Virtual Reality Without Vision: A Haptic and Auditory White Cane to Navigate Complex Virtual Worlds

Alexa F. Siu[1] <alexasiu.com>

Mike Sinclair[2], Rob Kovacs[3], Eyal Ofek[2],

Christian Holz[2,4], Ed Cutrell[2]

1. Stanford University, 2. Microsoft Research,

3. Hasso Plattner Institute, 4. ETH Zurich

travel & tourism

retail

social & entertainment

education

Images from Virtual Speech - Industries Using VR

Accessibility has thus far not been a consideration in the development of mainstream VR systems

Applications

entertainment

orientation & mobility training

previewing spaces from a safe environment

Navigating with the Aid of a Long Cane

Navigating with the Aid of a Long Cane

Kinesthetic feedback

Tactile feedback

Direct sounds &
Ambient noise

Echoes & reverberation

Kinesthetic feedback

🔊 of cane tap on wood

Tactile feedback

Direct sounds &

Ambient noise

Echoes & reverberation

Kinesthetic feedback

Tactile feedback

🔊 of cane sweep on concrete

Direct sounds &
Ambient noise

Echoes & reverberation

Kinesthetic feedback

Tactile feedback

Direct sounds &

Ambient noise

🔊 of footsteps

Echoes & reverberation

Kinesthetic feedback

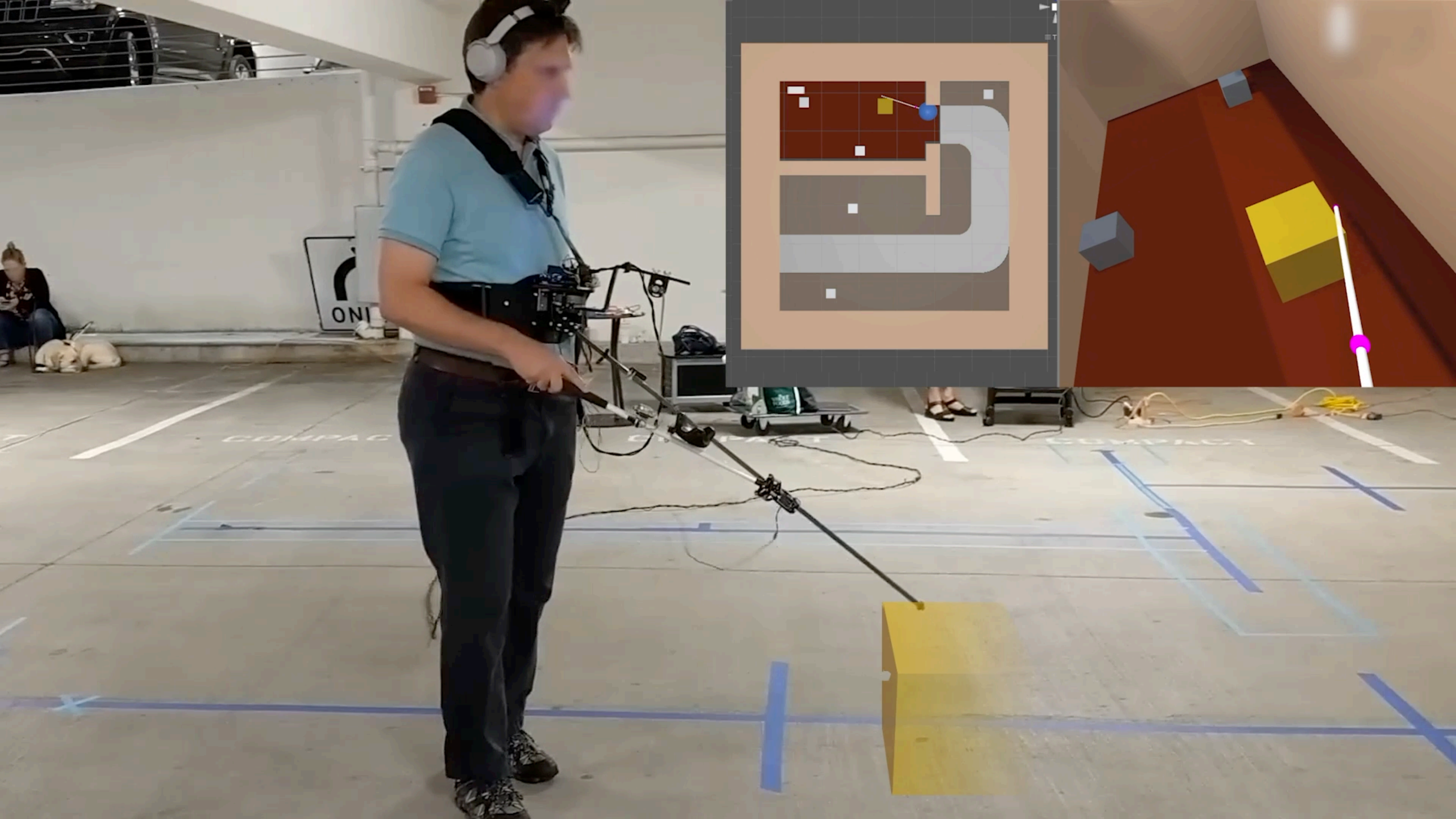
Tactile feedback

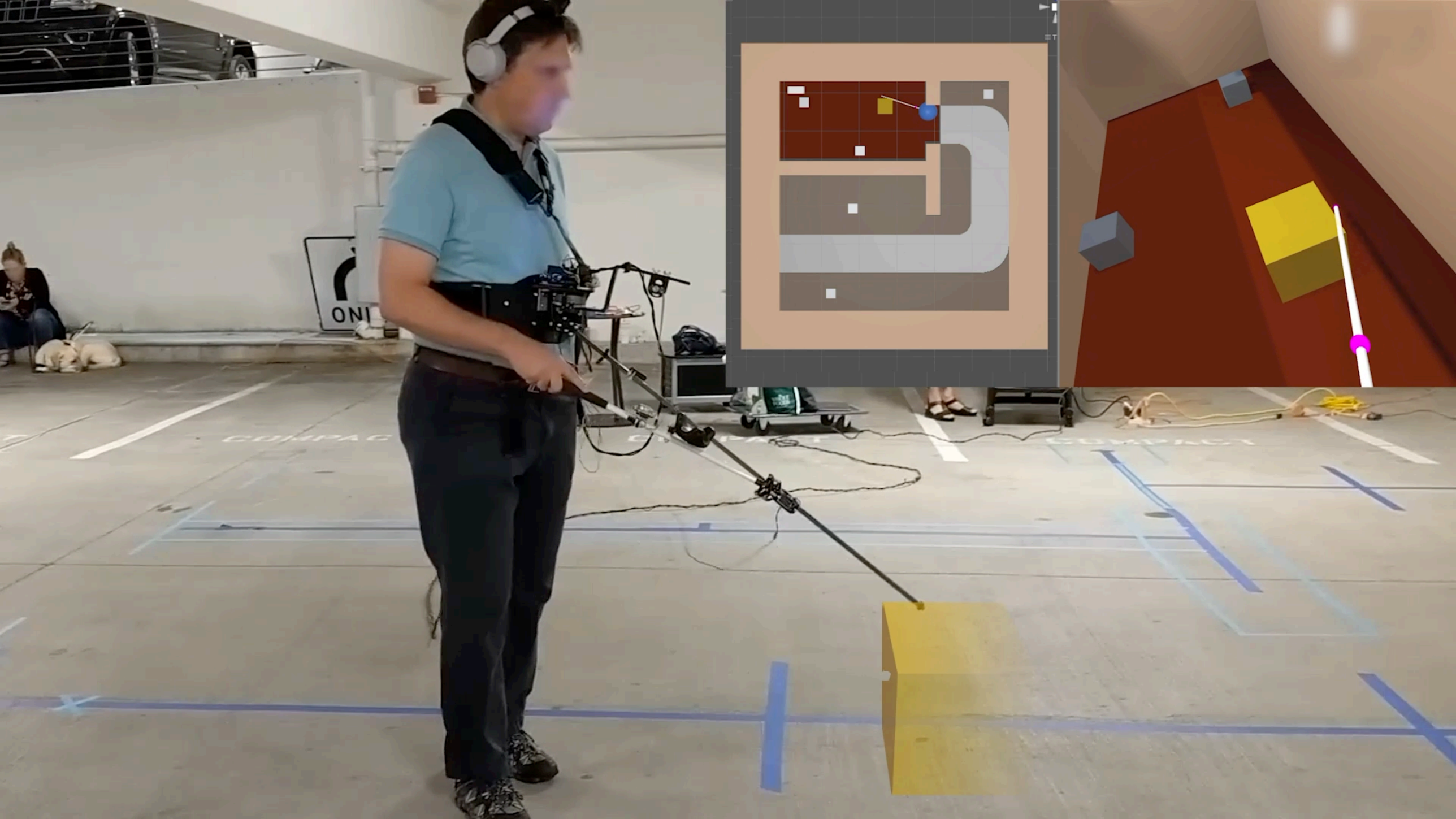
Direct sounds &

Ambient noise

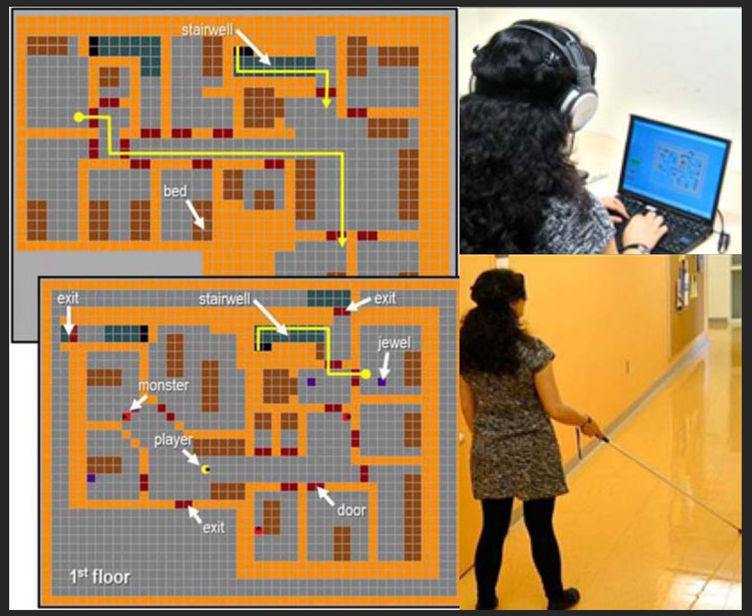
Echoes & reverberation

🔊 of busy street crossing

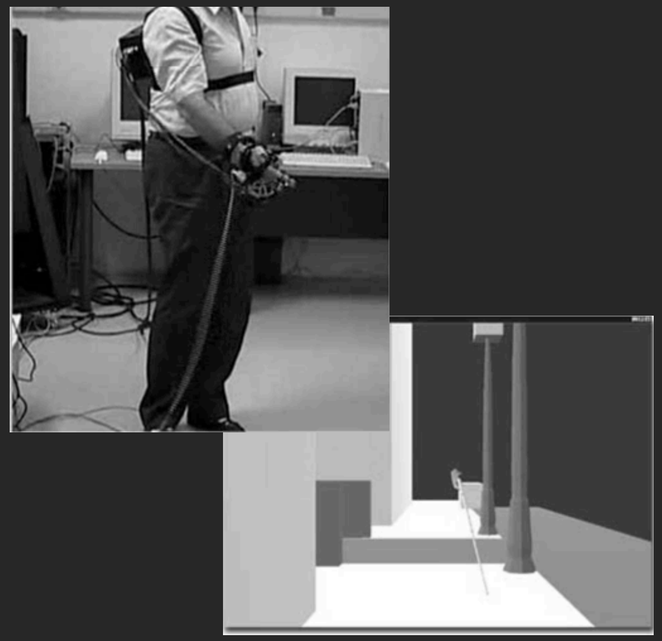




Prior Work



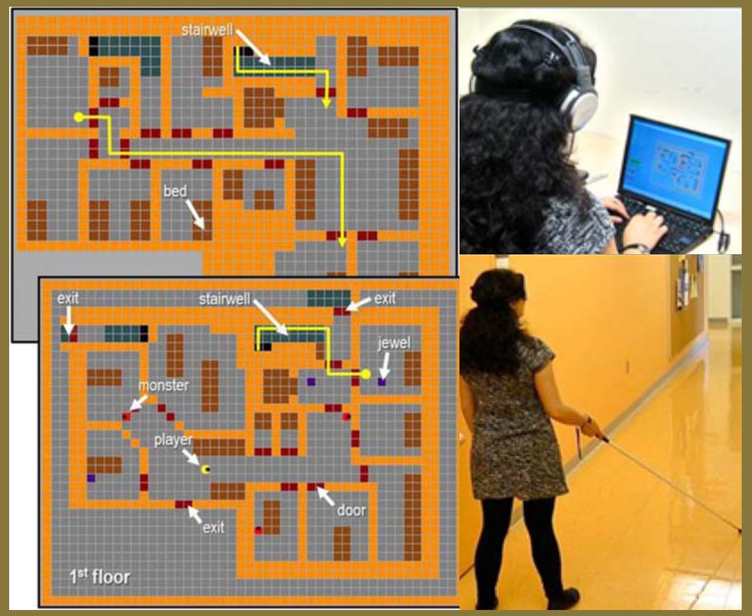
Connors et al. (2014). Action video game play and transfer of navigation and spatial cognition skills in adolescents who are blind.



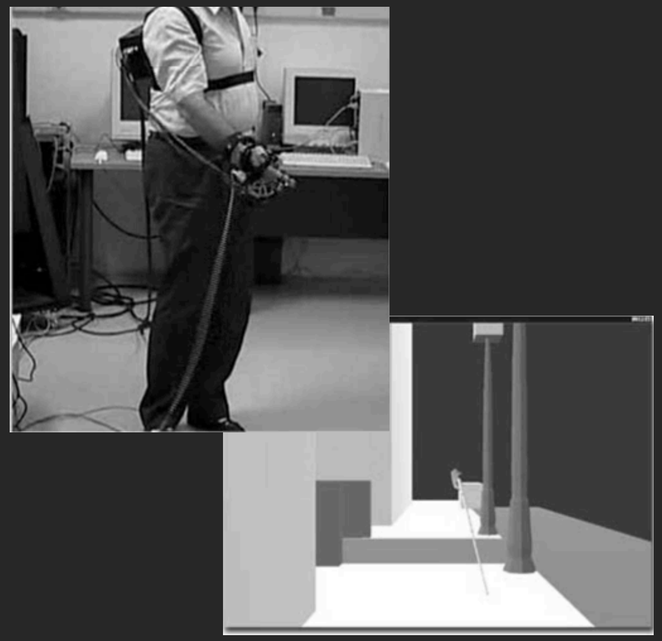
Tzovaras et al. (2004). Design and implementation of haptic virtual environments for the training of the visually impaired.

Zhao et al. (2018). Enabling people with visual impairments to navigate virtual reality with a haptic and auditory cane simulation.

Prior Work



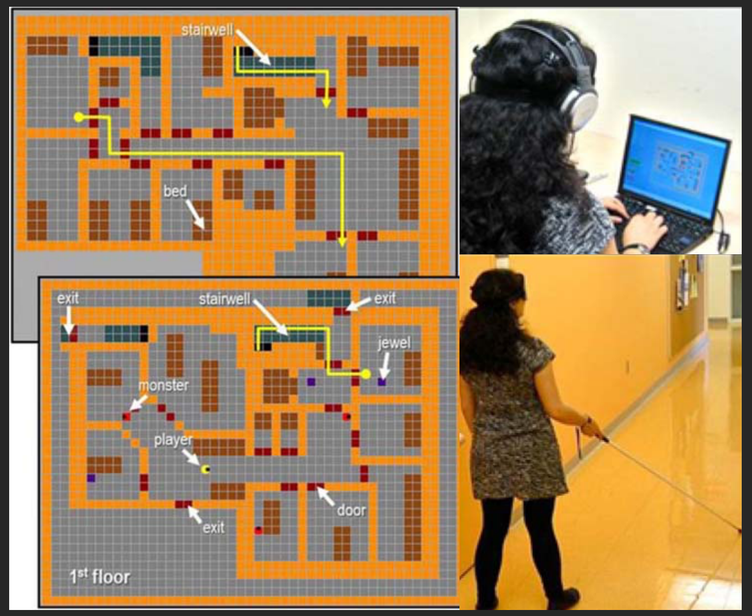
Connors et al. (2014). Action video game play and transfer of navigation and spatial cognition skills in adolescents who are blind.



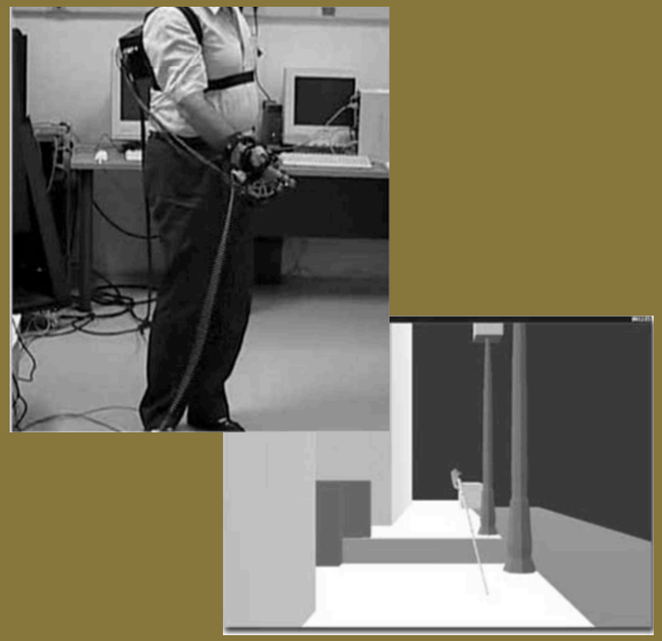
Tzovaras et al. (2004). Design and implementation of haptic virtual environments for the training of the visually impaired.

Zhao et al. (2018). Enabling people with visual impairments to navigate virtual reality with a haptic and auditory cane simulation.

Prior Work



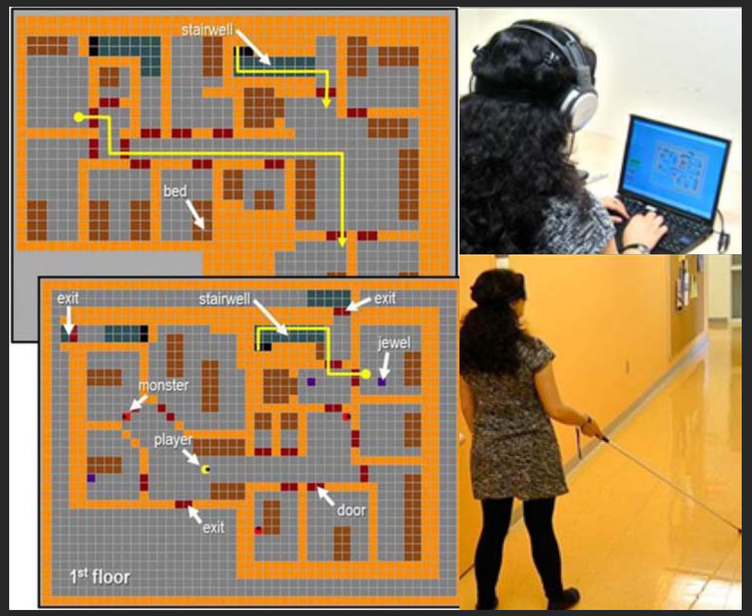
Connors et al. (2014). Action video game play and transfer of navigation and spatial cognition skills in adolescents who are blind.



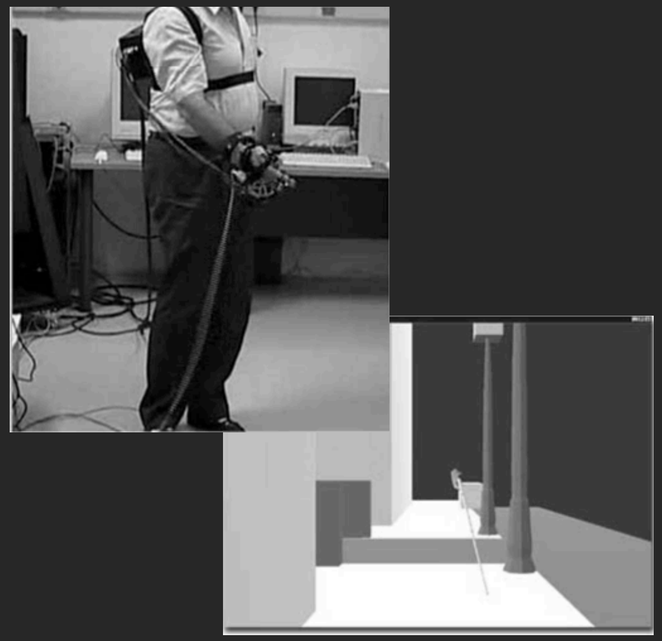
Tzovaras et al. (2004). Design and implementation of haptic virtual environments for the training of the visually impaired.

Zhao et al. (2018). Enabling people with visual impairments to navigate virtual reality with a haptic and auditory cane simulation.

Prior Work



Connors et al. (2014). Action video game play and transfer of navigation and spatial cognition skills in adolescents who are blind.

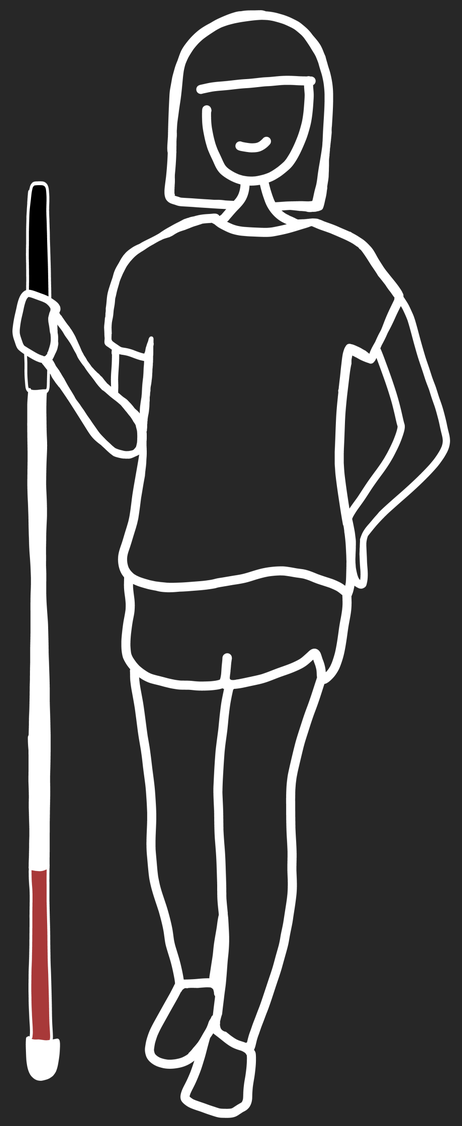


Tzovaras et al. (2004). Design and implementation of haptic virtual environments for the training of the visually impaired.

Zhao et al. (2018). Enabling people with visual impairments to navigate virtual reality with a haptic and auditory cane simulation.

Design Rationale

- Sound & Haptics
  - Cane Techniques
  - Material Properties & Tip Styles
  - Grip & Hand Position
  - Length and weight



Design Rationale

Cane Techniques

constant contact

APH Long Cane Techniques Study Guide

two-point touch

APH Long Cane Techniques Study Guide

Design Rationale

Cane Techniques

constant contact

two-point touch

Design Rationale

Cane Techniques

constant contact

two-point touch

Design Rationale

Cane Techniques

constant contact

two-point touch

Design Rationale

Cane Techniques

constant contact

two-point touch

Design Rationale

Cane Techniques

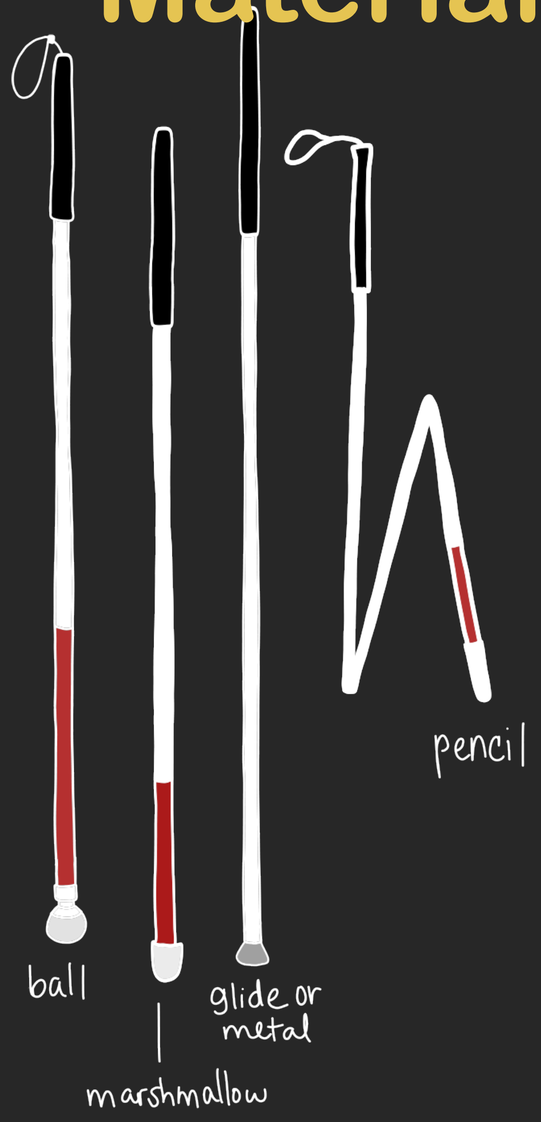
constant contact

two-point touch

1. T**hree orthogonal axes** (motion horizontally, vertically and radially)
2. C**ontact constraints, opposing the direction of motion**

Design Rationale

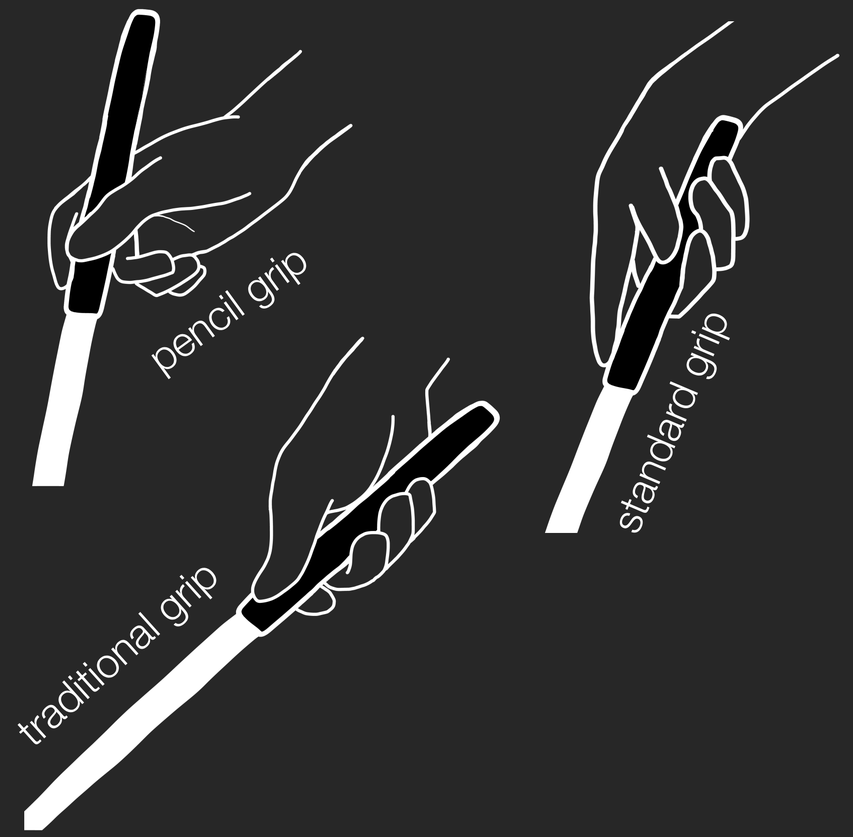
Material Properties & Tip Styles



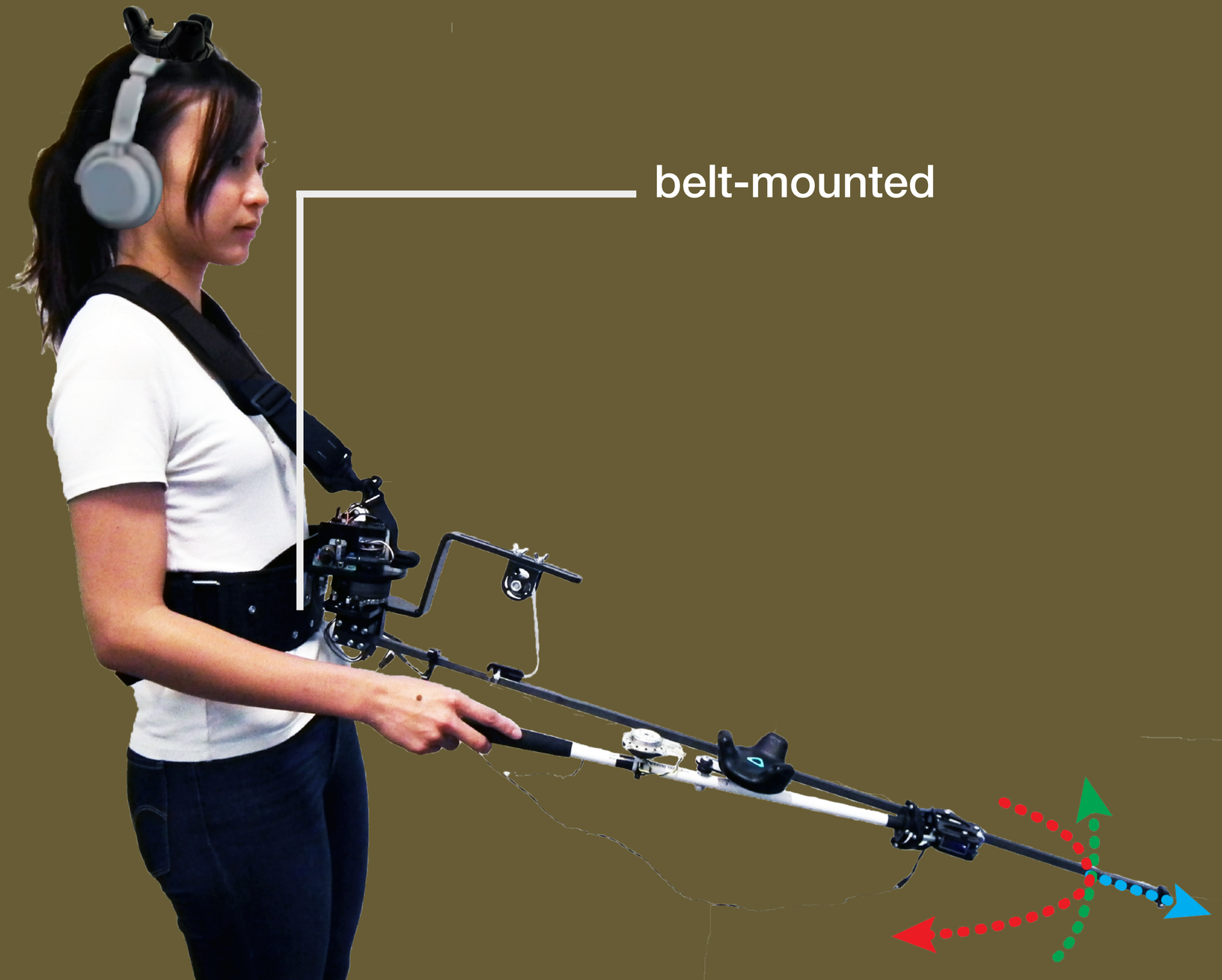
- The motion of the cane tip over a surface transmits sound and vibration from its tip to the hand
- Differences in:
  1. Tactile feedback —Surface textures
  2. Sound effects transmitted

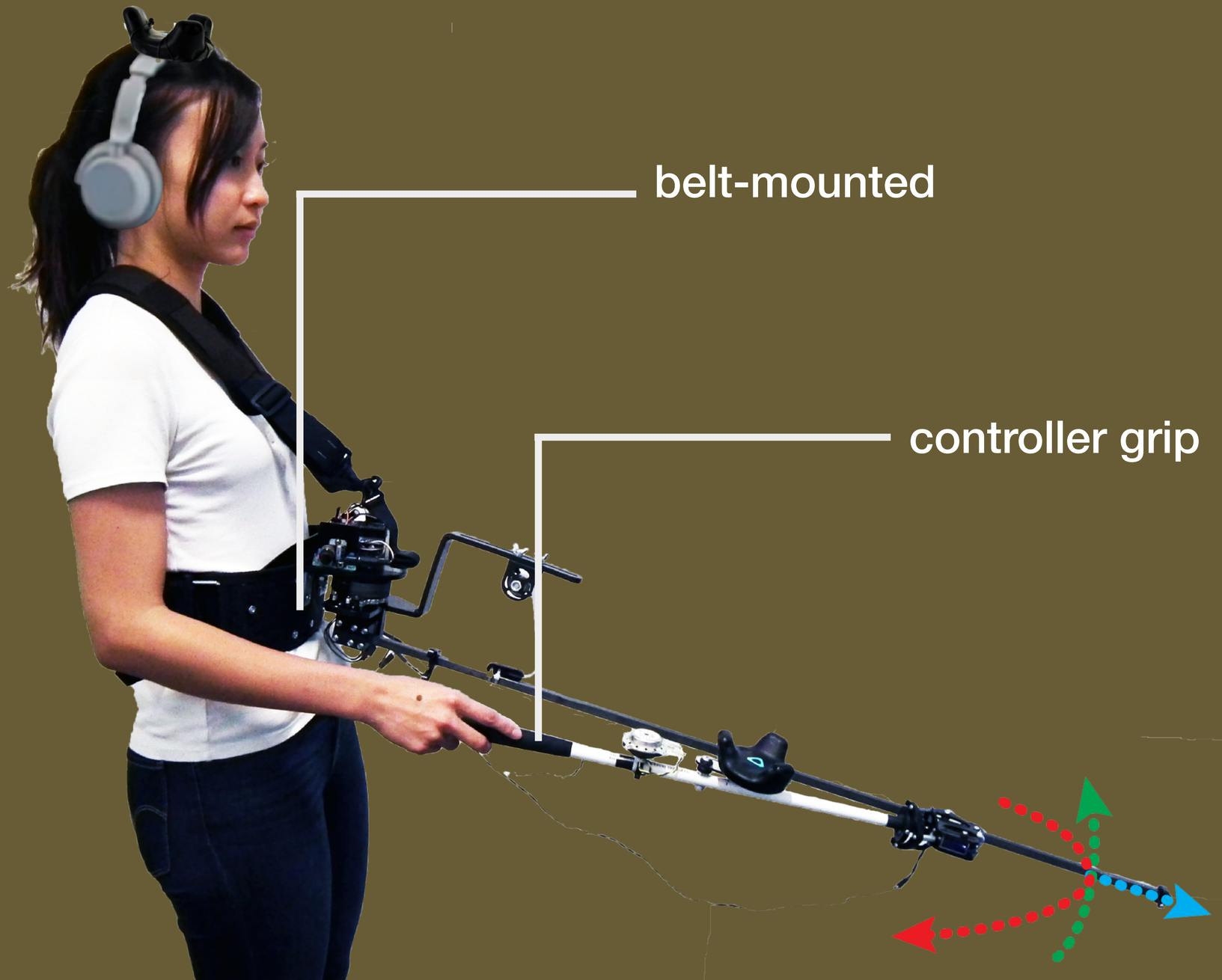
Design Rationale

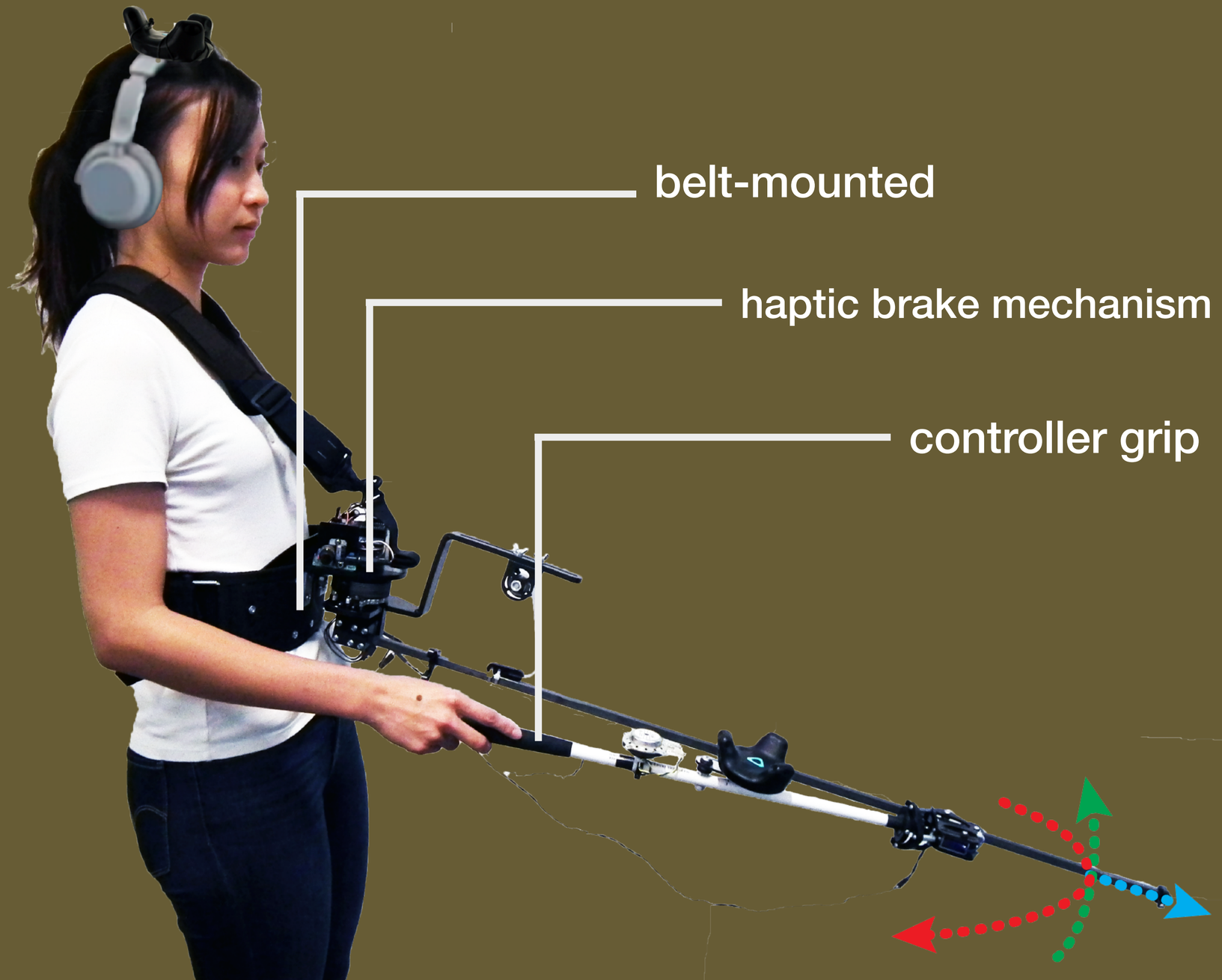
Grip & Position



- Users adapt their **grip and cane position** depending on the navigation task
- Need for:
    1. Versatility in the controller’s degrees-of-freedom such that various positions and grip styles are allowed.

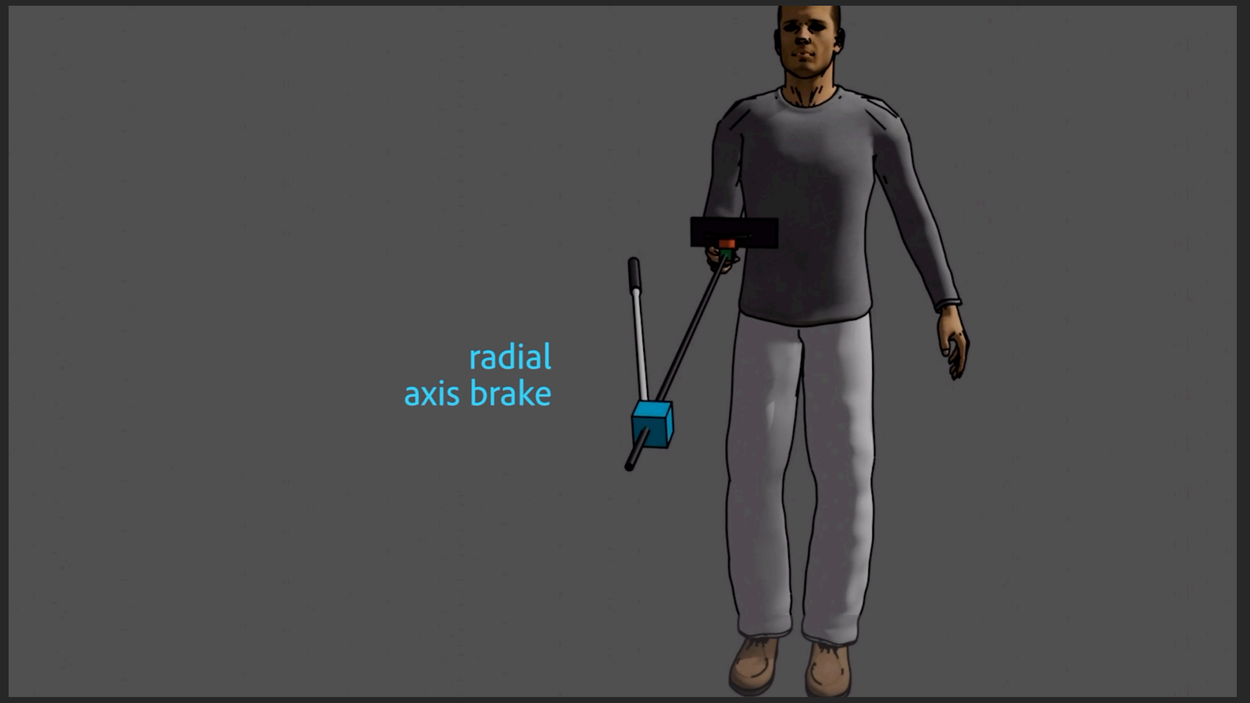

belt-mounted


belt-mounted
controller grip


belt-mounted
haptic brake mechanism
controller grip

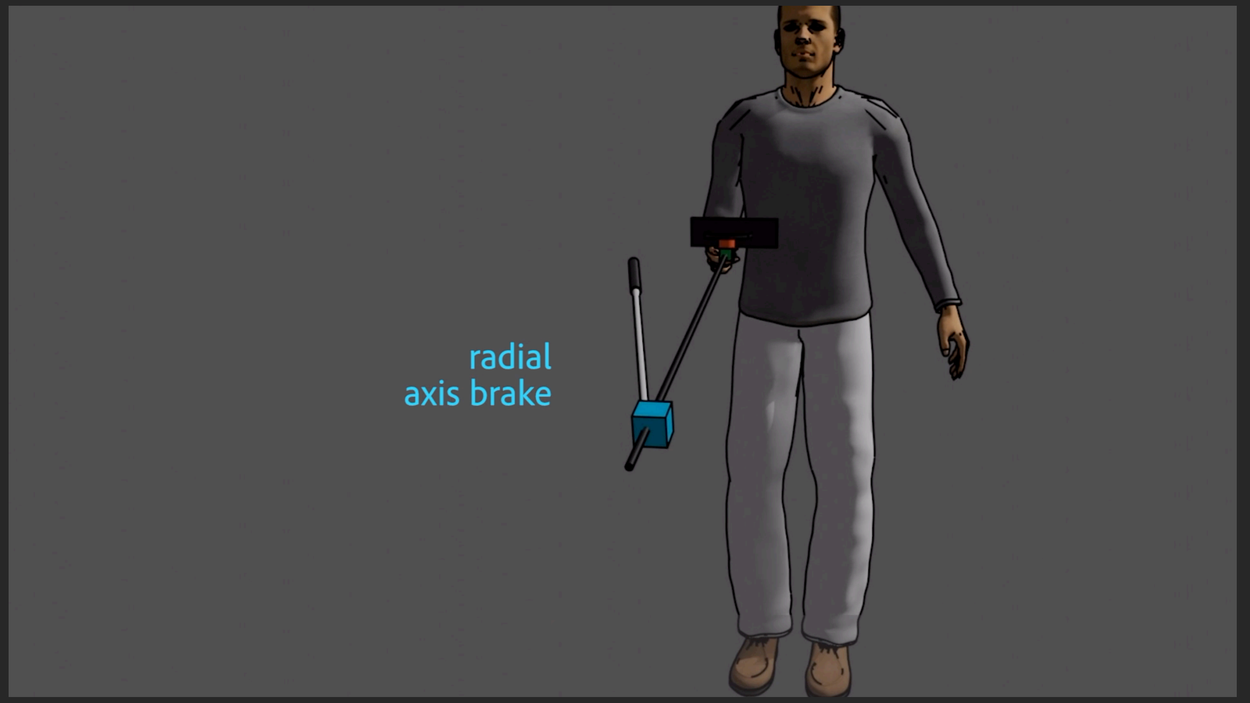
Three-Axis Brake Design

1. T**hree orthogonal axes** (motion horizontally, vertically and radially)
2. C**ontact constraints, opposing the direction of motion**



Three-Axis Brake Design

1. T**hree orthogonal axes** (motion horizontally, vertically and radially)
2. C**ontact constraints, opposing the direction of motion**

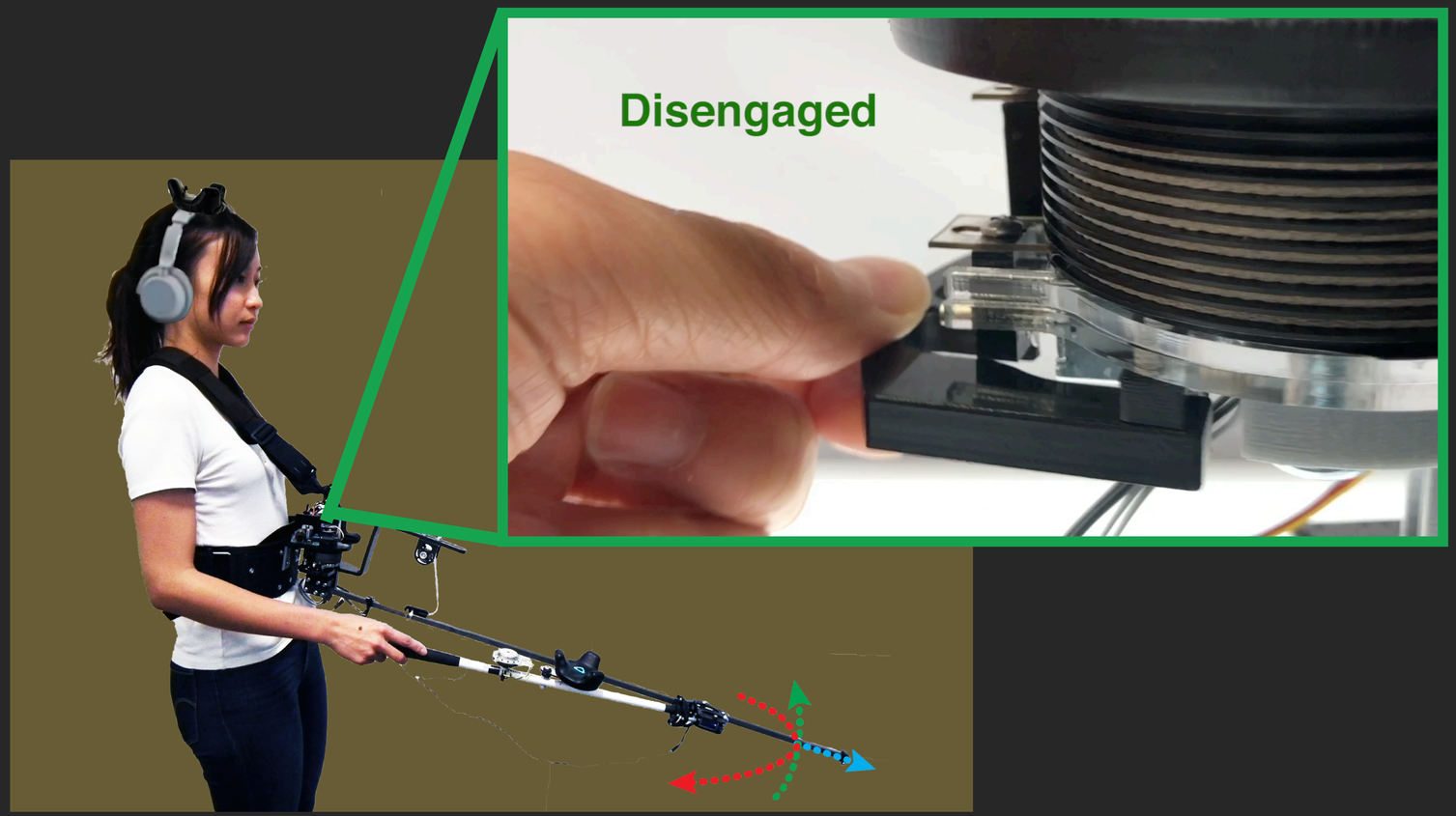


Three-Axis Brake Design

1. T**hree orthogonal axes** (motion horizontally, vertically and radially)
2. C**ontact constraints, opposing the direction of motion**

Three-Axis Brake Design

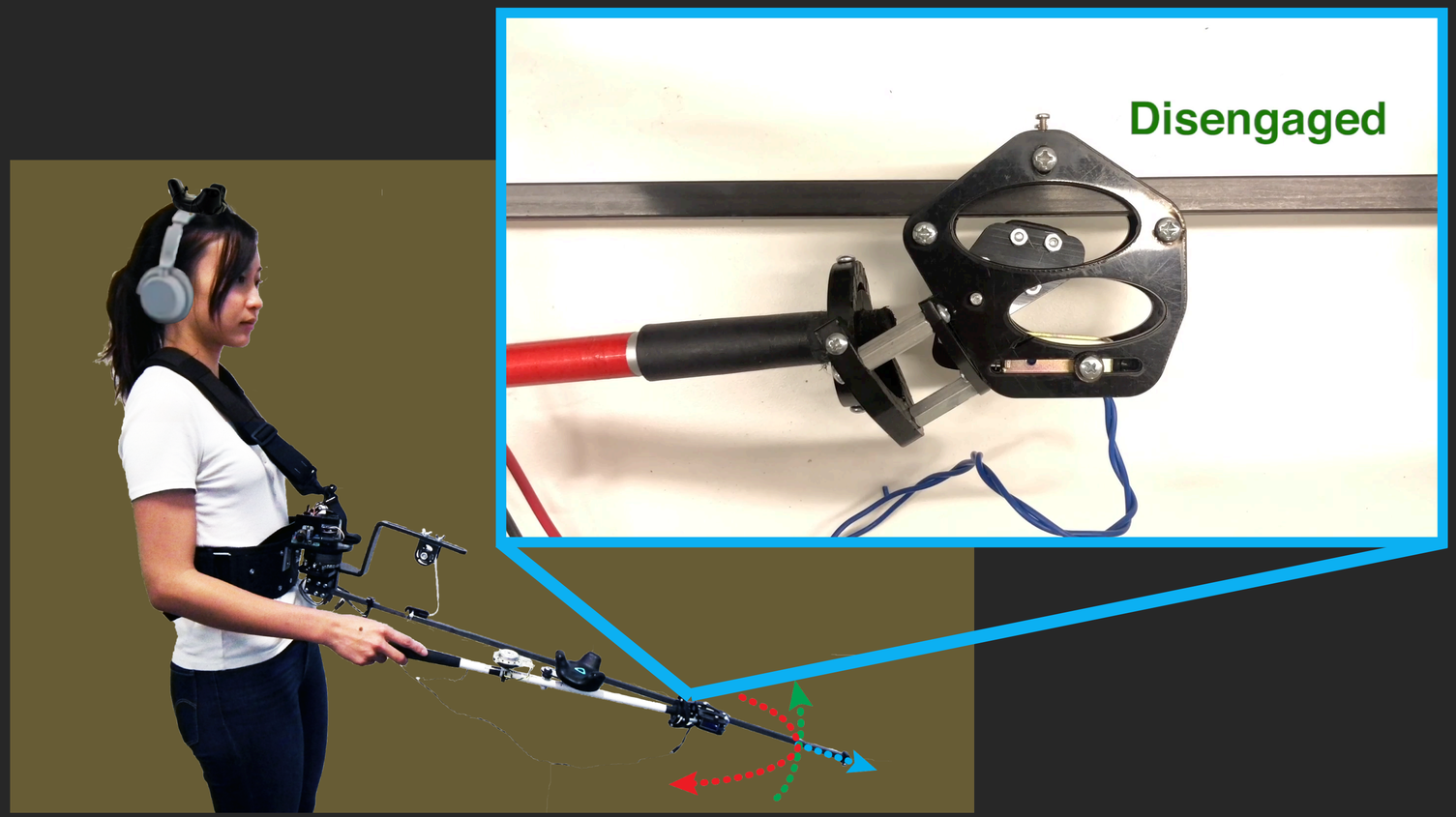
1. T**hree orthogonal axes** (motion horizontally, vertically and radially)
2. C**ontact constraints, opposing the direction of motion**



- **Bidirectional**
- **Asymmetric**
- **Fast actuation** speed
- Brake force that can be modulated

Three-Axis Brake Design

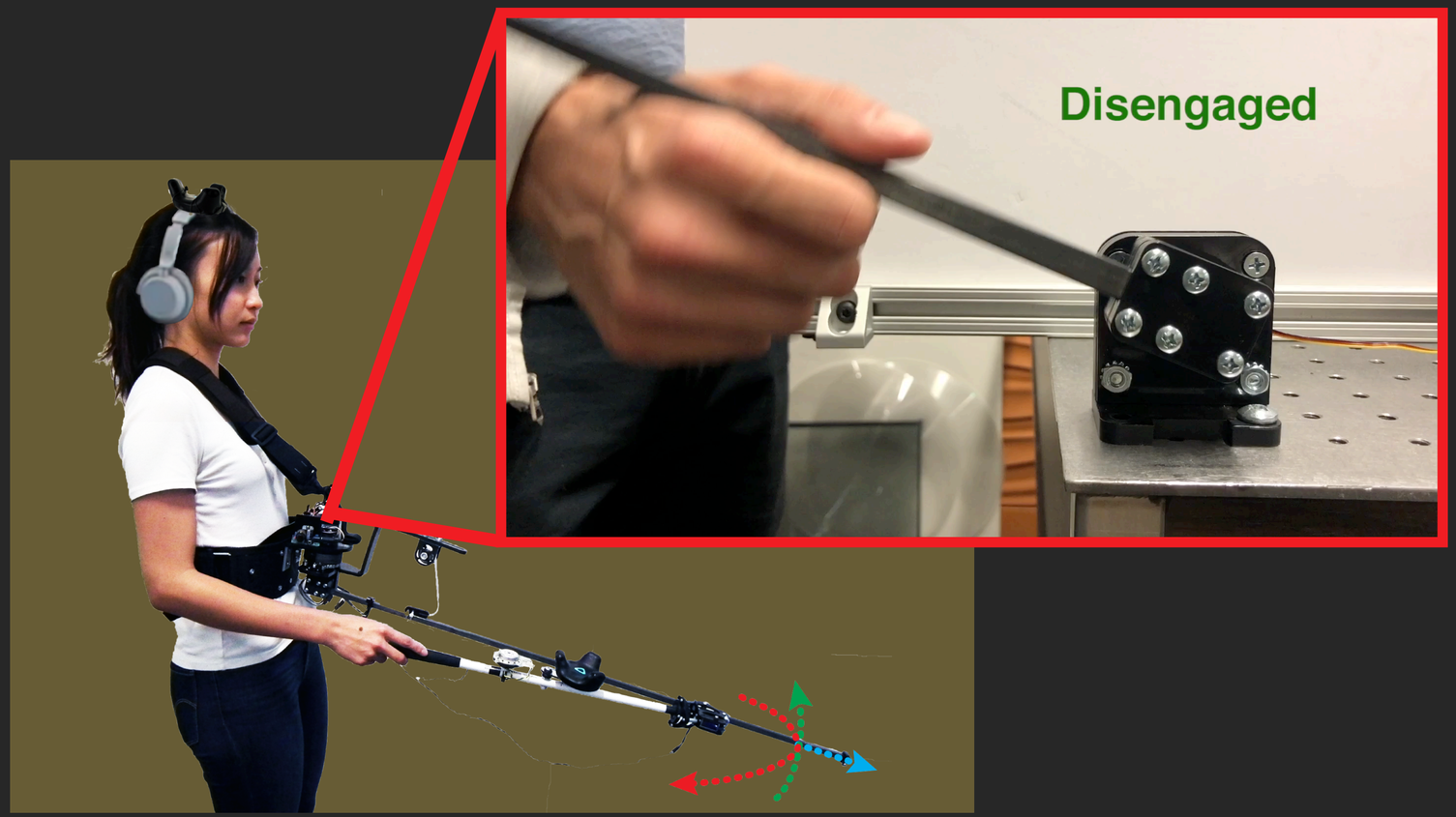
1. T**hree orthogonal axes** (motion horizontally, vertically and radially)
2. C**ontact constraints, opposing the direction of motion**



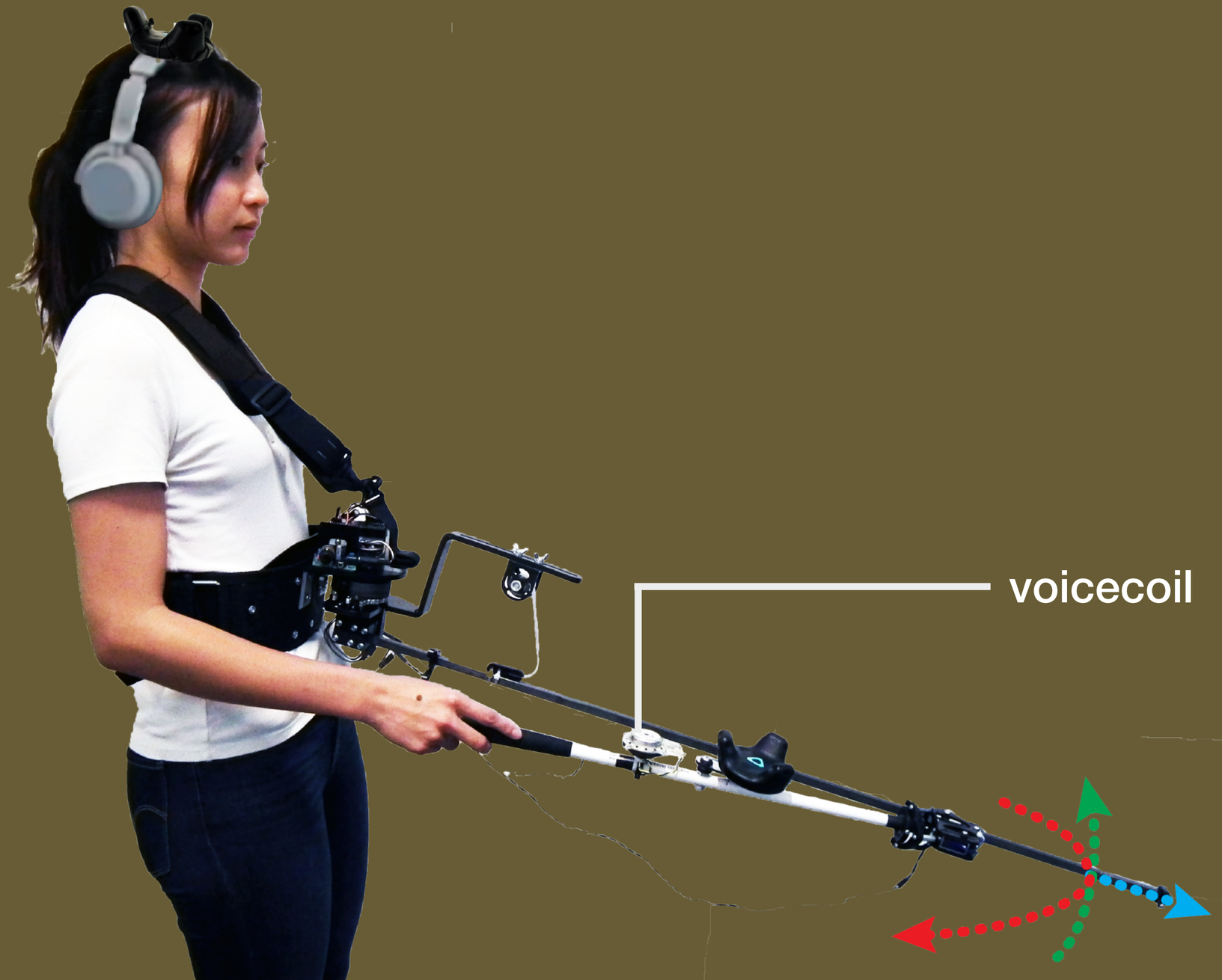
- **Unidirectional**
- Asymmetric
- Fast actuation speed

Three-Axis Brake Design

1. T**hree orthogonal axes** (motion horizontally, vertically and radially)
2. C**ontact constraints, opposing the direction of motion**

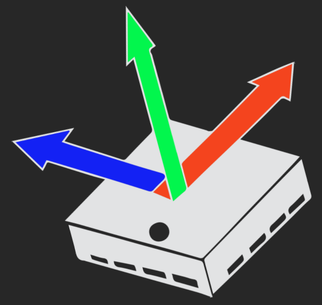


- Bidirectional
- Asymmetric
- **High torque**

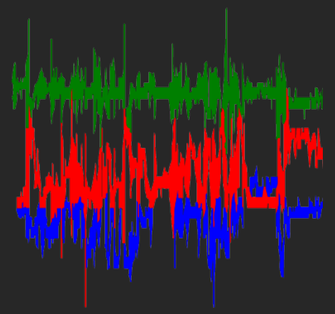

voicecoil

Surface Textures

Record



Accelerometer



Principal Component Analysis

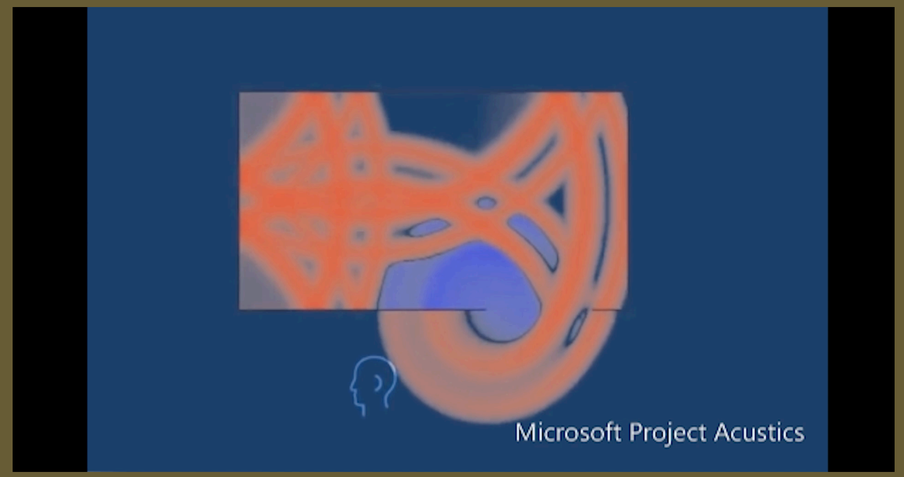
Adjust based on collision speed

Kuchenbecker, K. J., Yoshioka, T., & Romano, J. M. (2010). Automatic Filter Design for Synthesis of Haptic Textures from Recorded Acceleration Data.

Spatial Audio with Wave-Based Simulation

Spatial Audio with Wave-Based Simulation

stereo headphones

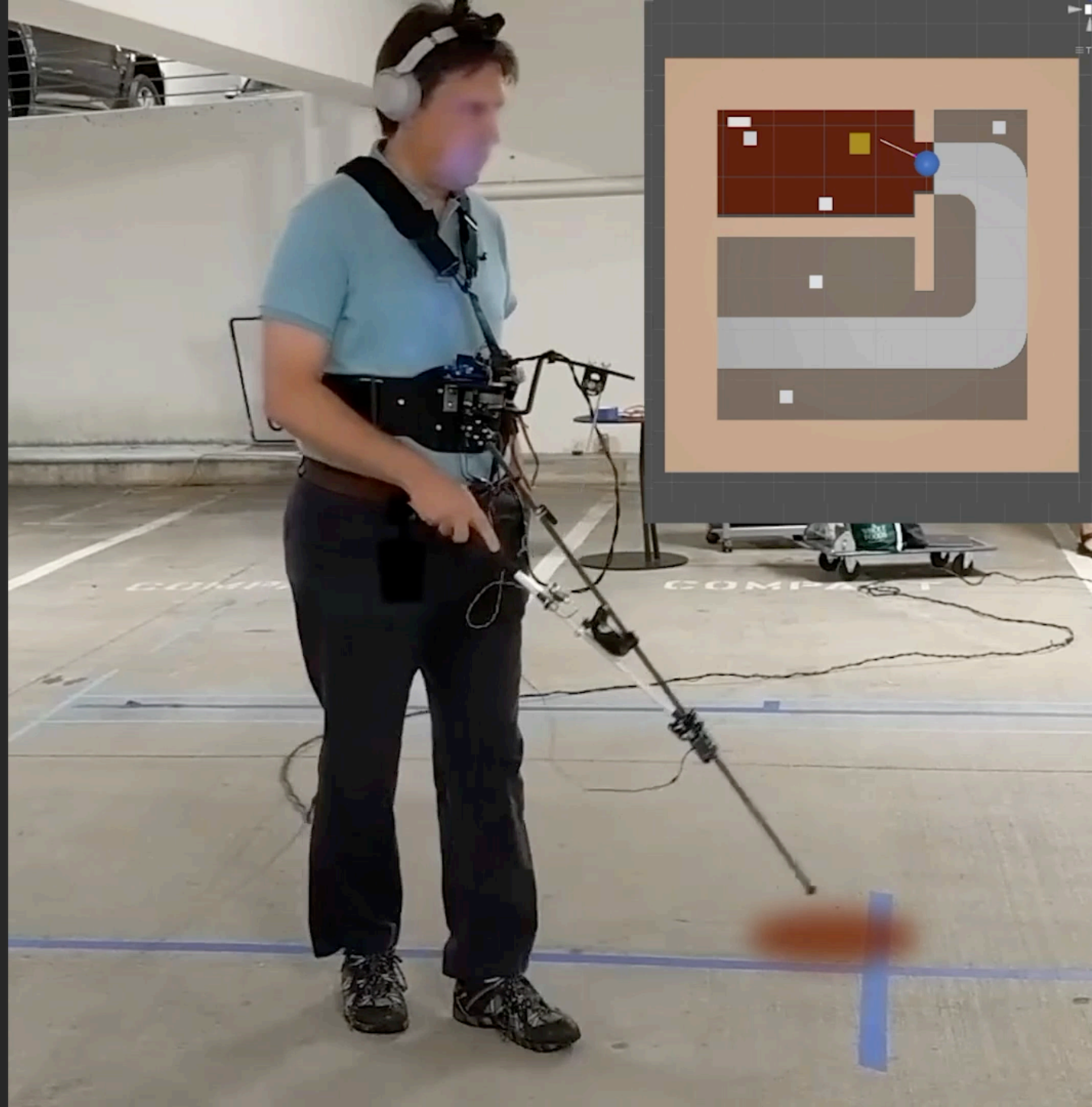


Raghuvanshi, N., & Snyder, J. (2018). Parametric directional coding for precomputed sound propagation. *ACM Transactions on Graphics (TOG)*, *37*(4), 1-14

aka.ms/Project-Triton

Evaluation

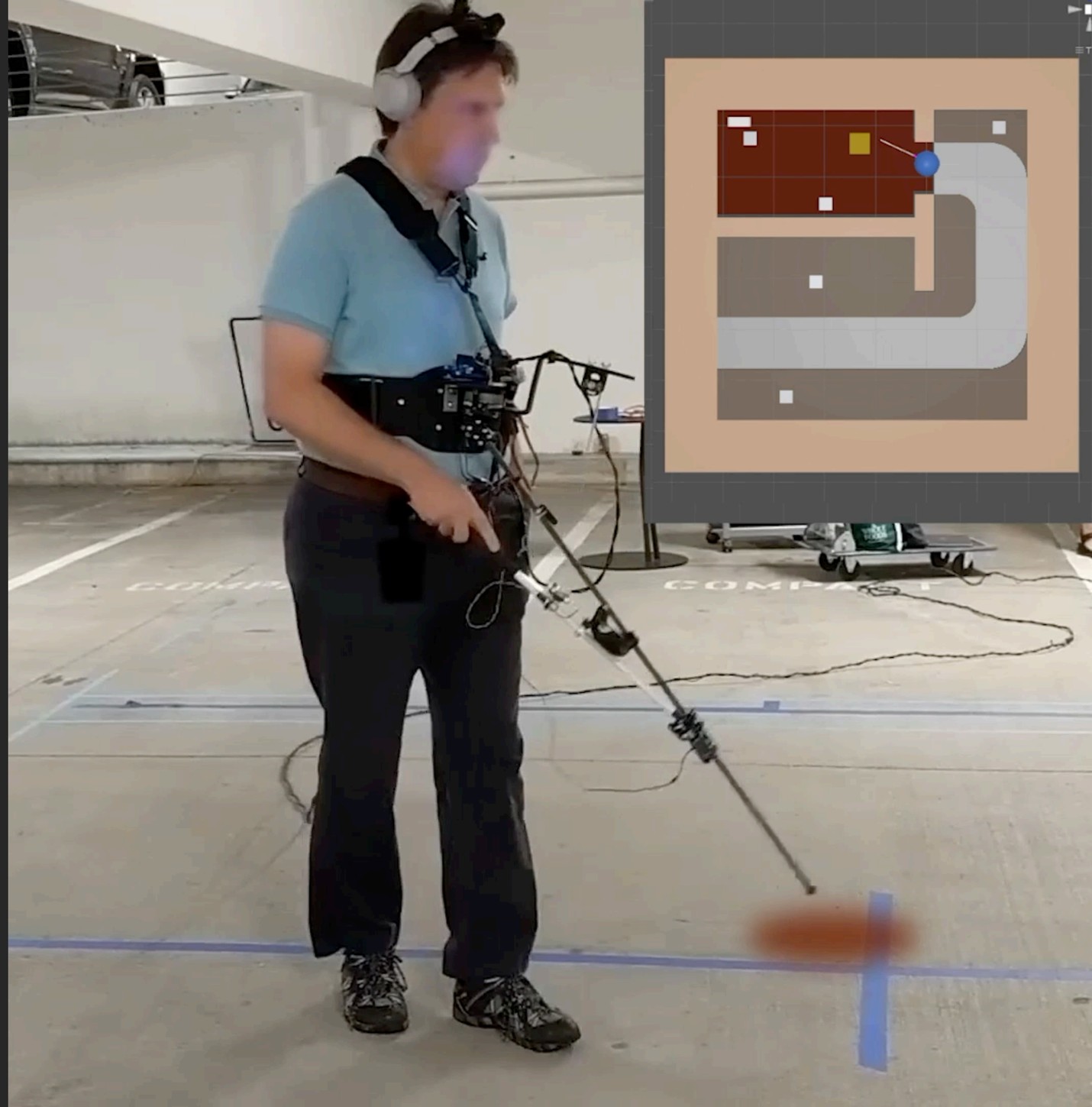
- Assess how the prototype enables independent navigation



Evaluation

- Assess how the prototype enables independent navigation

- Using the sense of touch and hearing, and apply known Orientation & Mobility skills



Evaluation Goals

Evaluation Goals

Realism

1. Can participants apply the same knowledge and skills in using their (physical) white cane to effectively and independently navigate the VE using the virtual cane?

Evaluation Goals

Realism

1. Can participants apply the same knowledge and skills in using their (physical) white cane to effectively and independently navigate the VE using the virtual cane?

Wayfinding

Evaluation Goals

Realism

1. Can participants apply the same knowledge and skills in using their (physical) white cane to effectively and independently navigate the VE using the virtual cane?

Wayfinding

2. Will repeated navigation of the same VE lead to increased egocentric and allocentric familiarity of the space?

Scavenger Hunt in VR

- Navigating a map (6x6m)
- Goals:
  1. Find as many targets
  2. Avoid collisions with hazards and room geometry

Scavenger Hunt in VR

- Navigating a map (6x6m)
- Goals:
  1. Find as many targets
  2. Avoid collisions with hazards and room geometry

Game Design

Cane techniques divided into four categories of function (APH Guidelines):

Rosen, S. (n.d.). APH Tech Long Cane Techniques: Study Guide. Retrieved from https://tech.aph.org/sbs/04_sbs_lc_study.html#12

Game Design

Cane techniques divided into four categories of function (APH Guidelines):

1. detection
   —> locate targets

Rosen, S. (n.d.). APH Tech Long Cane Techniques: Study Guide. Retrieved from https://tech.aph.org/sbs/04_sbs_lc_study.html#12

Game Design

Cane techniques divided into four categories of function (APH Guidelines):

1. detection
   —> locate targets
2. negotiating obstacles in the travel path
   —> avoid hazards

Rosen, S. (n.d.). APH Tech Long Cane Techniques: Study Guide. Retrieved from https://tech.aph.org/sbs/04_sbs_lc_study.html#12

Game Design

Cane techniques divided into four categories of function (APH Guidelines):

1. detection
   —> locate targets
2. negotiating obstacles in the travel path
   —> avoid hazards
3. negotiating doors
   —> navigating between rooms

Rosen, S. (n.d.). APH Tech Long Cane Techniques: Study Guide. Retrieved from https://tech.aph.org/sbs/04_sbs_lc_study.html#12

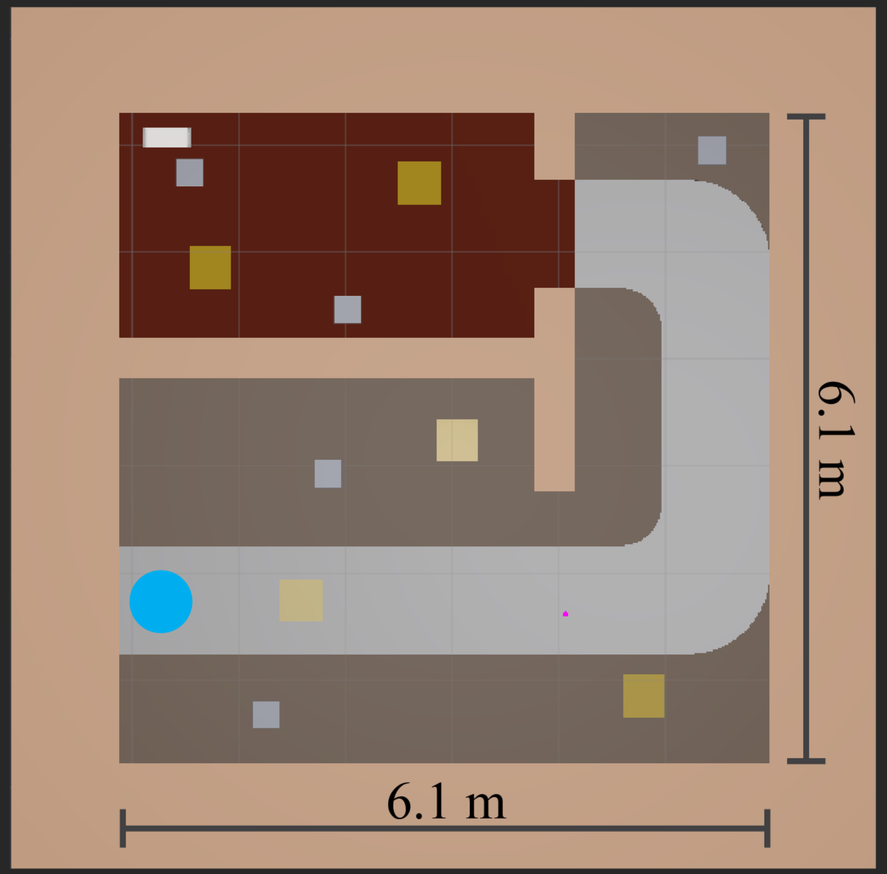
Game Design

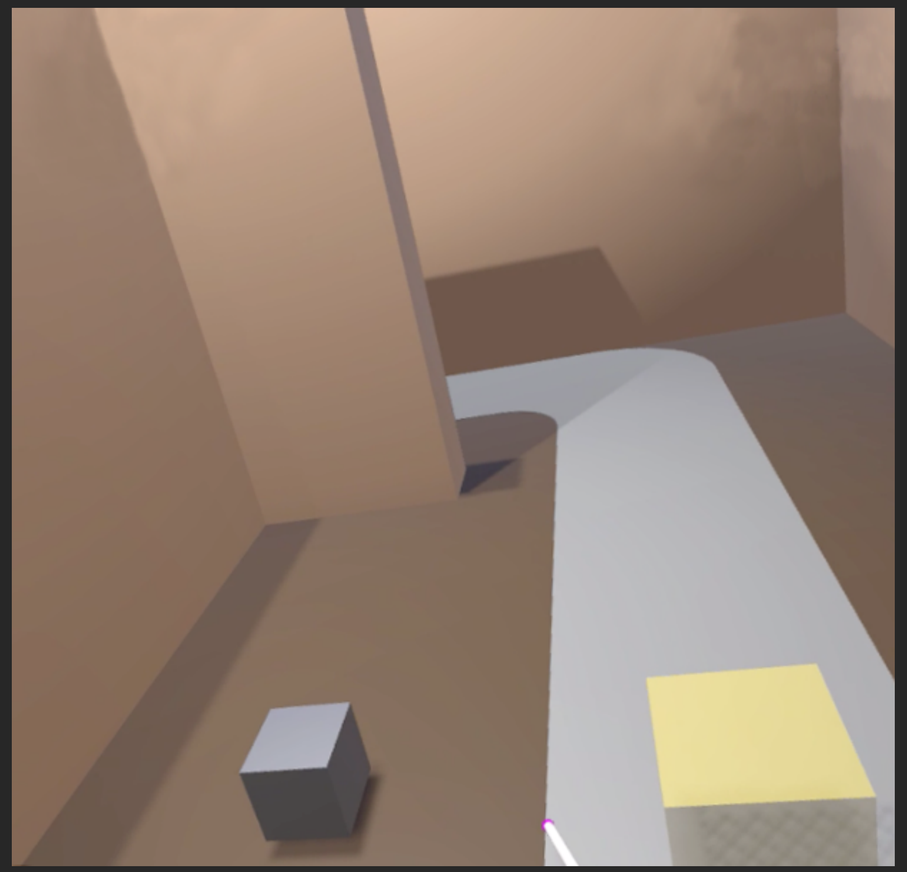
Cane techniques divided into four categories of function (APH Guidelines):

1. detection
   —> locate targets
2. negotiating obstacles in the travel path
   —> avoid hazards
3. negotiating doors
   —> navigating between rooms
4. following a shoreline
   —> avoiding walls and following a walkway

Rosen, S. (n.d.). APH Tech Long Cane Techniques: Study Guide. Retrieved from https://tech.aph.org/sbs/04_sbs_lc_study.html#12

- 5 targets
- 5 hazards
- 1 radio source





Participants

- 8 legally blind users
- All participants used a white cane as their preferred navigation aid with at least 5 years of experience
- Four used an NFB **carbon fiber** cane with a **metal glide tip**
- Four used a folding **aluminum** cane with a **nylon pencil tip**

Results

Game Statistics

Game Statistics

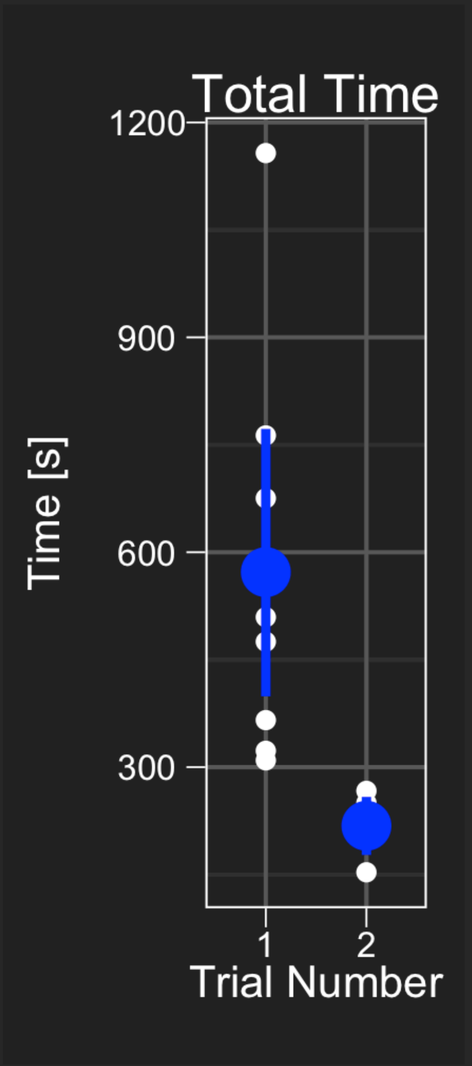
- Participants were successful in finding the targets to complete the game

Game Statistics

- Participants were successful in finding the targets to complete the game
- Became more familiar with the environment over time

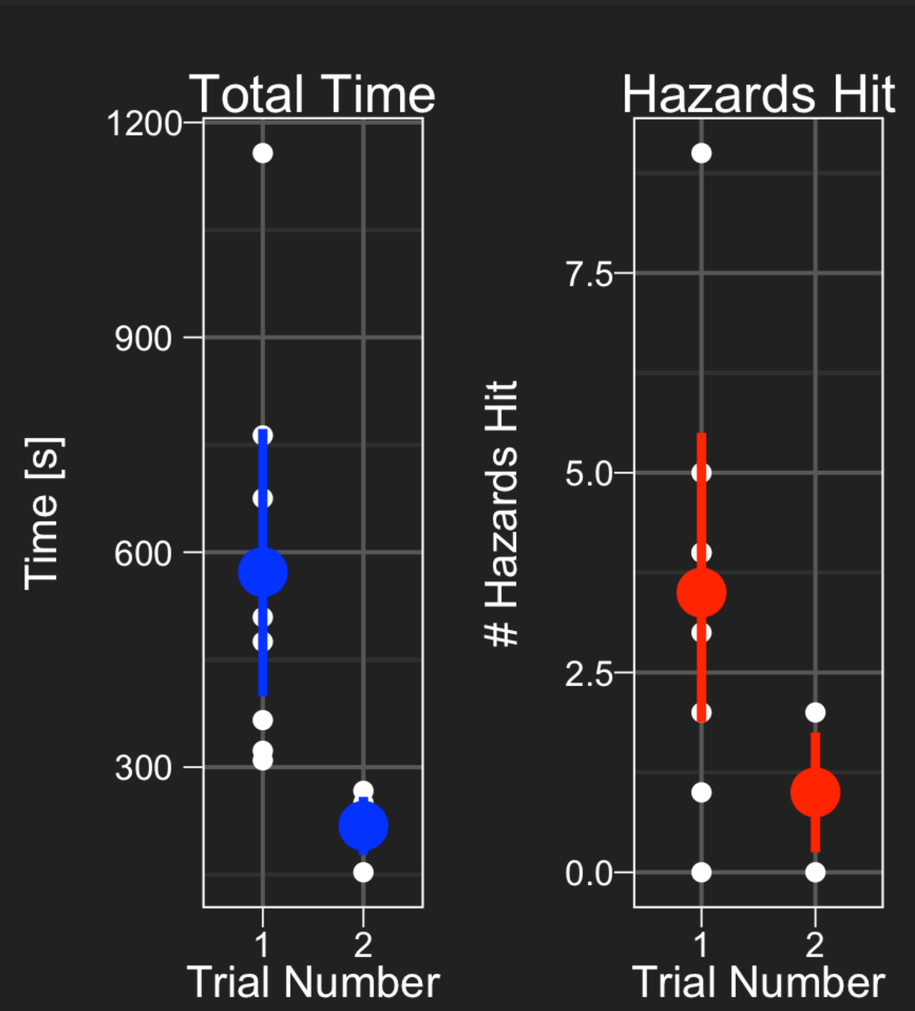
Game Statistics

- Participants were successful in finding the targets to complete the game
- Became more familiar with the environment over time



Game Statistics

- Participants were successful in finding the targets to complete the game
- Became more familiar with the environment over time

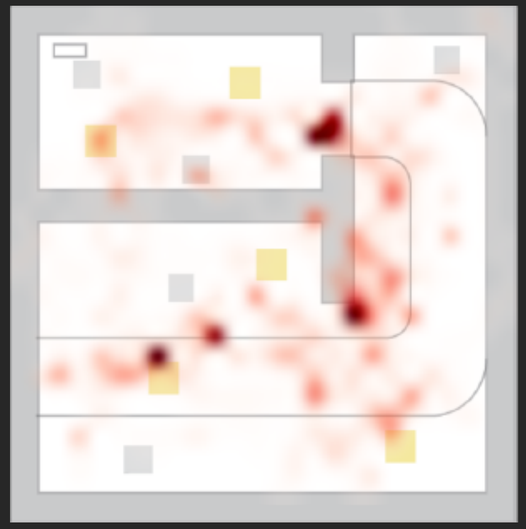


Game Statistics

- Similar to navigating the real world, participants had more difficulty navigating narrow spaces, such as corners and doorways

Game Statistics

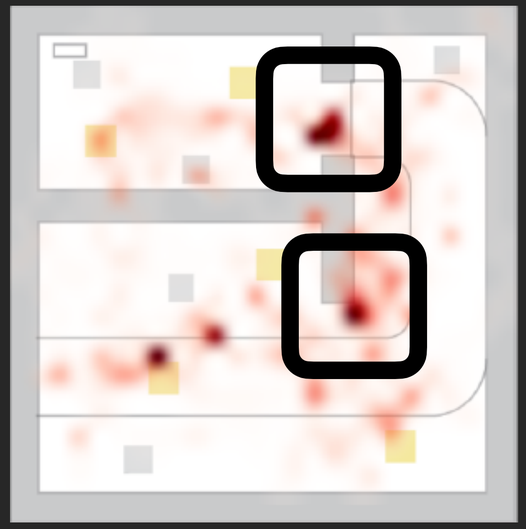
- Similar to navigating the real world, participants had more difficulty navigating narrow spaces, such as corners and doorways



Darker regions indicate the locations where participants spent longer time

Game Statistics

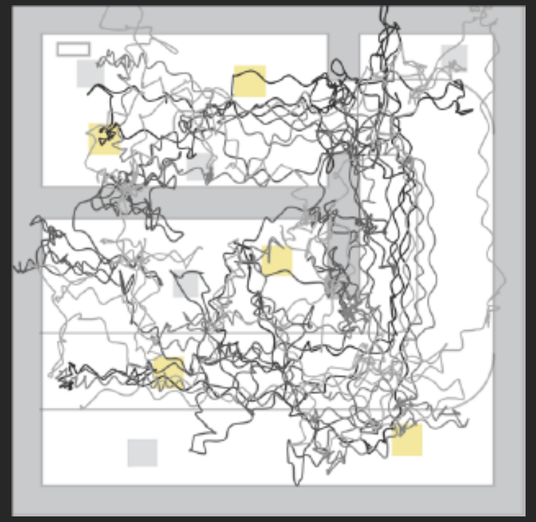
- Similar to navigating the real world, participants had more difficulty navigating narrow spaces, such as corners and doorways



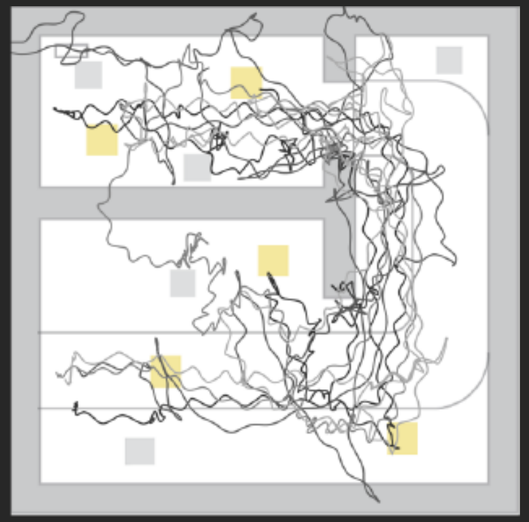
Darker regions indicate the locations where participants spent longer time

Game Statistics

- Similar to navigating the real world, participants had more difficulty navigating narrow spaces, such as corners and doorways



Trial 1

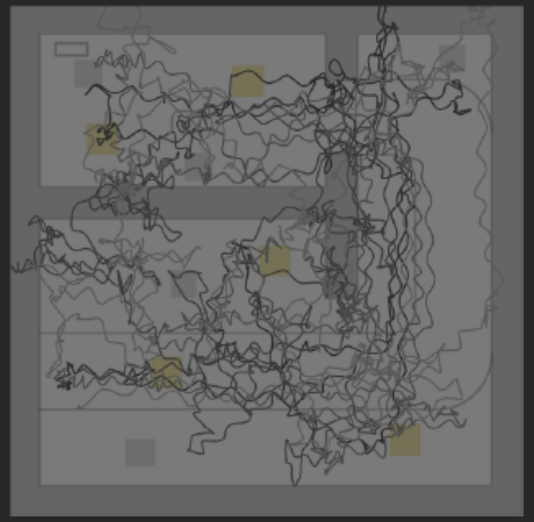


Trial 2

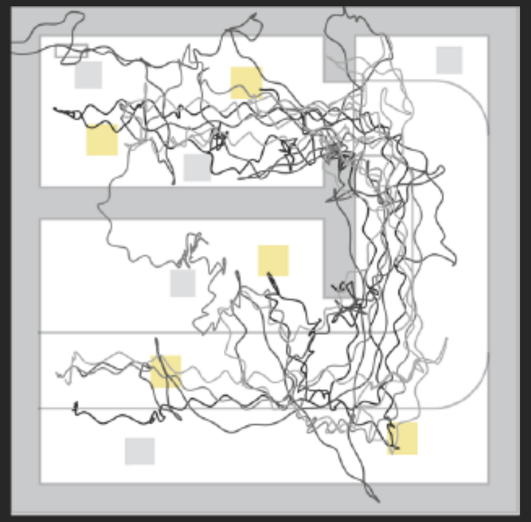
Results

Game Statistics

- Similar to navigating the real world, participants had more difficulty navigating narrow spaces, such as corners and doorways



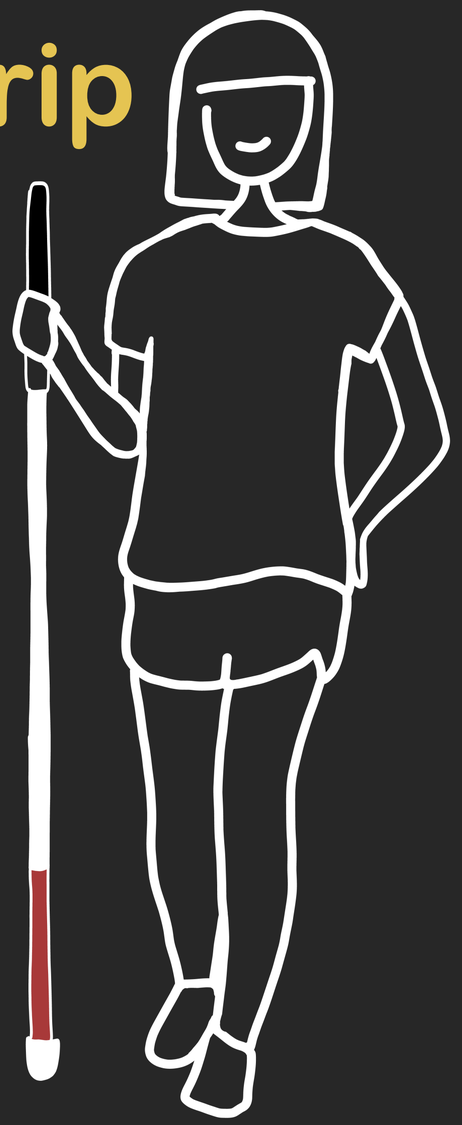
Trial 1



Trial 2

Cane Techniques & Grip

- Participants **relied on their typical cane strategies**
- Most common **constant-touch** and **two-point contact**
  - *“When I use my cane, I don’t glide, I usually do my tap motions. And that’s what I did in the game, but I did glide a bit just to see. So, I did a little bit of both and they were both spot on” (P2).*



Integrating Feedback

Kinesthetic feedback used for: **understanding the geometry**, and **finding open spaces** to walk in

- *"I **felt the clear entries** where I didn't encounter walls" (P5)*
- *"[It helped me detect] **where barriers were**, depending on the barrier type… how far across does it go…" (P1).*

Integrating Feedback

Kinesthetic feedback used for: **understanding the geometry**, and **finding open spaces** to walk in

- *"I **felt the clear entries** where I didn't encounter walls" (P5)*
- *"[It helped me detect] **where barriers were**, depending on the barrier type… how far across does it go…" (P1).*

Results

Integrating Feedback

Audio provided spatial information

- *"From the target audio cue, **I could know which direction to go** and **approximately how far** I had to go" (P8).*
- *"**The volume, depending on where you were helped a lot**; because that's what I usually use [in the real world]" (P5).*
- *"The audio was super real that's why I thought there were people around me." (P6)*

Results

Integrating Feedback

Audio provided spatial information

- *"From the target audio cue, **I could know which direction to go** and **approximately how far** I had to go" (P8).*
- *"**The volume, depending on where you were helped a lot**; because that's what I usually use [in the real world]" (P5).*
- *"The audio was super real that's why I thought there were people around me." (P6)*

Results

Cane Type Preferences

Cane Type Preferences

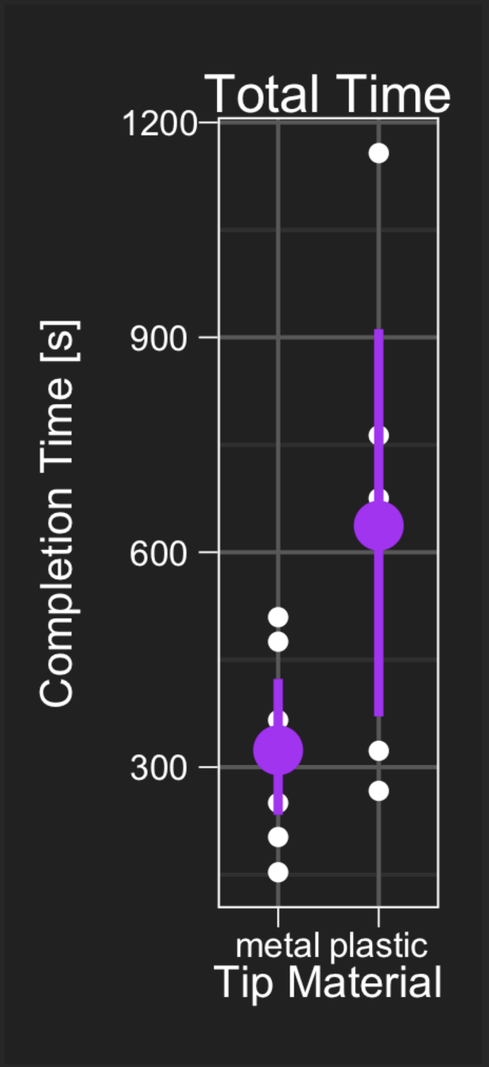
- Differences in performance between users of metal and plastic roller tips

Cane Type Preferences

- Differences in performance between users of metal and plastic roller tips
- Plastic tip users had more trouble understanding the meaning of the tactile feedback, and generally performed worse

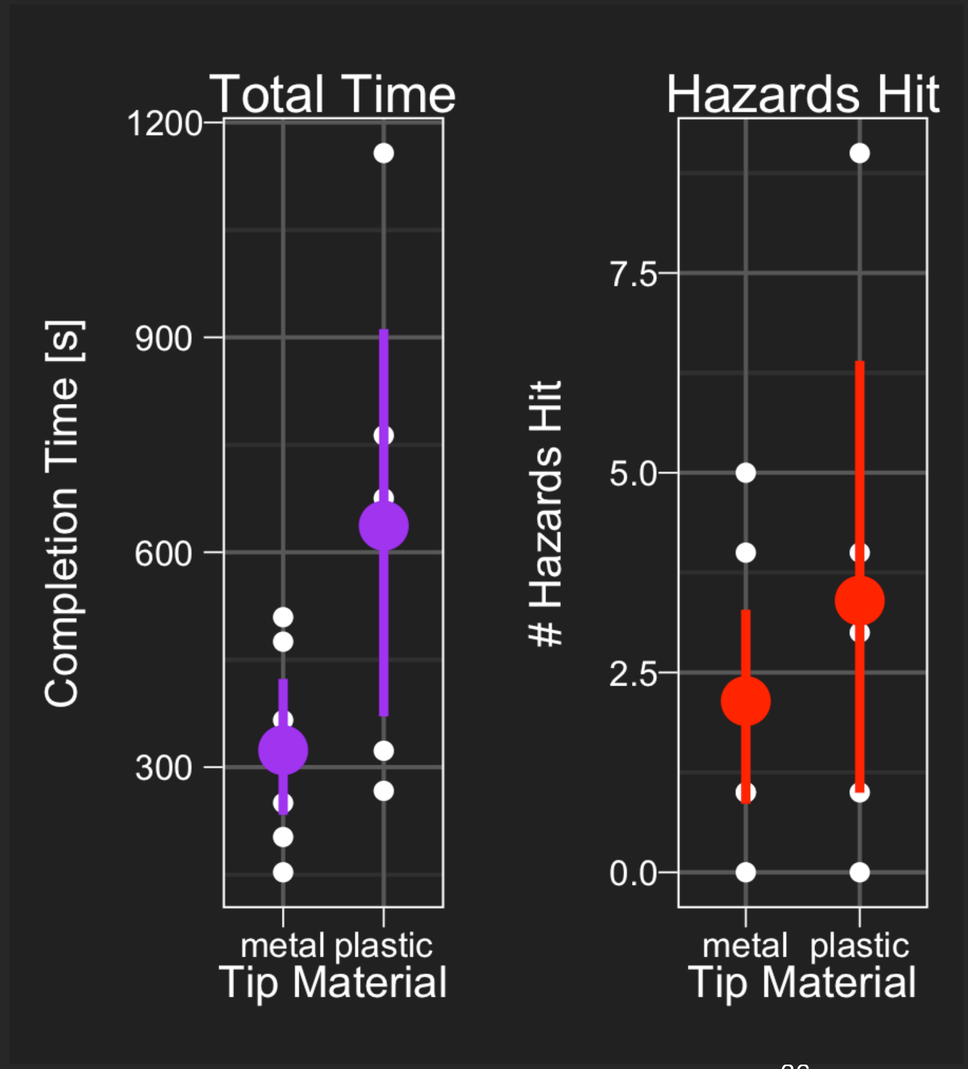
Cane Type Preferences

- Differences in performance between users of metal and plastic roller tips
- Plastic tip users had more trouble understanding the meaning of the tactile feedback, and generally performed worse

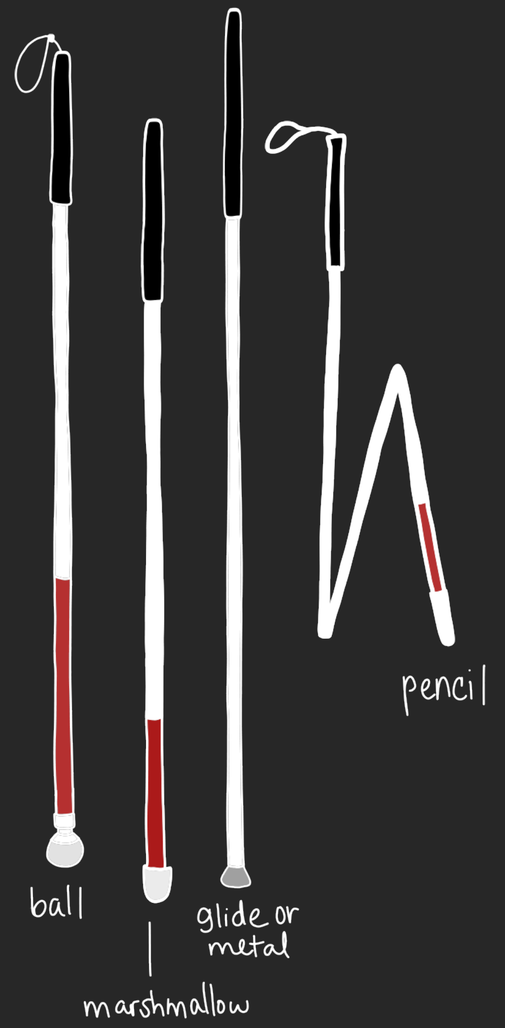


Cane Type Preferences

- Differences in performance between users of metal and plastic roller tips
- Plastic tip users had more trouble understanding the meaning of the tactile feedback, and generally performed worse

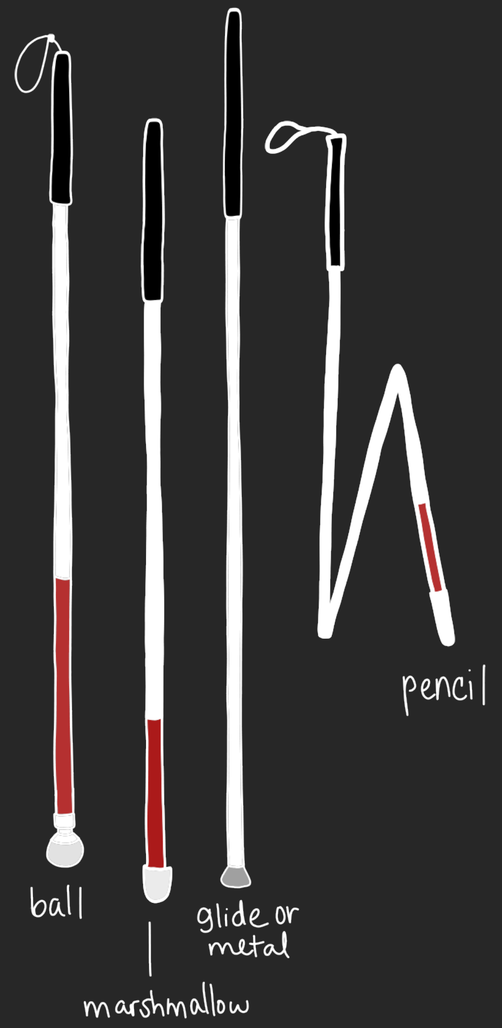


Cane Material Preferences



- Plastic-tip participants:
  - *"The cane was **vibrating a lot for reasons I don't know**".*
  - *"The **sensations are a little different**. To me. It almost felt I had like one of those, I don't know if you've seen, the NFB canes that are really flexible." (P4)*

Cane Material Preferences



- Metal-tip participants:
  - *"**What really set out was the tactile.** It seemed so real, specially outdoors…The cement was spot on…" (P2).*
  - *"The sweeping was very real… it helped me **locate what things might be**..." (P6).*

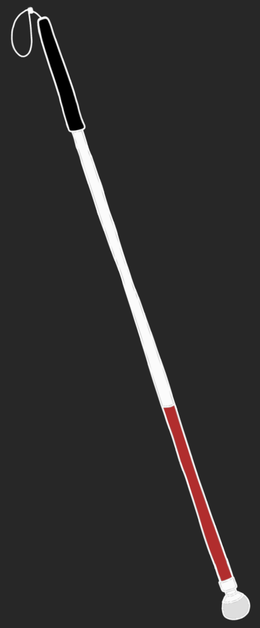
Limitations & Future Work

Diversity of user preferences that impact perception

Limitations & Future Work

Diversity of user preferences that impact perception

Modelling collisions



Limitations & Future Work

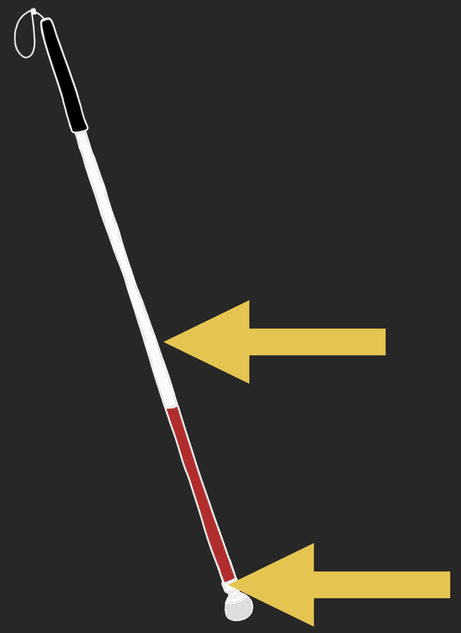
Diversity of user preferences that impact perception

Modelling collisions

Limitations & Future Work

Diversity of user preferences that impact perception

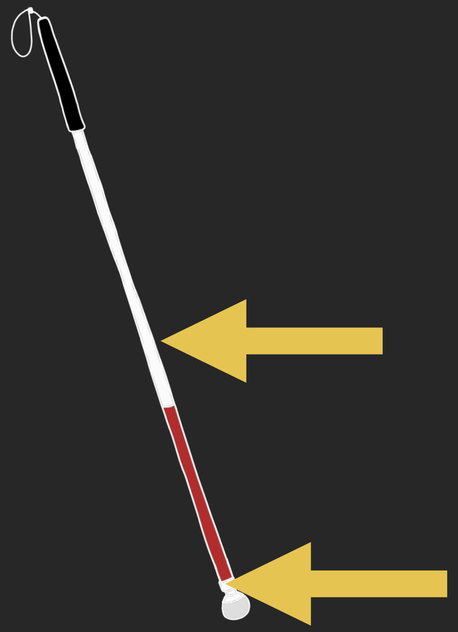
Modelling collisions



Limitations & Future Work

Diversity of user preferences that impact perception

Modelling collisions



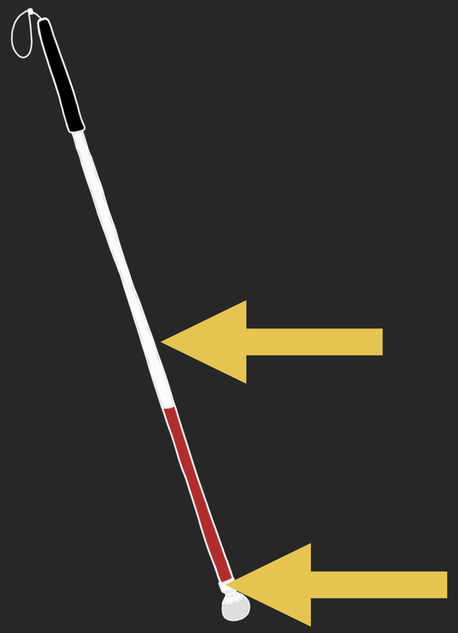
Enabling larger-scale navigation

Abtahi et al.(CHI 2019)

Limitations & Future Work

Diversity of user preferences that impact perception

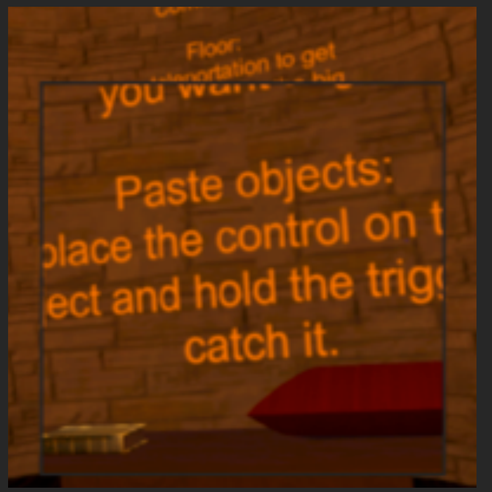
Modelling collisions



Enabling larger-scale navigation

Abtahi et al.(CHI 2019)

Enhancing user presence not just realism



SeeingVR - Zhao et al.(CHI 2019)

Conclusion

Conclusion

Conclusion

entertainment

Conclusion

entertainment

cane skills training

Conclusion

entertainment

spatial concepts
& wayfinding

cane skills training

Virtual Reality Without Vision: A Haptic and Auditory White Cane to Navigate Complex Virtual Worlds

Alexa F. Siu[1] <alexasiu.com>

Mike Sinclair[2], Rob Kovacs[3], Eyal Ofek[2],

Christian Holz[2,4], Ed Cutrell[2]

1. Stanford University, 2. Microsoft Research,

3. Hasso Plattner Institute, 4. ETH Zurich