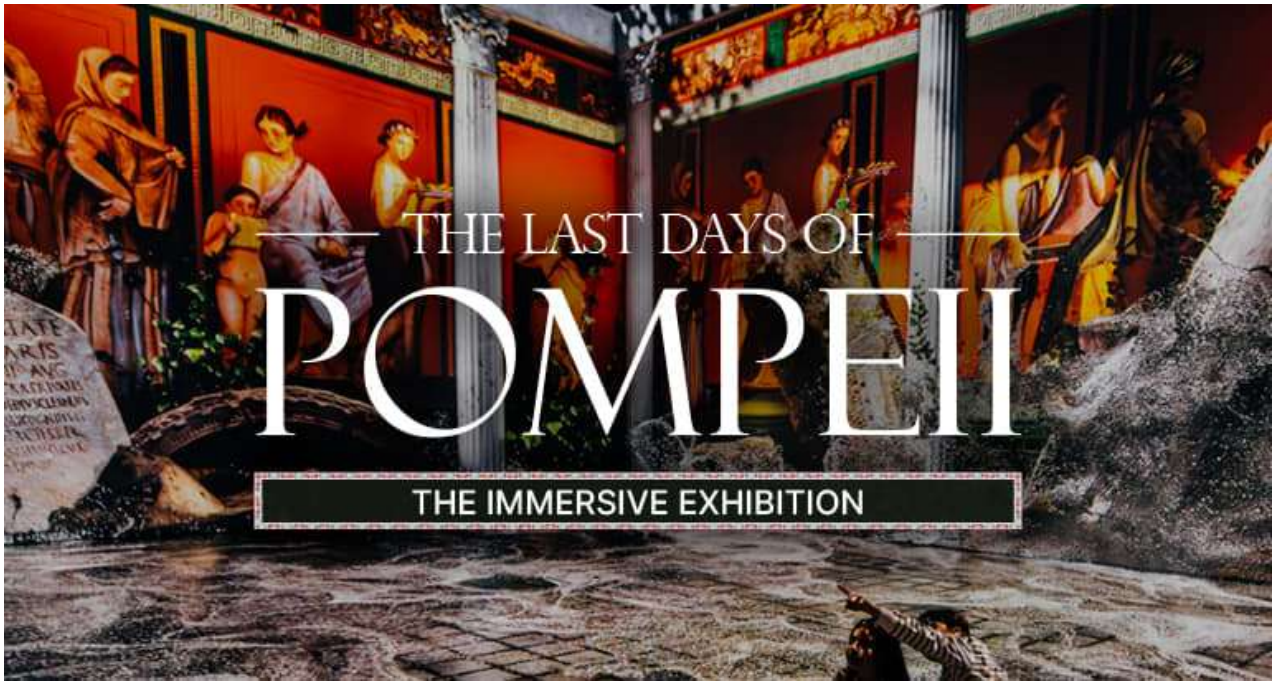
"A Virtual Reality is defined as a real or simulated environment in which a perceiver experiences telepresence"

We have gone a long way from the Sensorama…

XR is the “new” best thing for interactions…

…Right?

Application of VR in Heritage:
The Last Days of Pompeii – The Immersive exhibition



https://www.brussels-expo.com/en/event/les-derniers-jours-de-pompei/

My 4-year-old daughter's feedback on The Last Days of Pompeii in VR

"I do not see my feet, how can I walk?"

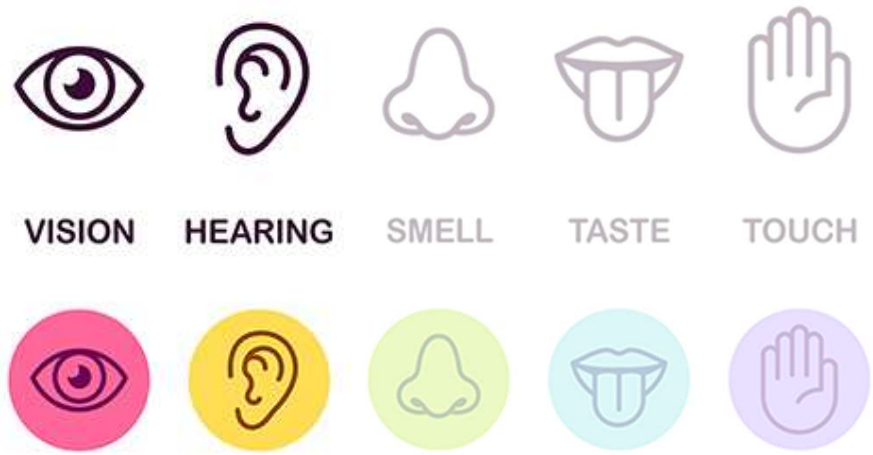
"I am afraid of the floating heads"

"I cannot touch anything"

"I am too afraid… I want to stop"

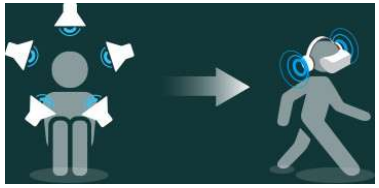
Screenshot taken from https://vimeo.com/914727839

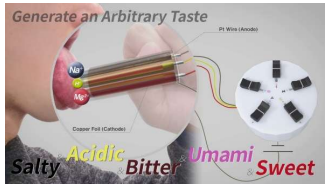
Current XR Experiences are…



…Mostly audiovisual

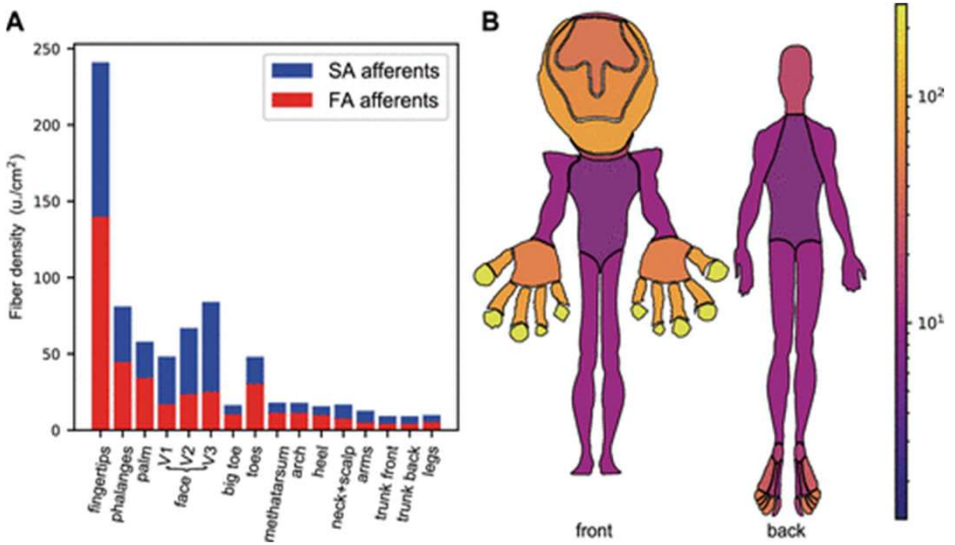
Is it possible to address the 5 senses?





https://www.smithsonianmag.com/smart-news/german-circus-uses-stunning-holograms-instead-live-animal-performers-180972376/
M. K. Soares Lopes et al., Stop to smell the virtual roses: a mixed-methods pilot study on the impact of multisensory virtual reality nature experiences on feelings of relaxation, Front. Virtual Reality, 5, 2024.
https://futurism.com/the-byte/device-simulate-any-flavor - 2020

Haptic interactions - Why gloves?



G. Corniani, et al., Tactile innervation densities across the whole body. J Neurophysiol. 2020 Oct 1;124(4):1229-1240. doi: 10.1152/jn.00313.2020. Epub 2020 Sep 23.

In fact, current Extended Reality includes Haptic options already…

Wireless connectivity

Head-Mounted Display

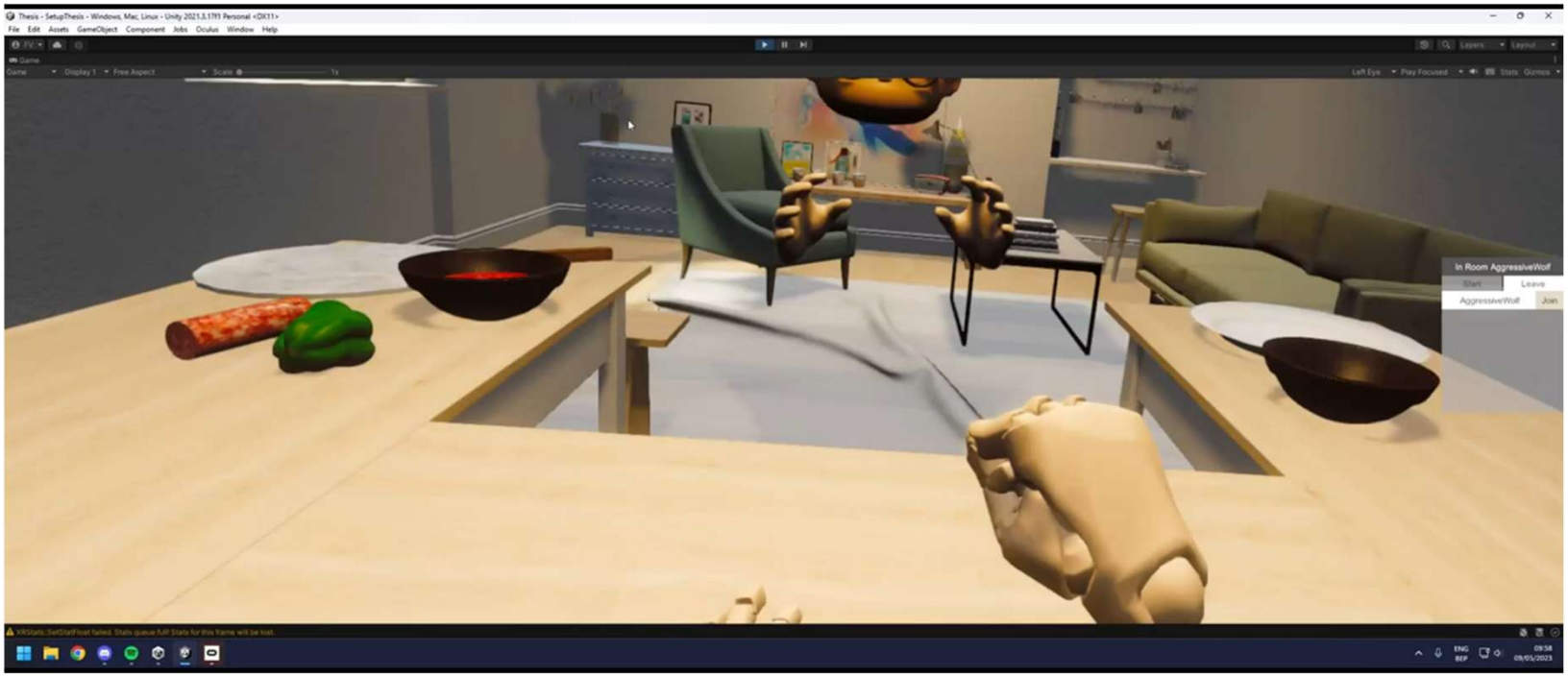
Omnidirectional Sound

In-built localization

Haptic feedback (with a glove or a controller)

Enhancing XR applications by means of Haptics – The Multi-user Pizza Baking Experience

Enhancing XR applications by means of Haptics – The Multi-user Pizza Baking Experience

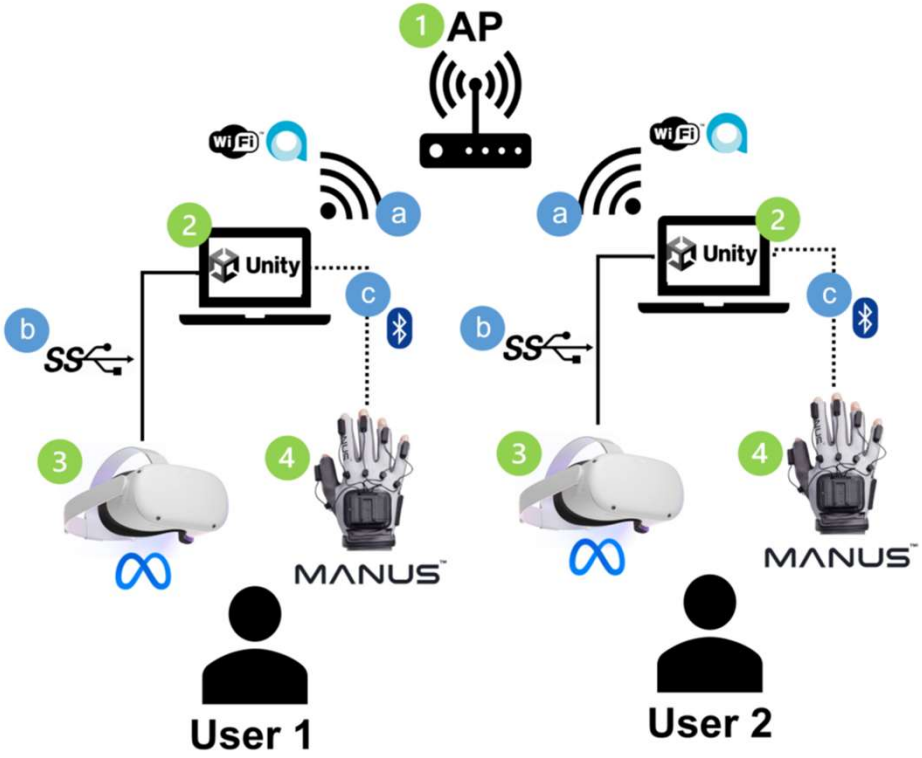


S. Van Damme, et al., 2023. A Haptic-enabled, Distributed and Networked Immersive System for Multi-User Collaborative Virtual Reality. In Proceedings of the 2nd International Workshop on Interactive eXtended Reality (IXR '23). Association for Computing Machinery, New York, NY, USA, 11–19. https://doi.org/10.1145/3607546.3616804

The Multi-user Pizza Baking Experience - Technology

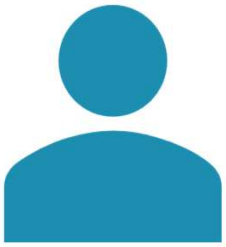
Manus Prime II VR Haptic gloves:

- Per finger haptic feedback:
  - Vibro-tactile.
- Hand tracking

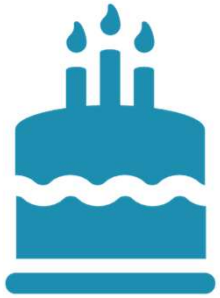


https://www.manus-meta.com/

The Multi-user Pizza Baking Experience - Participants



10 participants



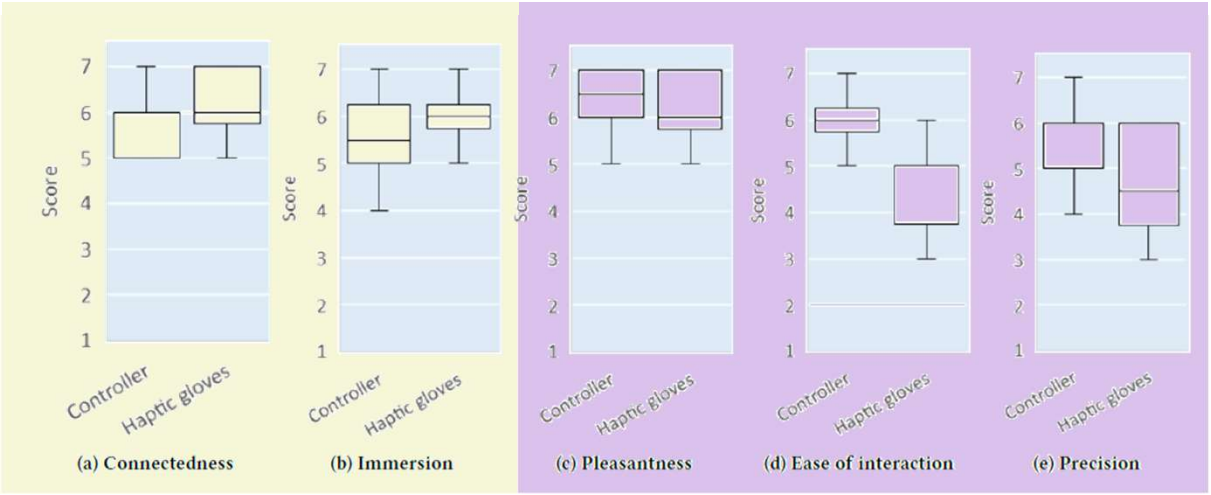
20-60 (26 avg.)

8 male, 2 female

7/10 Proficient with technology

S. Van Damme, et al., 2023. A Haptic-enabled, Distributed and Networked Immersive System for Multi-User Collaborative Virtual Reality. In Proceedings of the 2nd International Workshop on Interactive eXtended Reality (IXR '23). Association for Computing Machinery, New York, NY, USA, 11–19. https://doi.org/10.1145/3607546.3616804

The Multi-user Pizza Baking Experience - Results



- ✓ Haptic gloves are preferred when emphasis is on immersion
- ✓ Controllers are preferred when emphasis is on performance

S. Van Damme, et al., 2023. A Haptic-enabled, Distributed and Networked Immersive System for Multi-User Collaborative Virtual Reality. In Proceedings of the 2nd International Workshop on Interactive eXtended Reality (IXR '23). Association for Computing Machinery, New York, NY, USA, 11–19. https://doi.org/10.1145/3607546.3616804

An On-site Evaluation of Haptic-enabled VR with Industrial Workers

S. Van Damme, A. Stiévenart, P. Verguts, F. De Turck, M. Torres Vega, Usability, Usefulness and Ease of Use in Virtual Reality Training: An On-site Evaluation with Industrial Workers, in Springer Quality and User Experience Journal, 2026.

The company TEO, specialized in practical training for electricians brought us a XR digitation challenge…

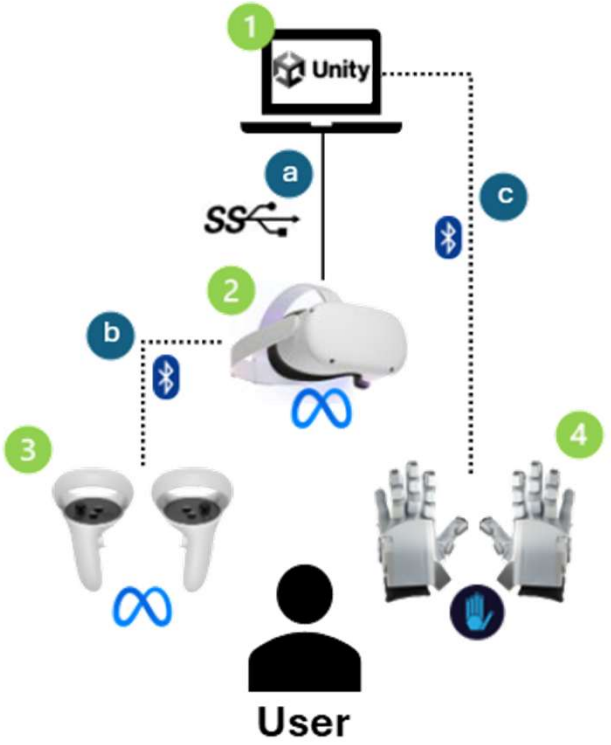
An On-site Evaluation of Haptic-enabled VR with Industrial Workers - Demo

Sam Van Damme, Alex Stiévenart, Piet Verguts, Filip De Turck, and Maria Torres Vega. "Usability, Usefulness and Ease of Use in Virtual Reality Training: An On-site Evaluation with Industrial Workers". Submitted to *Quality and User Experience*, Springer, 2025.

An On-site Evaluation of Haptic-enabled VR with Industrial Workers - Technology

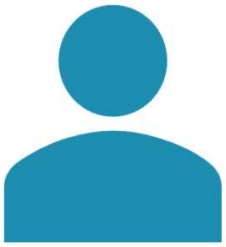
Senseglove Nova:

- Vibro-tactile feedback.
- kinesthetic feedback.
- Force-feedback on each finger with up to 20 N of force.
- Hand tracking

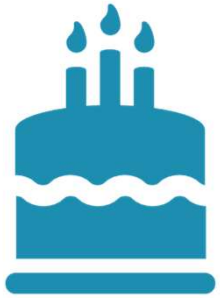


https://www.senseglove.com/product/nova-2/

An On-site Evaluation of Haptic-enabled VR with Industrial Workers – Participants' Demographics



8 participants



20-55 (41 avg.)

7 male, 1 female

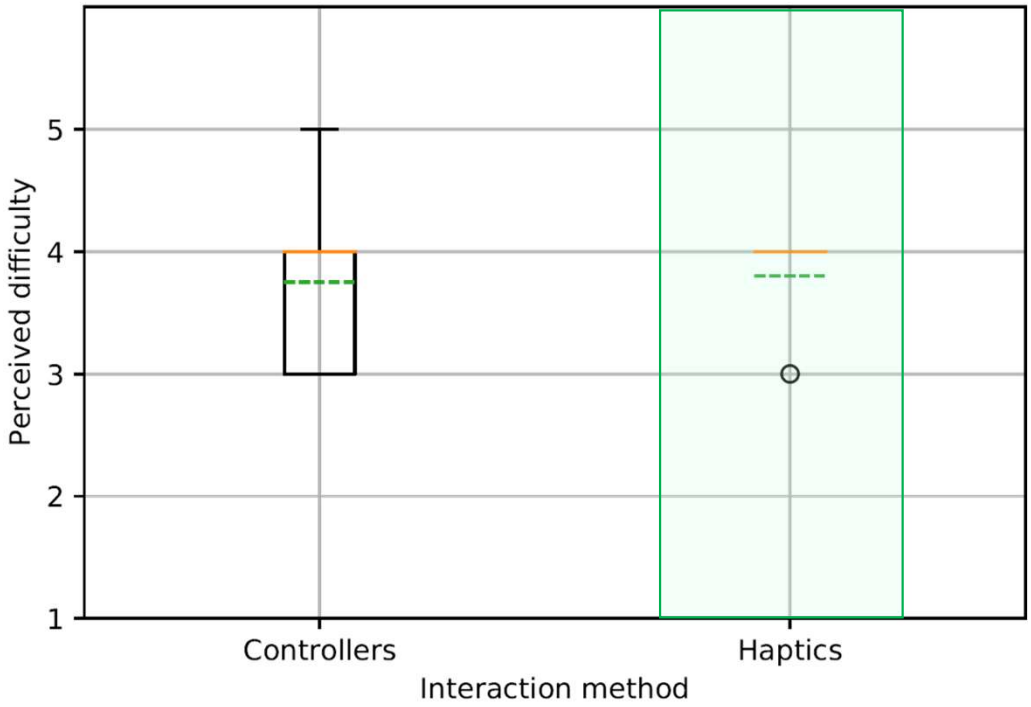
5 x Coca-Cola

3 x Volvo

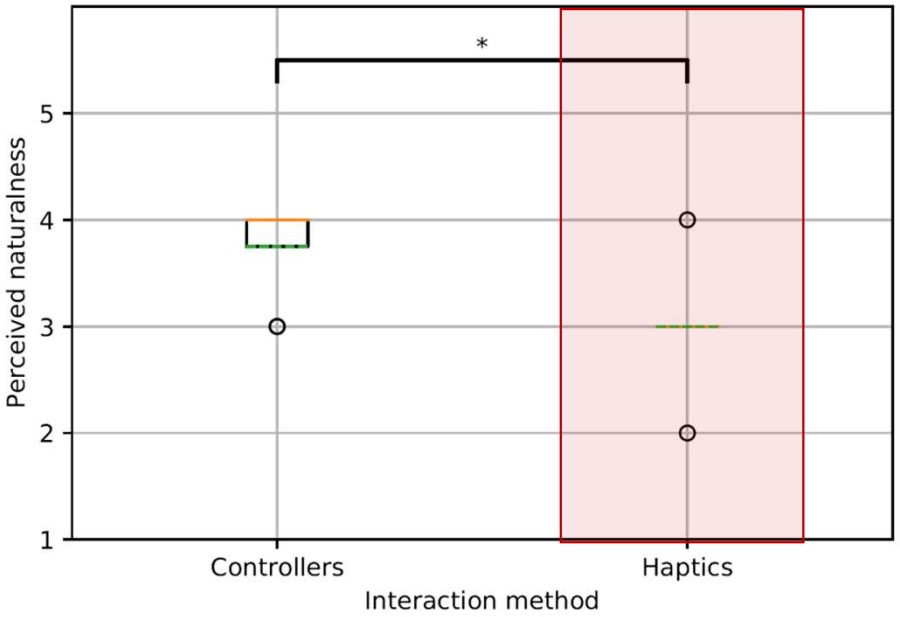
An On-site Evaluation of Haptic-enabled VR with Industrial Workers – Participants' Technological proficiency

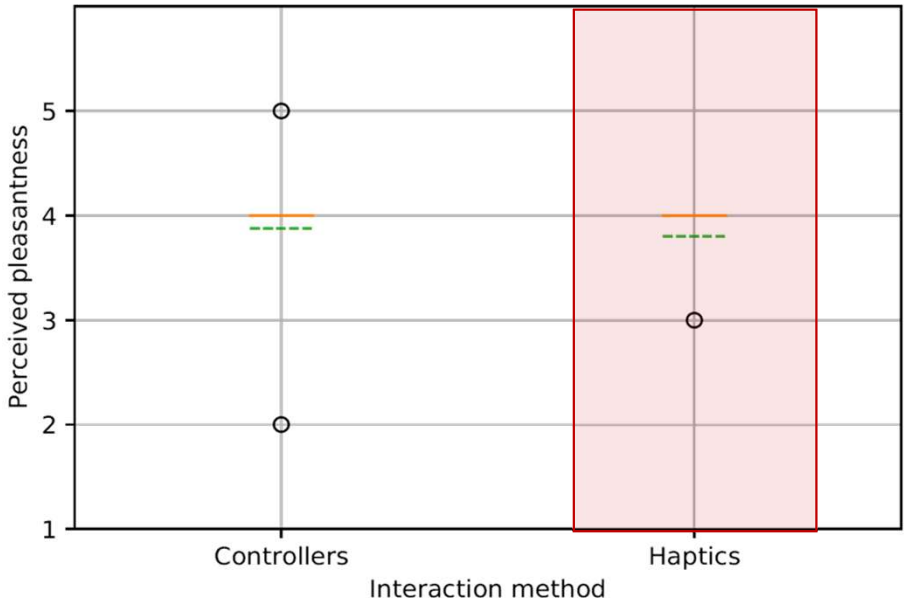
12,5 %	62,5%	20%
High proficiency	Medium proficiency	Low proficiency

The Haptic Interaction feels less difficult …



BUT…The interaction felt less natural and pleasant





Why are haptics and tracking not fulfilling the needs of the users of immersive applications? – Answers to interviews

“Interaction is not very intuitive or natural”;

“I did not feel embodied in the experience”;

Can we provide seamless interactions to the user?

“I did not see the added value of the haptics compared to the regular controllers”

Can we enhance the interaction at the hand level?

“The feedback just on the hand was not enough”

Can we go beyond the hand for haptic interaction?

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Seamless interactions to the user – The MultiSenseVR Dataset

J. Sameri, N. Nisar Bhat, F. De Turck, R. Berkvens, J. Famaey, and M. Torres Vega. 2026. MultiSenseVR: An open multimodal dataset for human pose estimation and perception in interactive VR. In Proceedings of the ACM Multimedia Systems Conference 2026 (MMSys '26). https://doi.org/10.1145/3793853.3799815

Current XR systems rely on tracking on inside-out visual inertial tracking…

Head-Mounted Display

In-built localization

- ✓ accurate localization
- ✓ Partial representation of the user's body
- ✓ No possibility to map expressive gestures.
- ✓ No possibility for fully body tracking

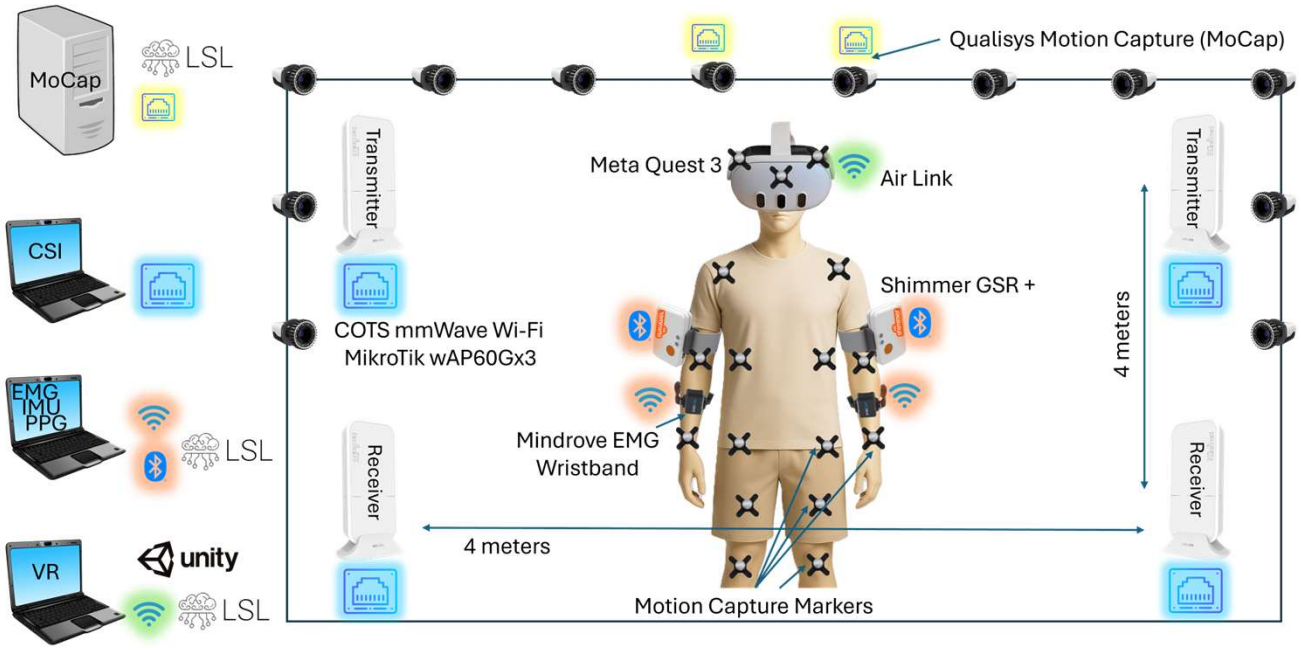
BUT we need multimodal full-body tracking…

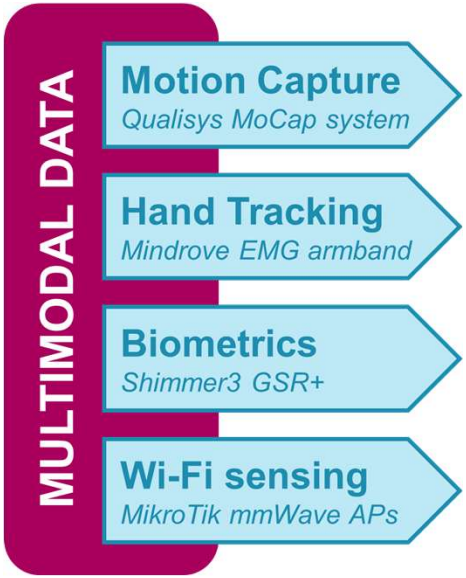
Option 1: Complex Motion Capture (MoCap)

Option 2: Multimodal data sensing

- Full body tracking?
  Wi-Fi Sensing
- Accurate Hand Tracking?
  Electromyography
- Perception?
  Biometry

MultiSenseVR – the testbed and data collected

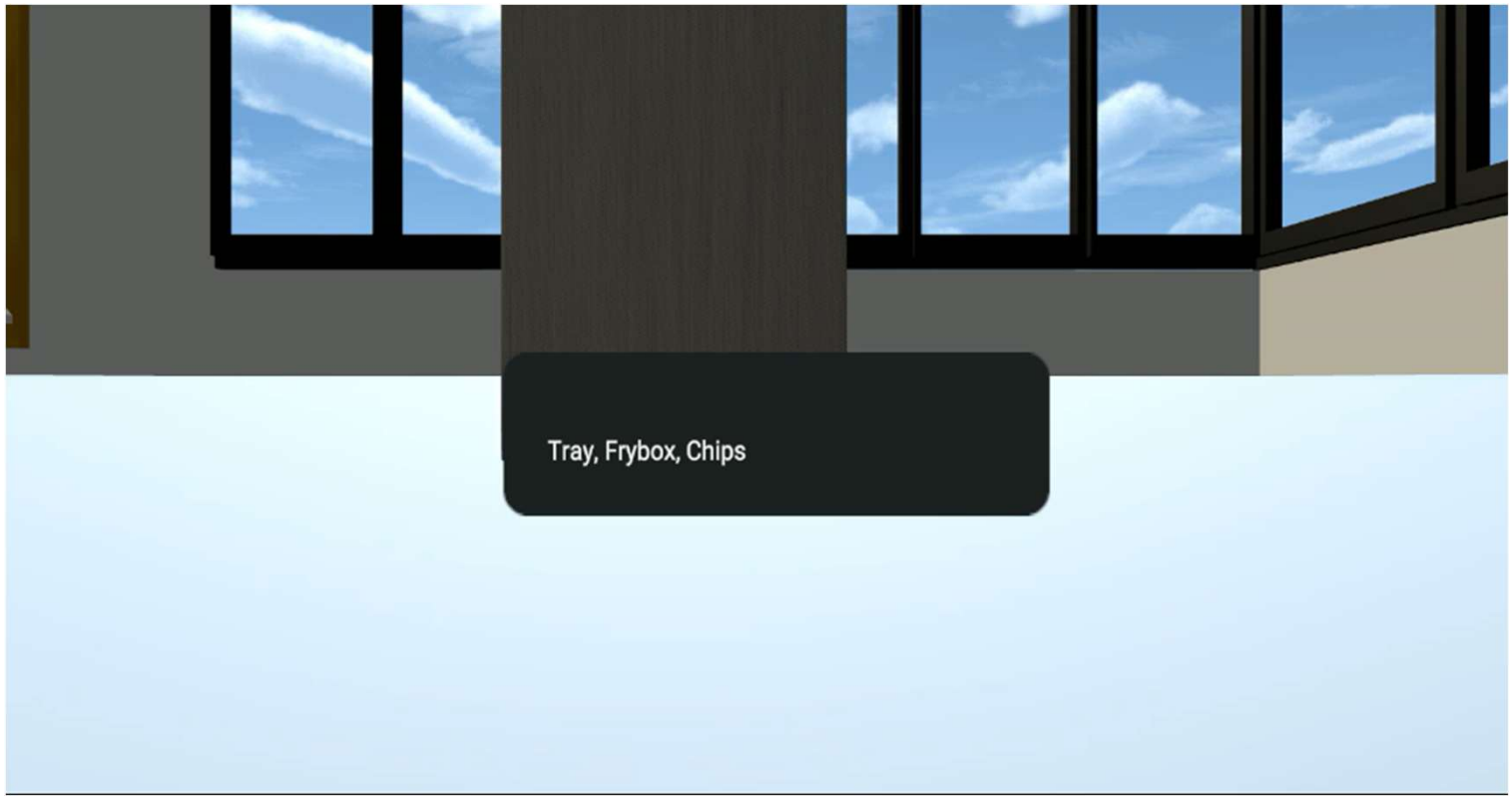




MultiSenseVR – The VR Kitchen Simulator

MultiSenseVR – The VR Kitchen Simulator – Tutorial

MultiSenseVR – The VR Kitchen Simulator - Playthrough



MultiSenseVR – Dataset collection

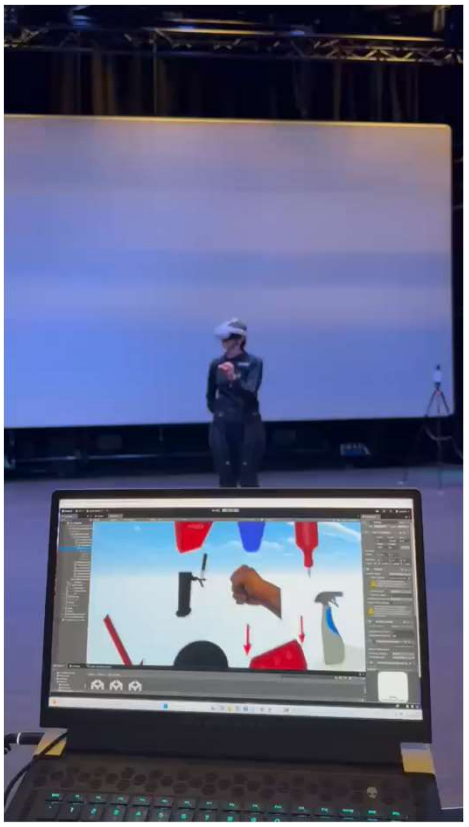
24 participants

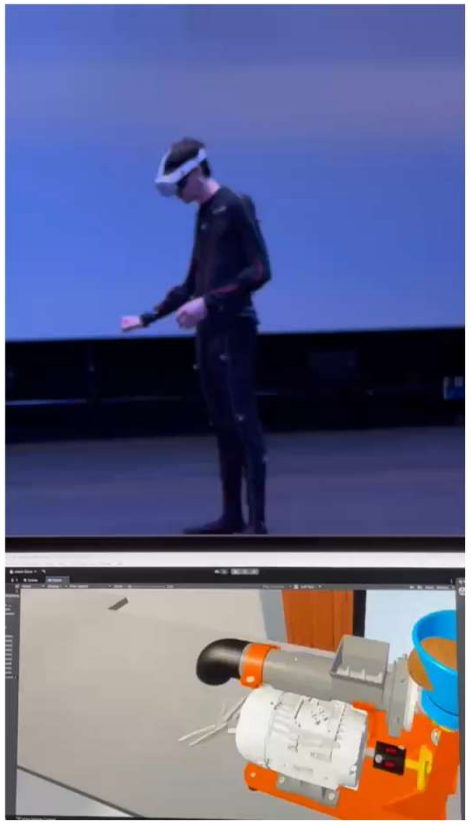
16 male / 8 female

19 right-handed/
5 left-handed

Ages 24 – 40

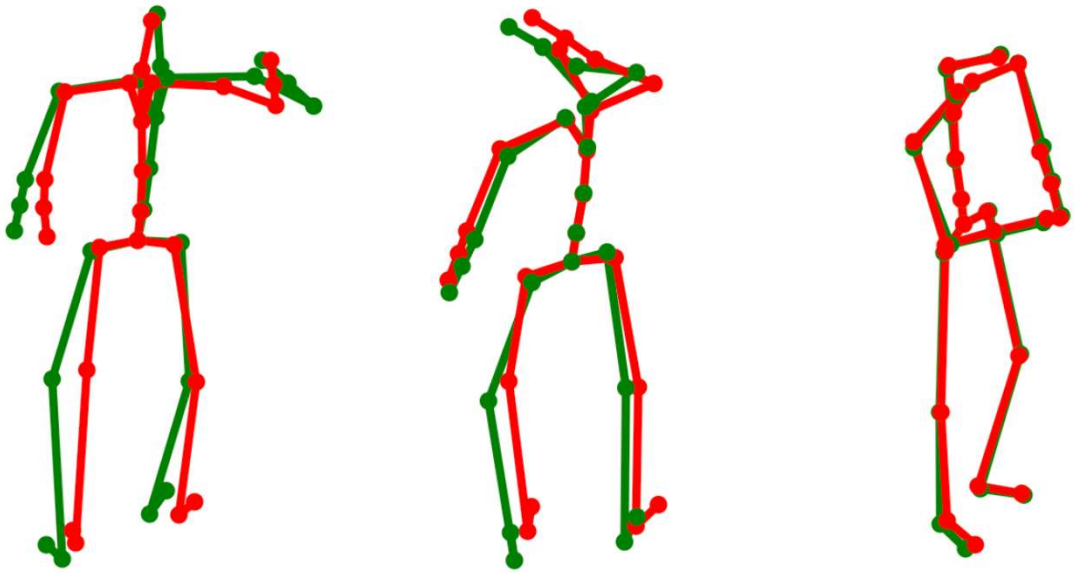
13 experienced
with VR





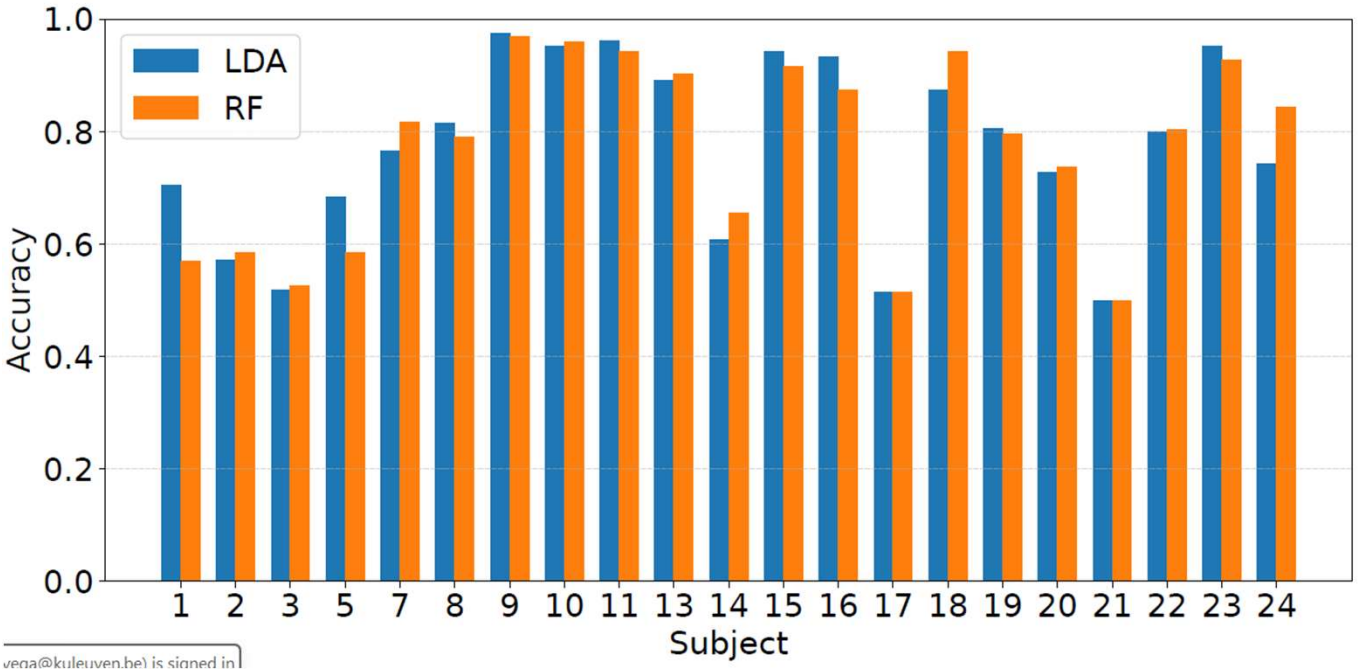
MultiSenseVR – Some early results – WiFi Sensing

Pose prediction using **mmWave Wi-Fi (red)** and **ground truth (green)**



P_{95} joint error **< 10cm**

MultiSenseVR- Some Early results – EMG Sensing



Avg. accuracy **> 76%**

Why are haptics and tracking not fulfilling the needs of the users of immersive applications? – Answers to interviews

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Multimodal Haptics for Realistic Texture Rendering in Extended Reality

Vivian Tsang, Jonathan Valgaeren, Marlon Rodriguez, Carlos Rodriguez-Guerrero, Maria Torres Vega, Multimodal Haptics for Realistic Texture Rendering in Extended Reality, ACM International Conference on Interactive Media Experiences (IMX) 2026, Athlone, Ireland.

State of the Art on Haptic Glove interactions

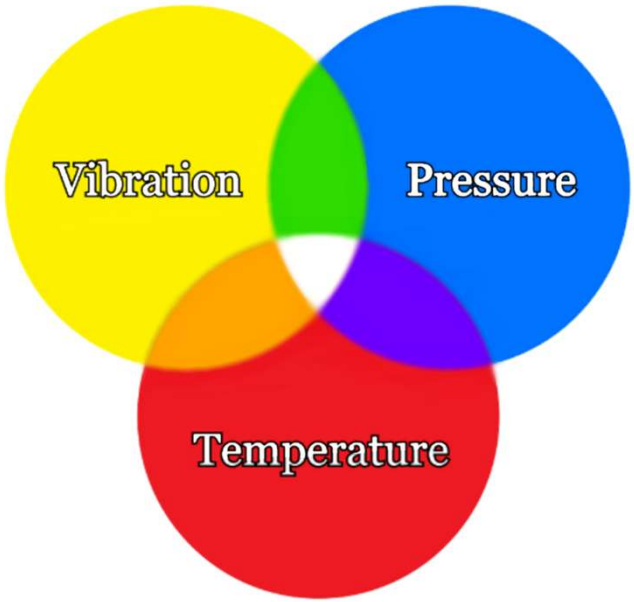
Manus Prime II VR Haptic gloves:
- Vibro-tactile

Senseglove Nova:
- Vibro-tactile
- **Force**

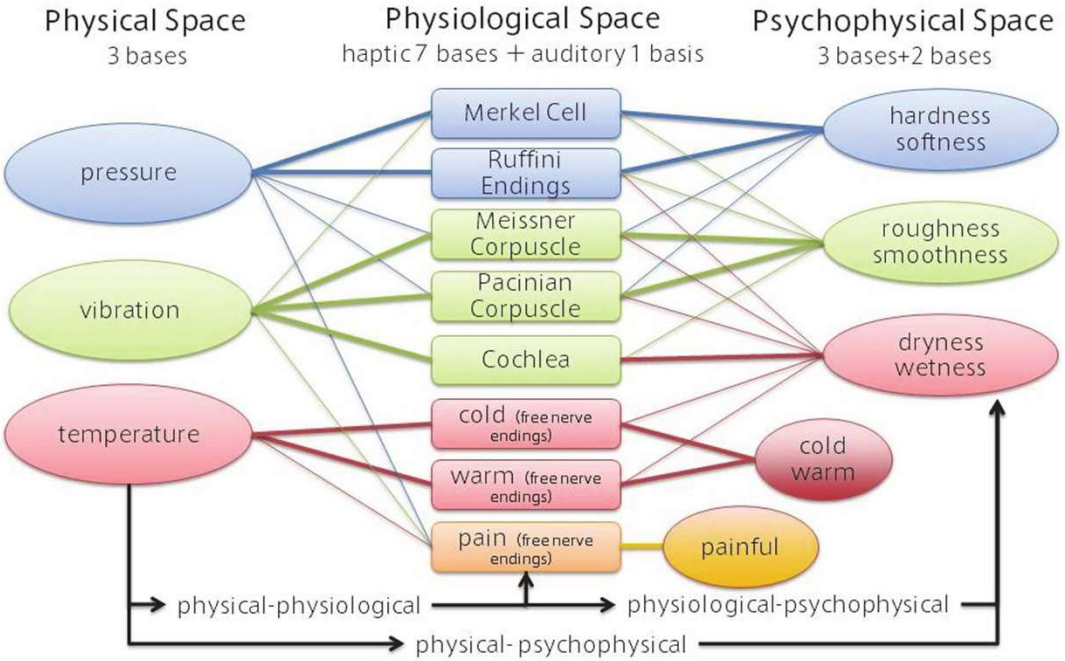
WEART TouchDIVER Pro:
- Vibro-tactile
- Force
- **Temperature**

https://www.manus-meta.com/
https://www.senseglove.com/product/nova-2/
https://weart.it/

Haptic Primary Color (HPC) Theory



Tachi Lab's HPC definitions



https://tachilab.org/en/about/hpc.html#:~:text=Thus%2C%20in%20physical%20space%2C%20we,real%E2%80%9D%20touching%20of%20an%20object.

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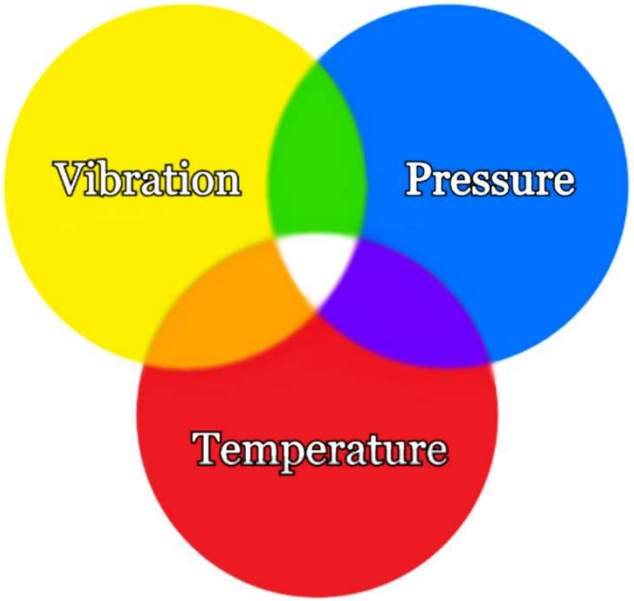
How essential are the different haptic types in recreating a sense of texture within extended reality?

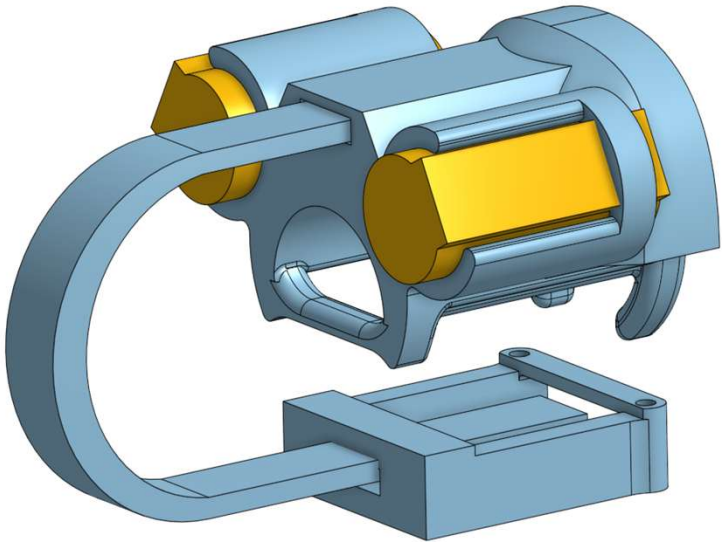
Can we identify psychophysical bases using multimodal haptics?

Can real textures be conveyed by using multimodal haptics?

Our approach – A Multimodal Haptic framework

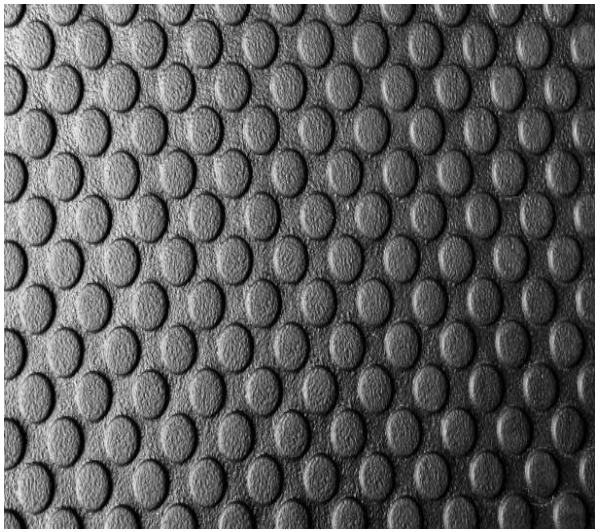


Vibration: Vibrotactile Haptic Motors



Vibration modes to recreate texture…

Macroscopic roughness
~ Bumps



5-20Hz

⟷Flat

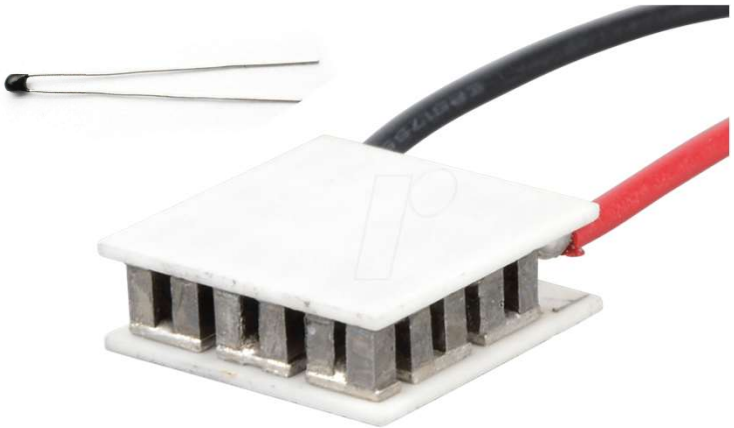
Microscopic roughness

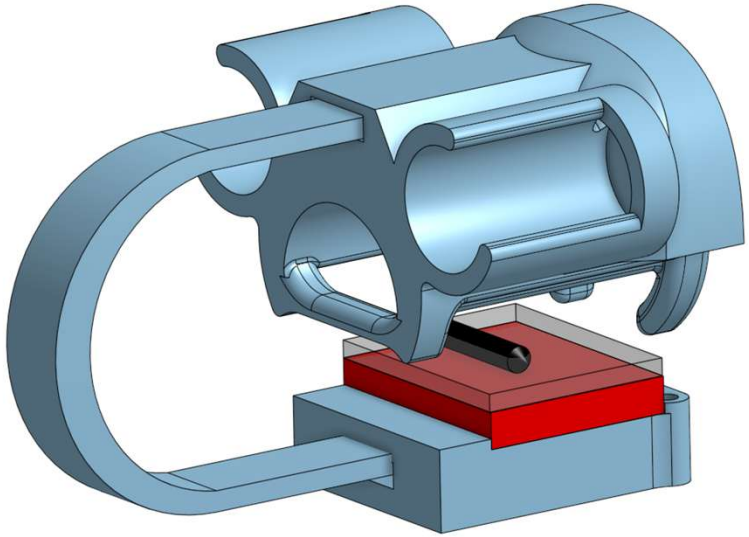
35-150Hz

⟷Smooth

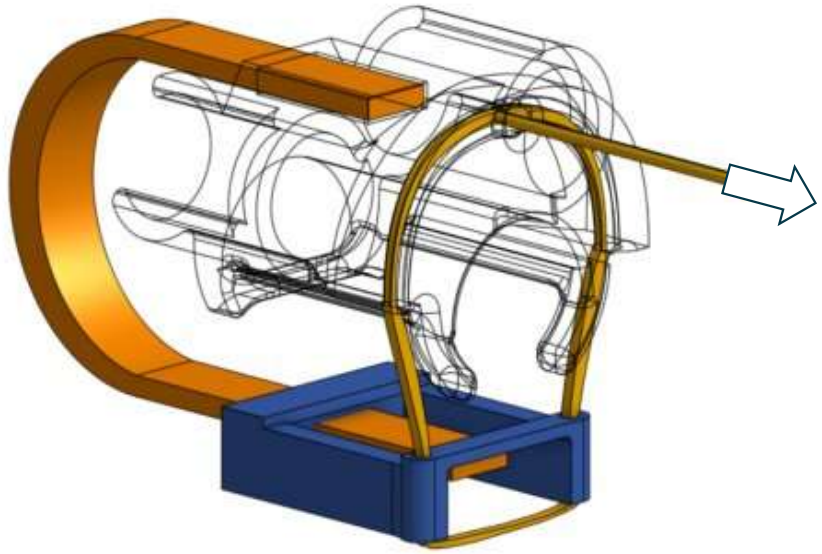
Temperature: Peltier Module

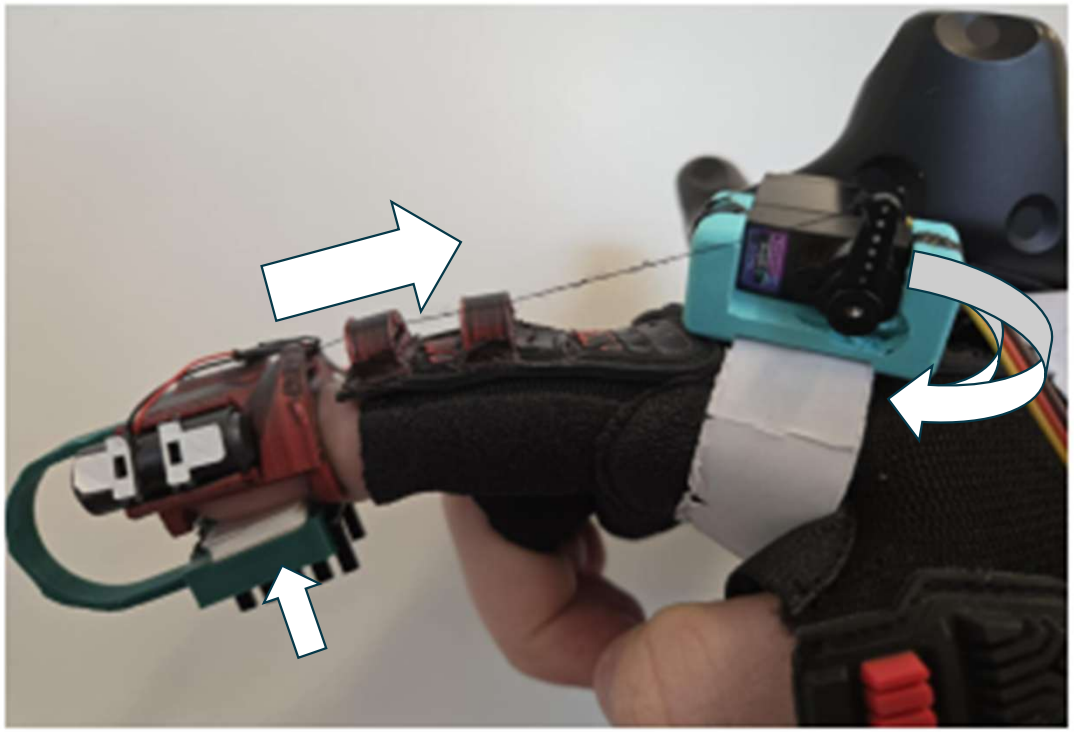
- Replicate the heat transfer





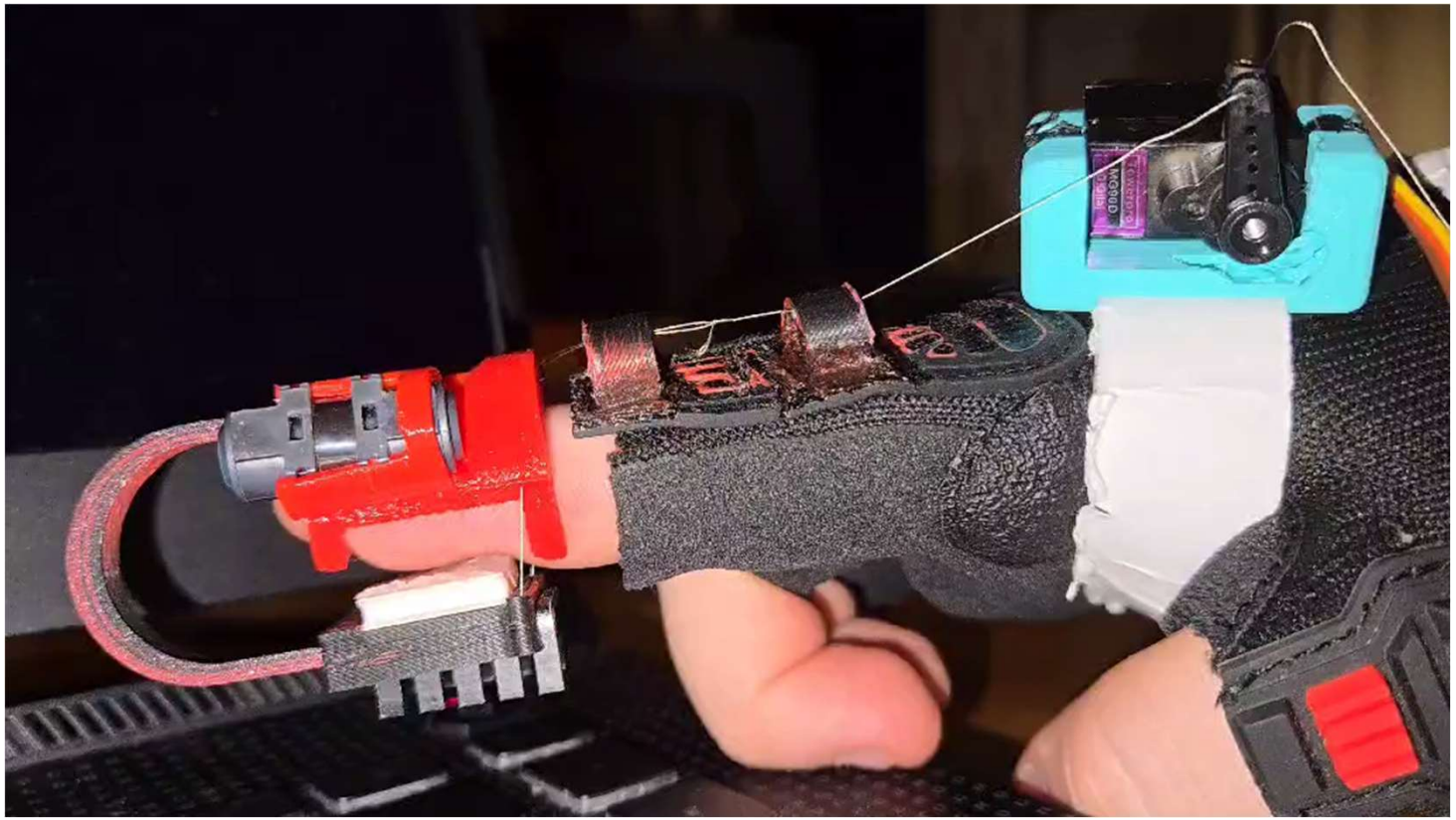
Force: Servo & Mechanism



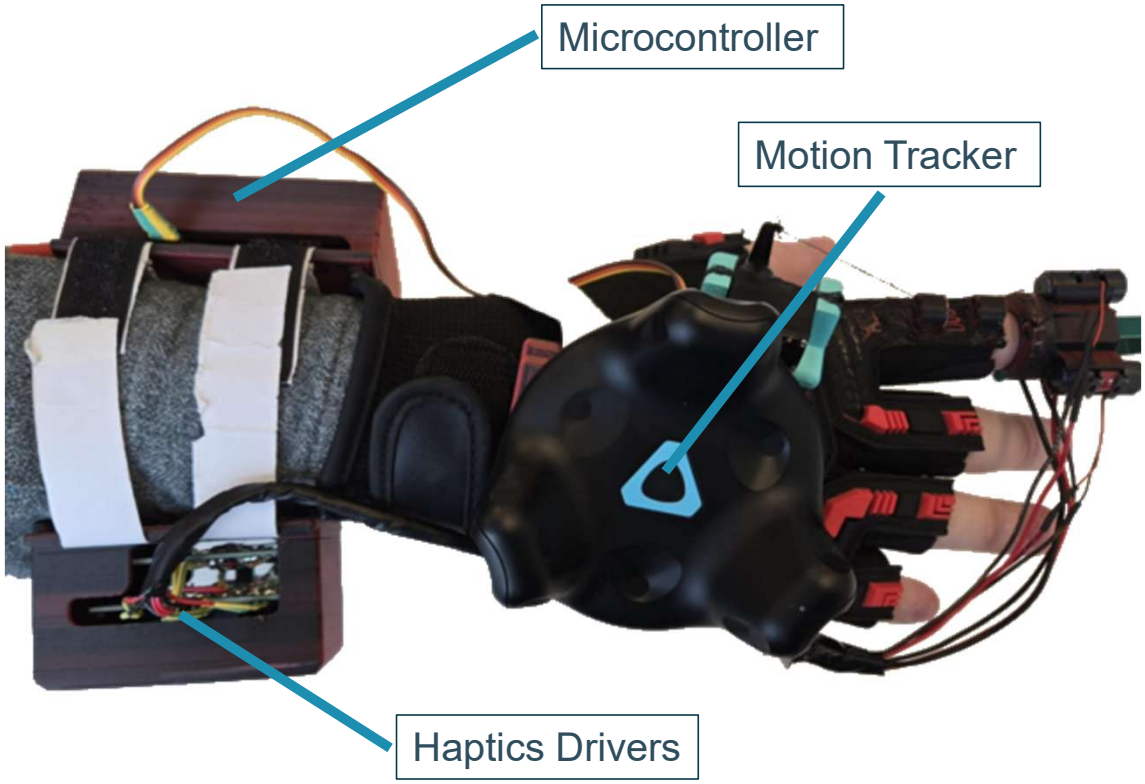


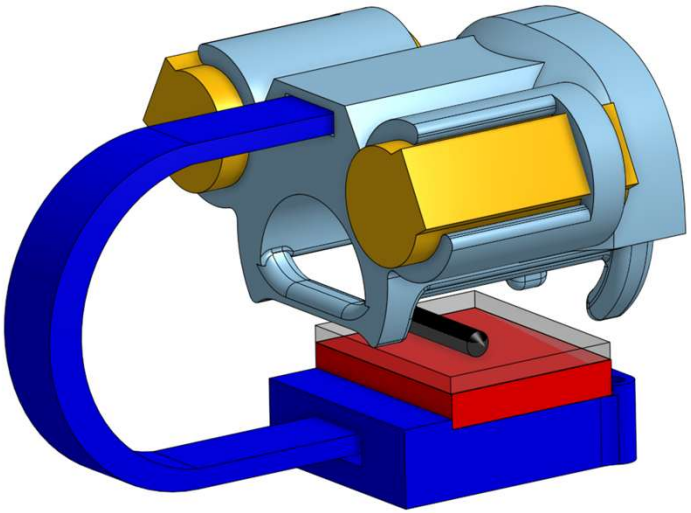
- **Softness**: force increases gradually
- **Hardness**: force increases abruptly

Force: Servo & Mechanism



Haptic Glove Prototype Overview





User study for validation

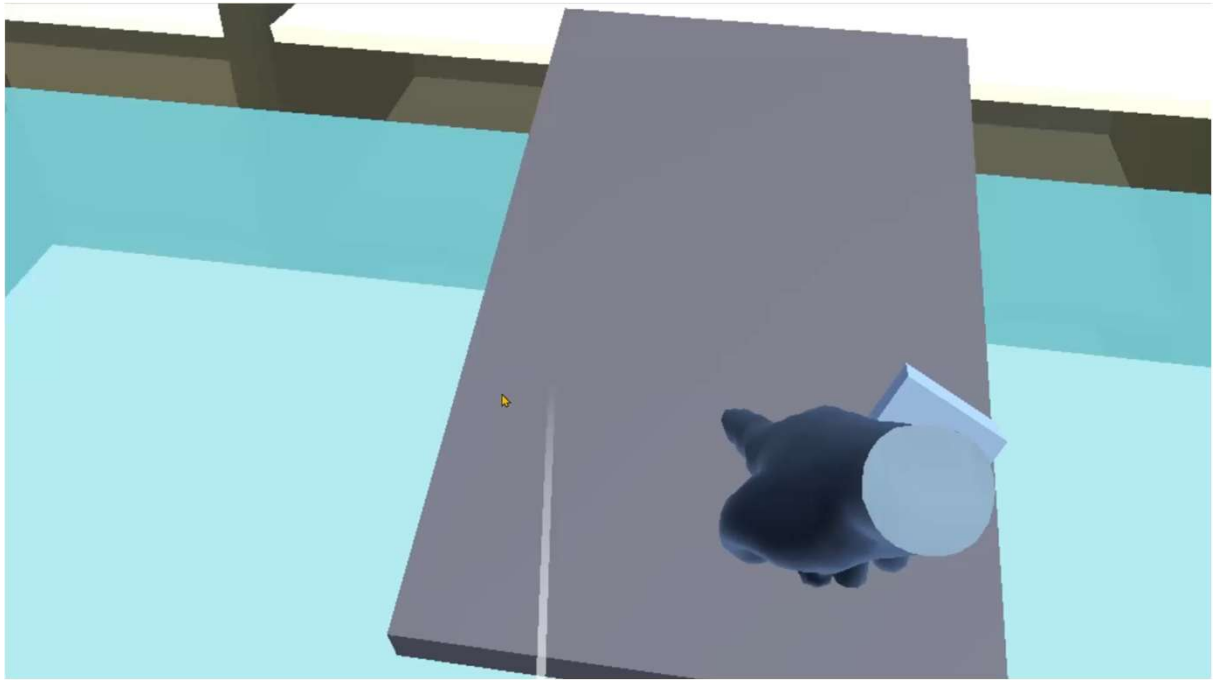
- 28 participants
- 2 User study sessions:
  - Blind test - Can the independent psychophysical bases be identified using the haptic primary colours?
  - Material test - Can real textures be conveyed by combining the haptic primary colours?

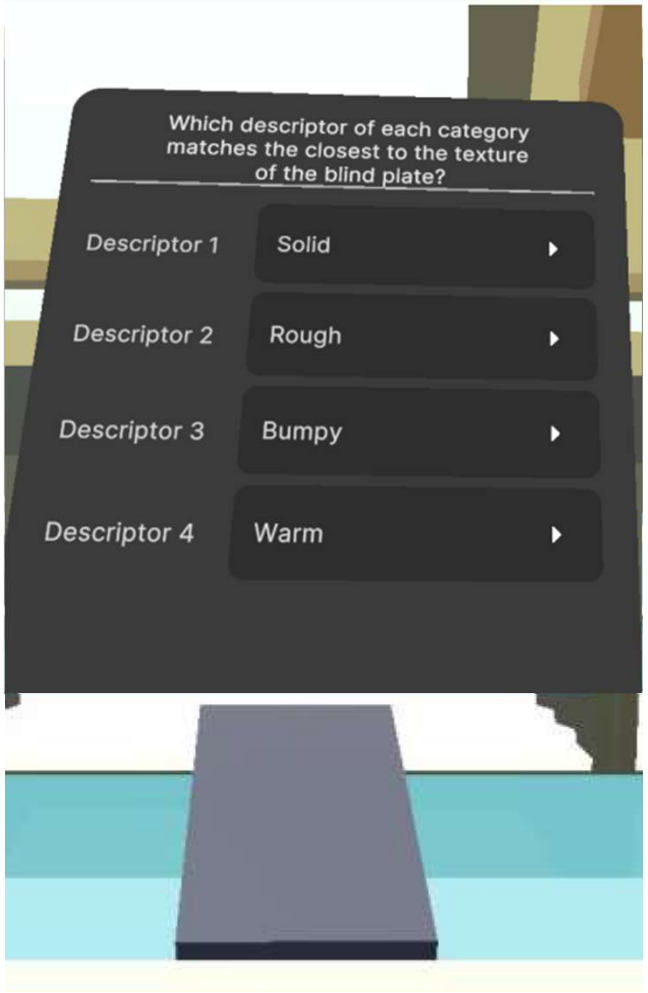
User Test 1: Blind Test

SQ1: Can the independent psychophysical bases (descriptors) be identified?

- Solid ↔ Soft
- Warm ↔ Cold
- Smooth ↔ Rough
- Flat ↔ Bumpy

User Test 1: Blind Test

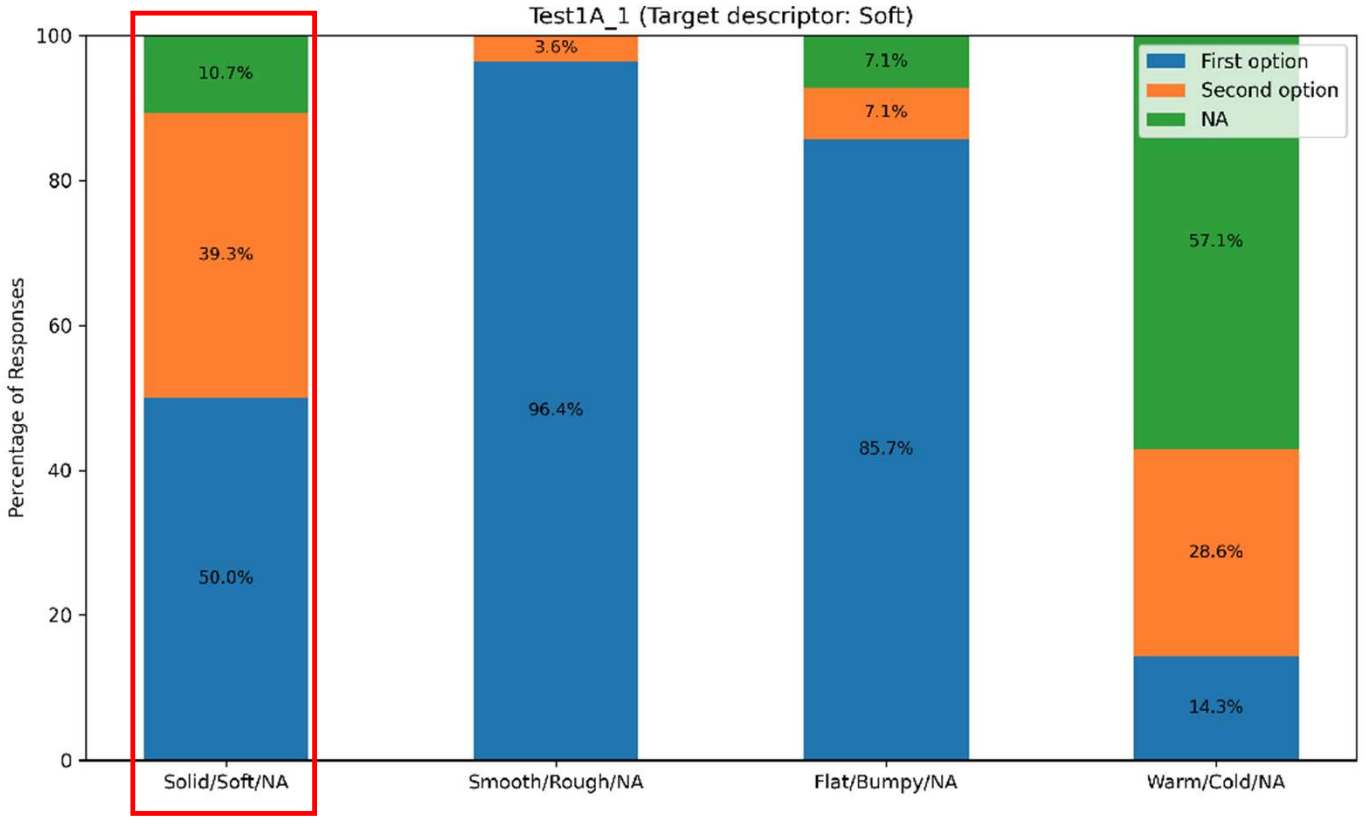




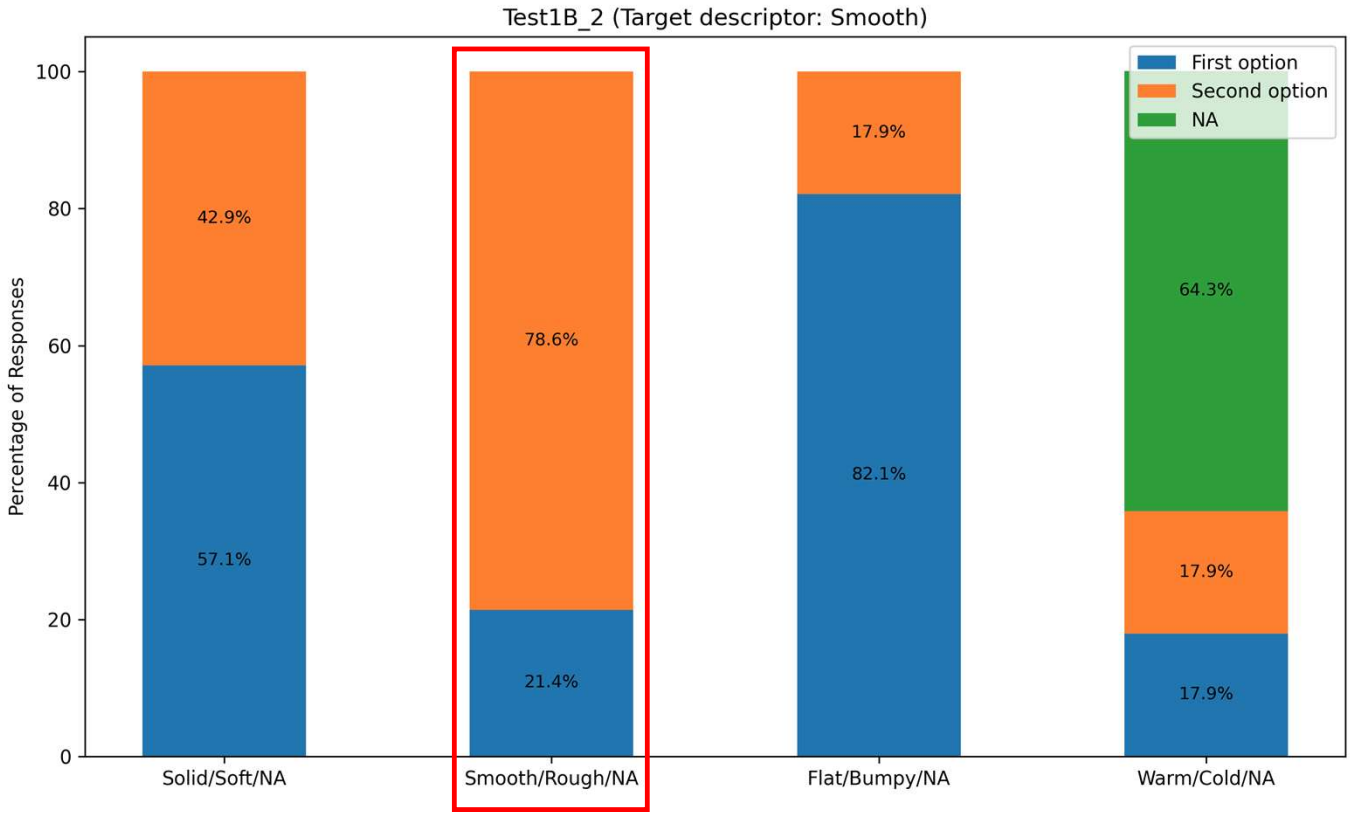
Blind Test Results

- ✓ Participants perceiving the intended psychophysical base
- ✓ High detection rates for:
  - Hardness
  - Roughness
  - Bumpy
  - Warmth
- ✓ Problems to detect:
  - Softness
  - Smoothness

Softness detection



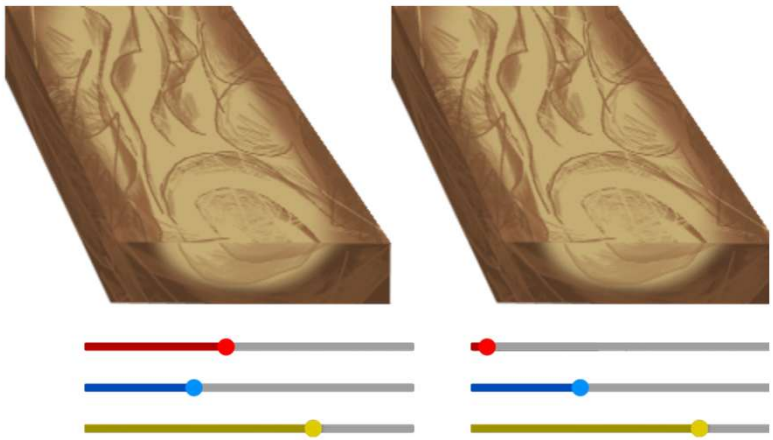
Smoothness detection



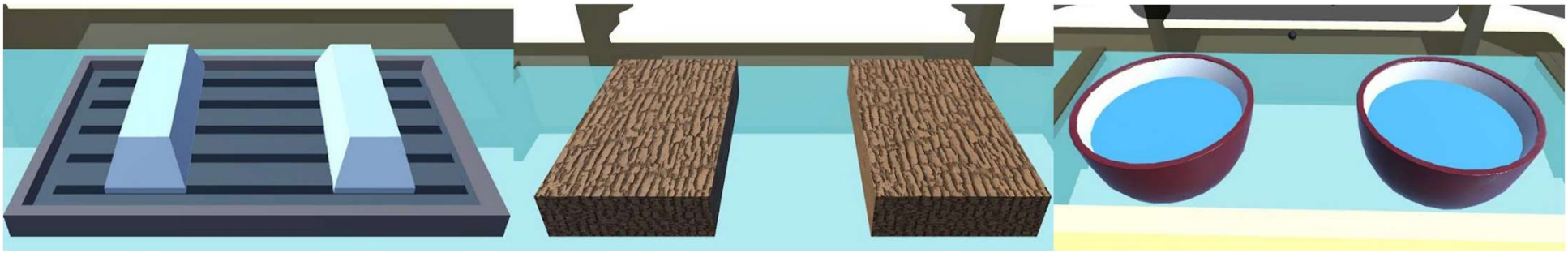
User Test 2: Material Test

SQ2: Can real textures be conveyed by multimodal haptics?

- Use of real material textures
- Two virtual objects -> double stimulus test



User Test 2: Material Test



Material	Hard	Soft	Rough	Smooth	Bumpy	Flat	Warm	Cold
2A (Metal)	X			X				X
2B (Wood)	X		X		X			
2C (Water)				X			(X)	(X)

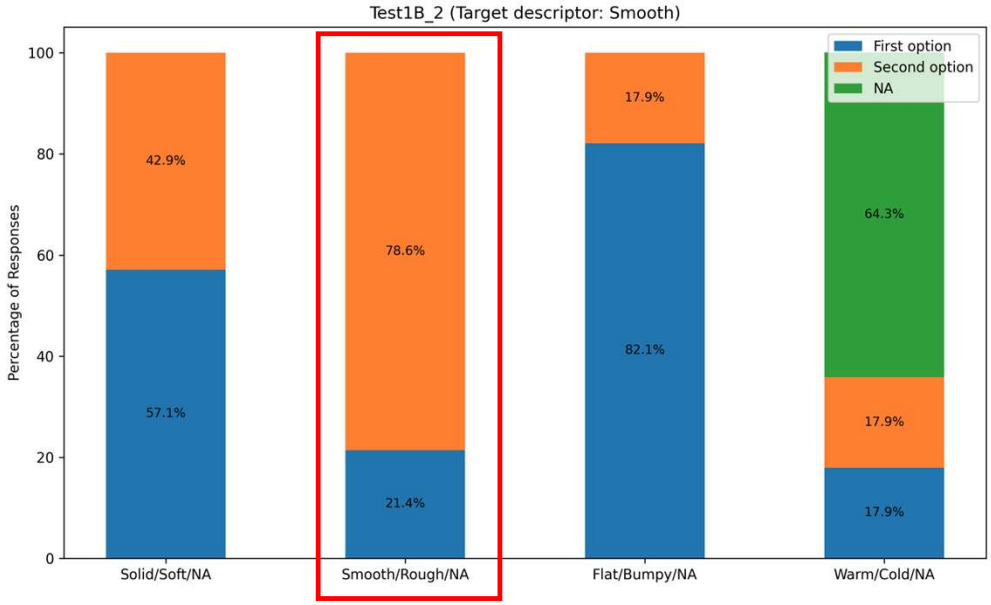
Material Test Questionnaire

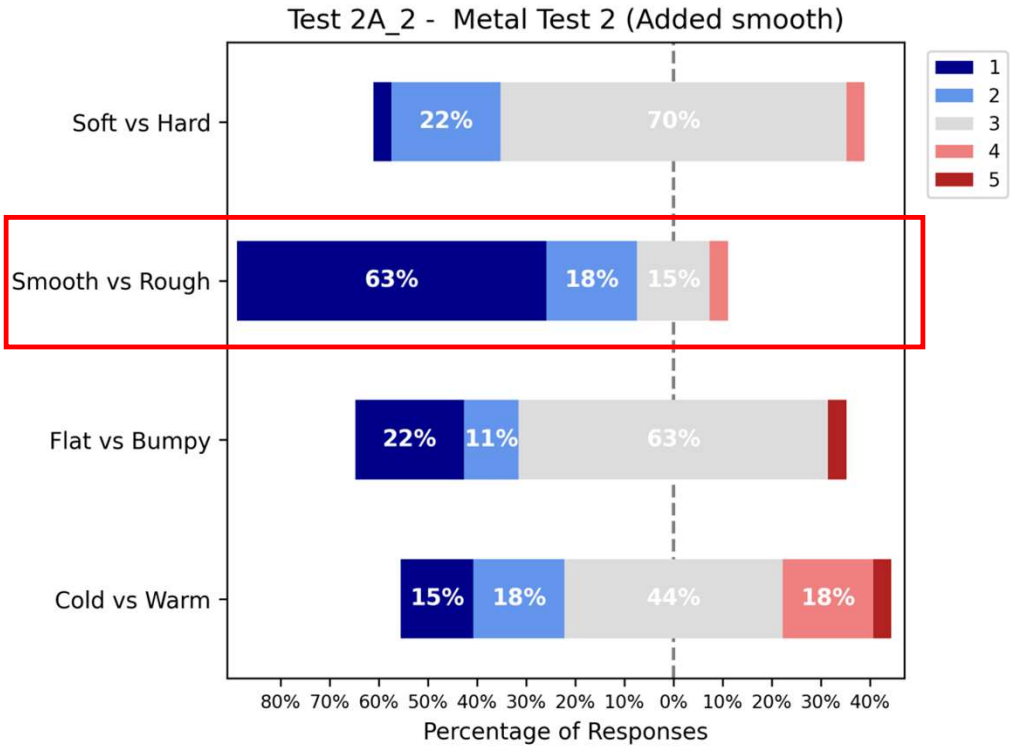
Material Test Results

- Participants perceiving changes between materials ☺
- Different modality was noticed ☺
- High similarity ratings for metal and wood ☺
- Lower similarity ratings for water 😐
- **What happens to the smoothness?**

Back to smoothness... Impact of visual cues

- Effect of visual cues





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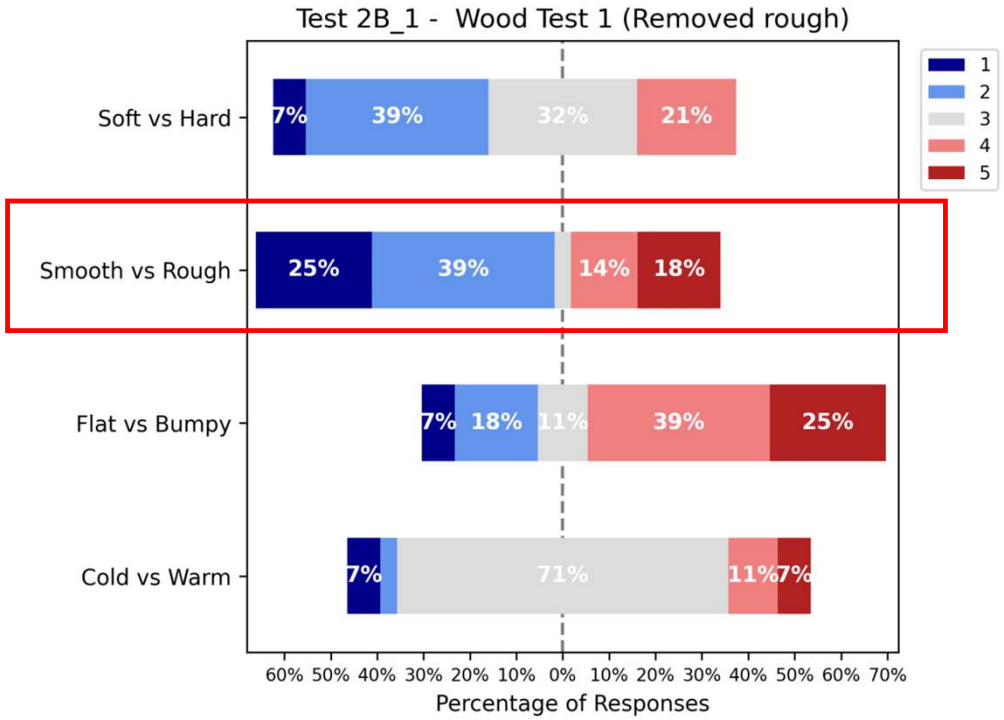
Smoothness?

- Lack of the opposite sensation



Conclusion of the approach

- **The Multimodal haptics are able to convey most psychophysical bases through their designated actuators, especially when visual cues are added.**
  - (UT1) Hardware was successfully mapped to its corresponding textures
    - Except softness and smoothness
  - (UT2) Adding visual cues
- **The approach is able to convey real textures**
  - adding more haptic modalities resulted in higher similarity ratings
- **To recreate realistic textures, all three modalities are essential – Maybe even a 4th (for the case of fluids)!**

Why are haptics and tracking not fulfilling the needs of the users of immersive applications? – Answers to interviews

“Interaction is not very intuitive or natural”;

“I did not feel embodied in the experience”;

Can we provide seamless interactions to the user?

“I did not see the added value of the haptics compared to the regular controllers”

Can we enhance the interaction at the hand level?

“The feedback just on the hand was not enough”

Can we go beyond the hand for haptic interaction?

Haptic interaction beyond the hand – Virtual Gravity

M. Różycka, S. Lika, J. Chatterjee, C. Rodriguez and M. Torres Vega, "Virtual Gravity: Enhancing Weight Sensation in Virtual Reality with Haptic Interfaces," *2025 17th International Conference on Quality of Multimedia Experience (QoMEX)*, Madrid, Spain, 2025, pp. 1-4, doi: 10.1109/QoMEX65720.2025.11219893.

Virtual Gravity – Weight sensation in VR

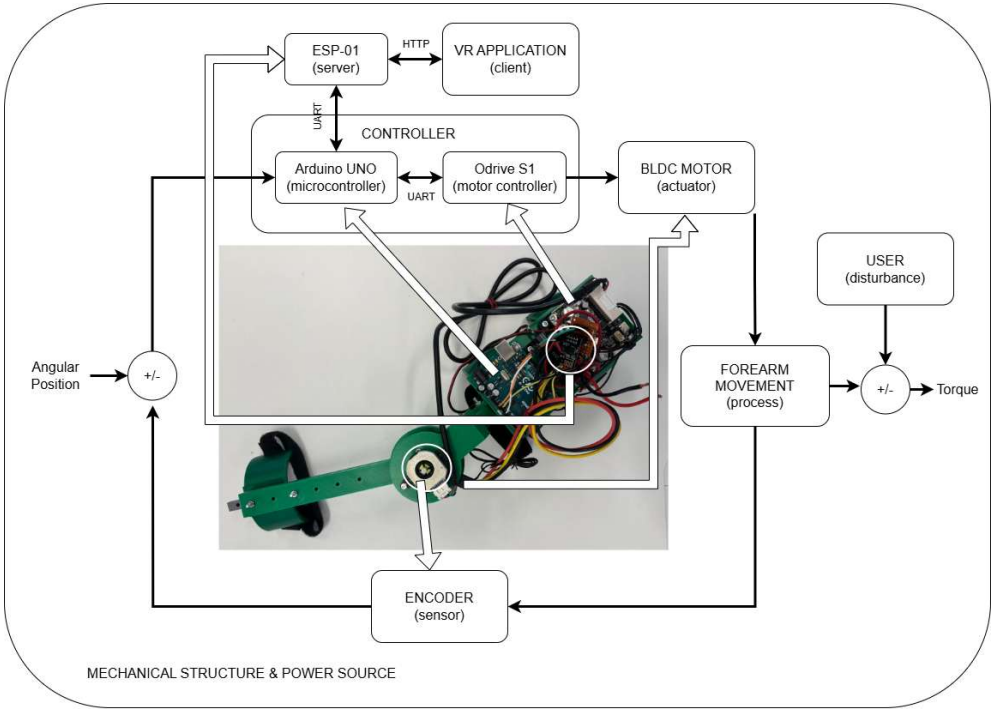
- Current VR simulators for gravity are audio visual
- No tactile interaction

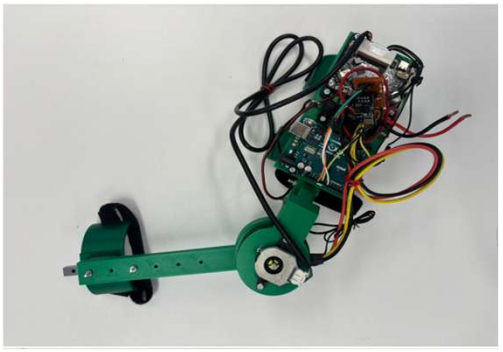
Can an exoskeleton actuator system, in combination with a VR headset, simulate weight sensation across different gravitational fields on the user's forearm?

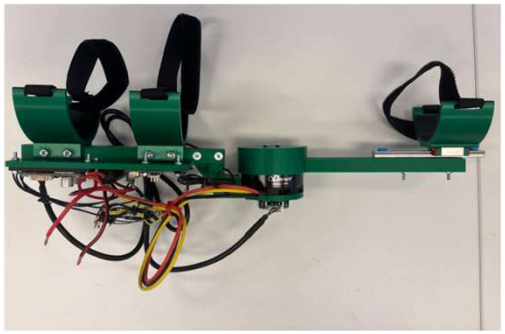
https://pale.blue/2020/08/12/paleblue-provides-a-vr-simulator-for-the-iss/

M. Różycka, S. Lika, J. Chatterjee, C. Rodriguez, M. Torres Vega, "Virtual Gravity: Enhancing Weight Sensation in Virtual Reality with Haptic Interfaces", submitted to QoMEX 2025

Virtual Gravity - The haptic forearm







Virtual Gravity - Emulating gravity by torque actuation

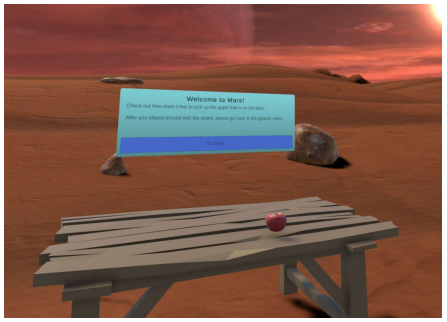
$$T = m \times g \times r$$

- Object => apple
  - Newton's law of gravitation
  - A familiar object
  - m=0.1 kg
- Average arm length r = 0.3m
-

Planet	Gravity (m/s^2)	Torque (Nm)
Mars	3.70	0.111
Mercury	3.71	0.111
Uranus	8.72	0.262
Venus	8.90	0.267
Saturn	8.99	0.270
Earth	9.81	0.294
Neptune	10.99	0.330
Jupiter	23.1	0.693

Virtual Gravity – VR Simulator

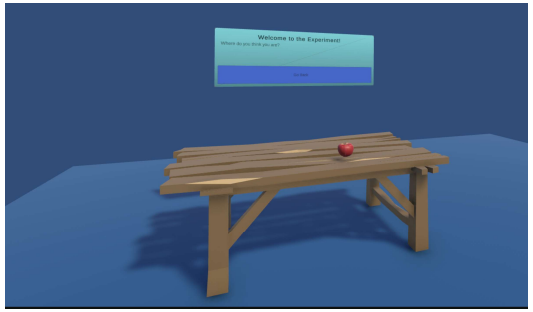
Earth



Mars

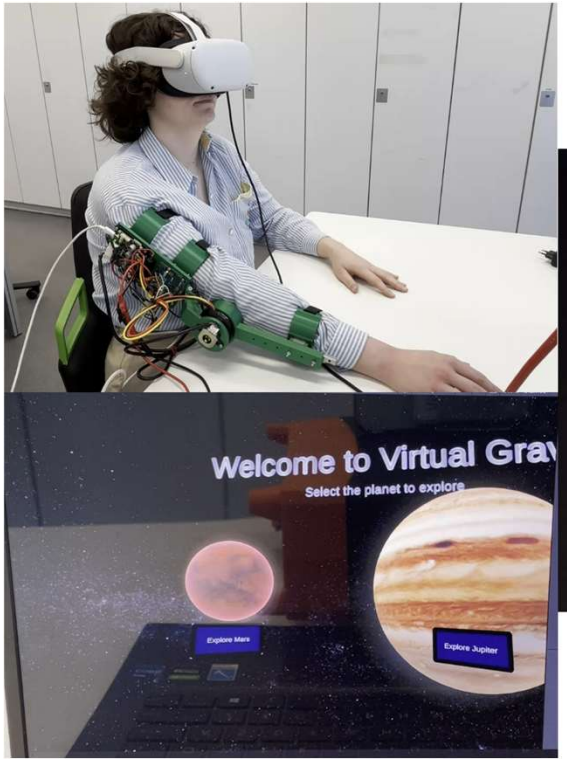
Jupiter

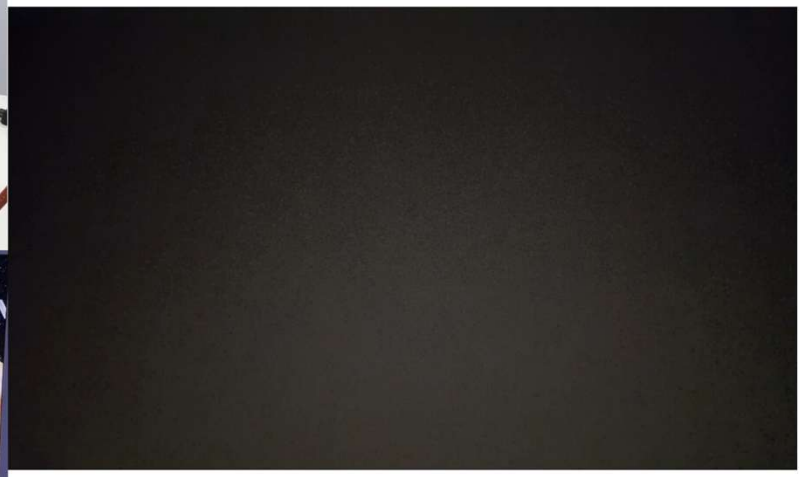
Menu



Experiment

Virtual Gravity - Demo





User Study

Goal:

Assess user perception of:

1. Weight sensation (WS)
2. Comfort of use (CofU)
3. Portability

Participants: 12 users

Arm length & demographics

Device weight: 793 g

Test Procedure:

1. Wear exoskeleton + HMD
2. Training: Explore Earth, Mars, Jupiter
3. Test: Identify unknown planet
4. Questionnaire (WS and CofU)
5. Portability Test:

-move with exoskeleton (inactive) for 2 min

Session duration: ~25 minutes

User Study

Key Findings:

Weight Sensation:

11/12: felt like lifting an apple

Jupiter felt heaviest for all users

10/12: Mars felt lightest

6/12: correctly identified the test planet

– **Importance of the visual cues**

Comfort:

83%: low–medium discomfort

84%: low–medium fatigue

9/12: easy–moderate to put on/off

84%: good or very good fit

Portability:

Most users reported moderate to high freedom of movement while wearing it

What the future brings…

Conclusions

- Multimodal interactions can be enabled by sensing and haptic actuation BUT:
  - Seamless tracking cannot be done only with the headsets

Multimodal sensing can provide both body as well as fine-grained tracking

  - Hand-based haptics fail to provide the required realism and textures

Adding more modalities we can enhance the realism

  - They are mostly focused on the hand

Addressing other body parts (e.g., Virtual Gravity) can enhance the experience

Our References

SCAN TO DOWNLOAD

https://osf.io/f6r7d

Our references

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