Virtual Embodiment of Human Feet in the Neurorobotics Platform

Jason Janse van Rensburg

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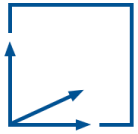


Final: Bachelor Informatik: Games Engineering

Supervisor: Sandro Weber

Introduction / Motivation

- Virtual environment **should affect** user's body
  - **Can‘t exert forces** on user's **real body**
  - User can **do things** he **should not** be able to
- Idea: **separate virtual** & **real** body
- Problem: **Discrepancies** between virtual & real body occur

Problem Description: Issues

- Encourage user to **prevent** discrepancies
- **Make** user **aware** of discrepancies
- Help user **resolve** discrepancies
- Have a low negative impact on user's **immersion**

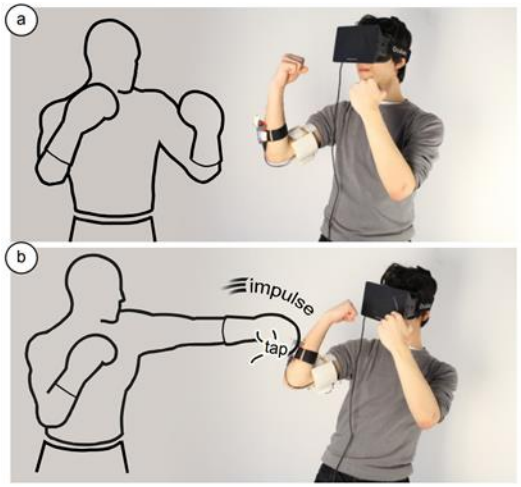
--> Preserve user's **Sense of Embodiment**

Existing Solutions / Related Work

- Haudenschild
  Virtual Embodiment: Dealing with Discrepancies between Virtual and the Real Body [1]:
  - Various **Feedback Mechanisms** for Discrepancies at **Hands & Head**: Optical, Auditory, Haptic
- Caserman et al.
  Real-time body tracking in virtual reality using a Vive tracker [2]:
  - Evaluated multiple methods of **full body tracking** in VR:
    - Microsoft Kinect
    - Multi-cam + motion capture suits (eg. OptiTrack)
    - Inertial measurment units attached to limbs (eg. PrioVR)
  - Propose system combining **Vive Trackers** with **Inverse Kinematics** due balance of **accuracy** and **ease of use**

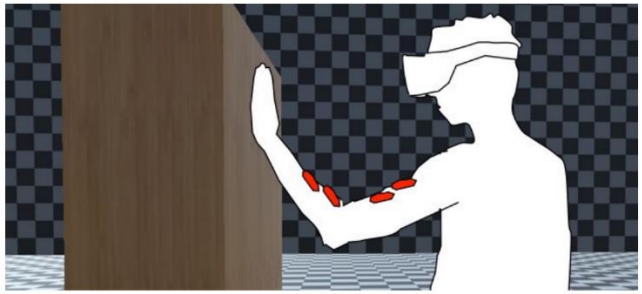
Existing Solutions / Related Work

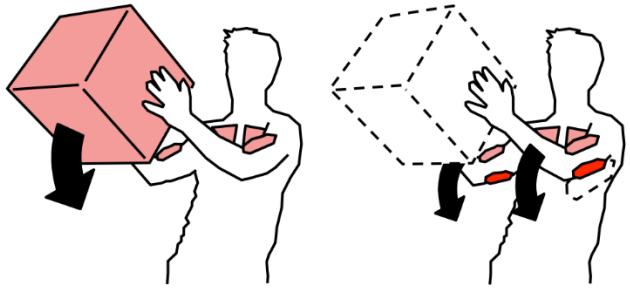
- Boldt et al.
  You Shall Not Pass: Non-Intrusive Feedback for Virtual Walls in VR Environments with Room-Scale Mapping [3]:
  - Most commercial VR applications provide **no sensory feedback** when interacting with wall s, instead **avoid such situations**
  - Implemented **feedback mechanisms** in experiment:
    - HMD-wall collisions: black vision, muffled background music
    - Controller-wall collisions: knocking sound, vibration
  - Participants with feedback mechanisms enabled were **significantly less likely to walk through walls** than control group
- Lopes et al.
  Impacto: Simulating Physical Impact by Combining Tactile Stimulation with Electrical Muscle Stimulation [4]:
  - Device using solenoid for **tactile stimulation**, and **EMS** for simulating **impulse**
  - Attachable to limb or props (eg. bat to simulate hitting a ball)



Existing Solutions / Related Work

- Lopes et al.
  Providing Haptics to Walls & Heavy Objects in Virtual Reality by Means of Electrical Muscle Stimulation [5]:
  - Use **EMS** to create sensation of **heavy** or **immovable** objects





- Insko
  Passive Haptics Significantly Enhances Virtual Environments [6]:
  - **Mimic** virtual environment with **simple props** in real world

Goals of this Thesis

- Assess **importance** and **usefulness** of additional **feedback** mechanisms for discrepancies at the **feet**
  - In **Neurorobotics Platform Unity3D Client**
  - Applicable to **other use cases** as well
- Improve **Sense of Embodiment** for users of the NRP Unity3D Client

Critical Research Issues

How to increase Sense of Embodiment? [7]
--> Increase following components:

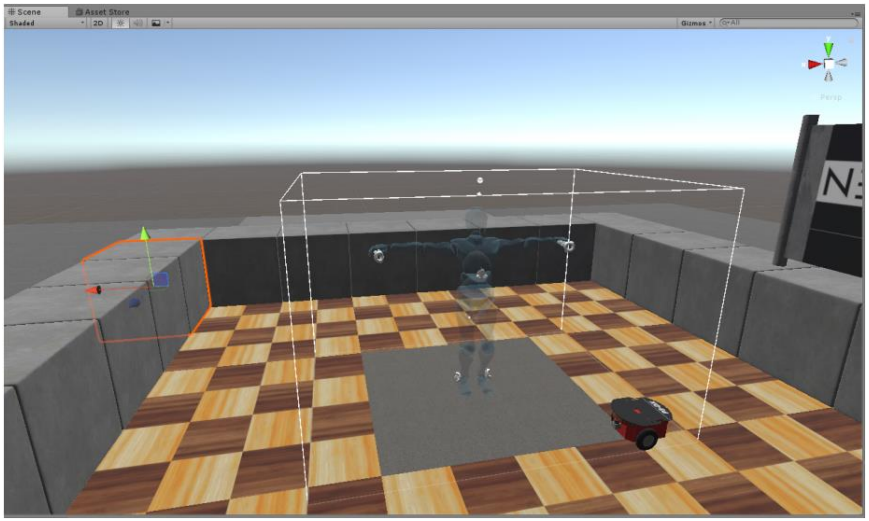
- Sense of **self-location**
  - Maintain **visuospatial perspective**
  - Matching **vestibular signals**
- Sense of **agency**
  - **Intended** and **percieved** action should **match**
  - **Low latency** between action and percieved action
- Sense of **body ownership**
  - Visual, tactile and kinesthetic **stimuli in sync**
  - **Morphological similarity** of virtual & real body

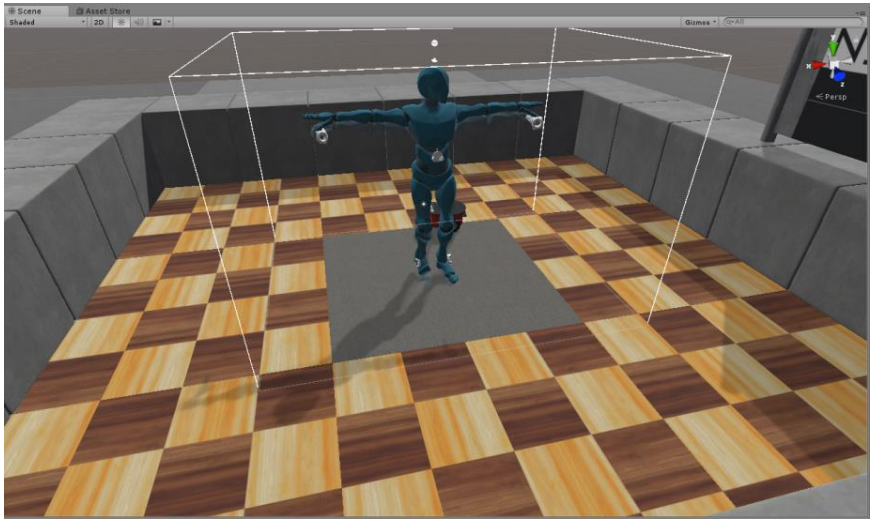
Proposed Work / Approach

- Come up with **visual**, **auditory**, **haptic** feedback mechanisms
- **Implement** them in NRP Unity3D Client (for feet, as well as hands & head)
- **Evaluate** feedback mechanisms for **feet** in a user study

Implementation

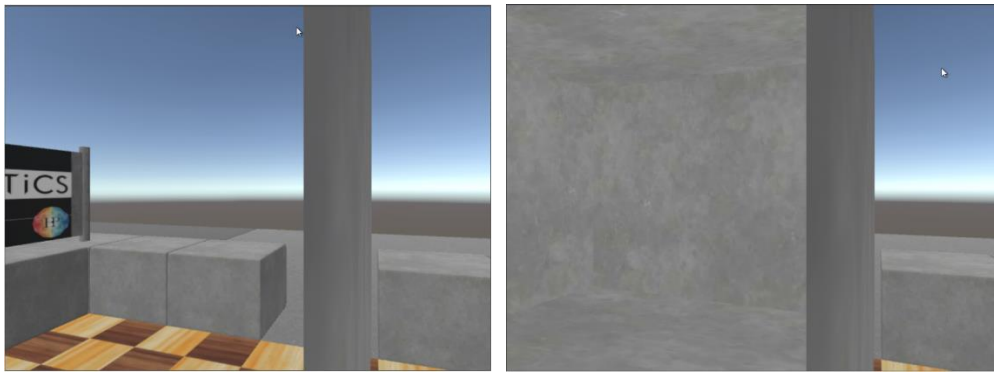
- Existing implementation:
  - **Local** avatar
    - Unity3D builtin Inverse Kinematics
    - IK targets attached to controllers & HMD
    - Follows user‘s movements
    - **No physics** interaction
  - **Remote** avatar
    - Simulated on NRP
    - **Physics** interaction on NRP
    - Tries to follow local avatar
- Added system to assign correct trackers & controllers at runtime



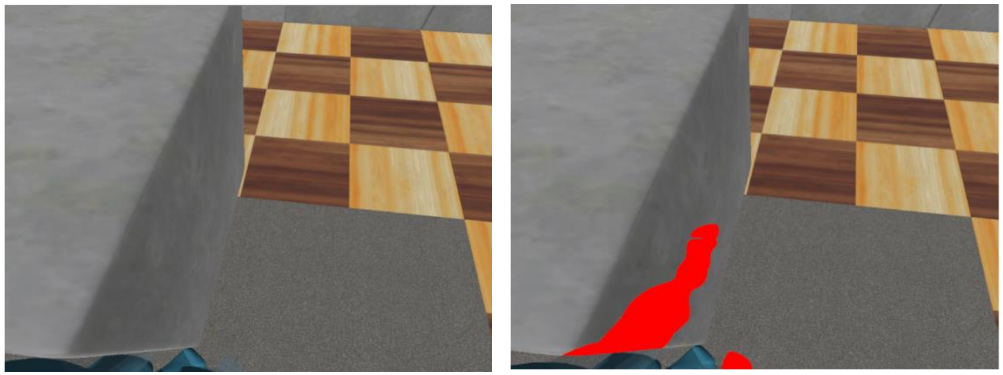


Implementation

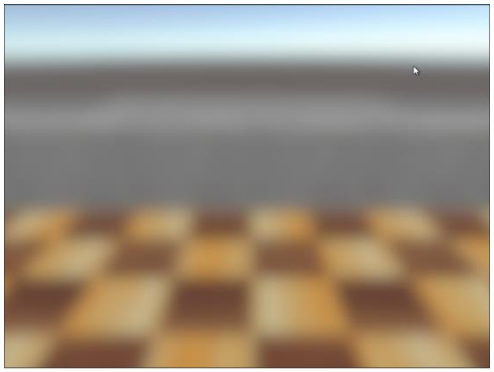
- Render interior of objects:



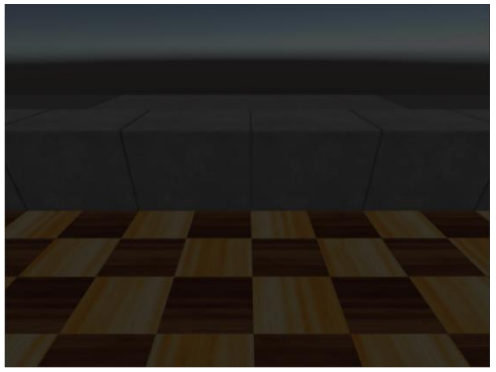
- Avatar visible in objects:



- Blur:

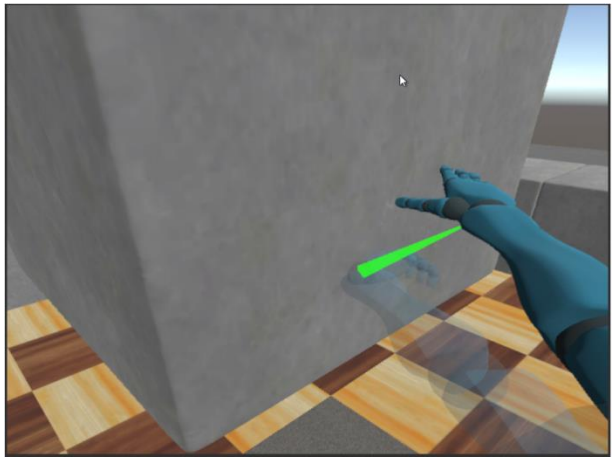


Fade to black:



Implementation

- Line effect:



- Haptic effect:
  - Controller vibrates in **pulses**
    - Larger discrepancy --> longer pulse
    - Longer duration of discrepancy --> more frequent pulses
  - **Vive Trackers** have **no vibration** motors :(

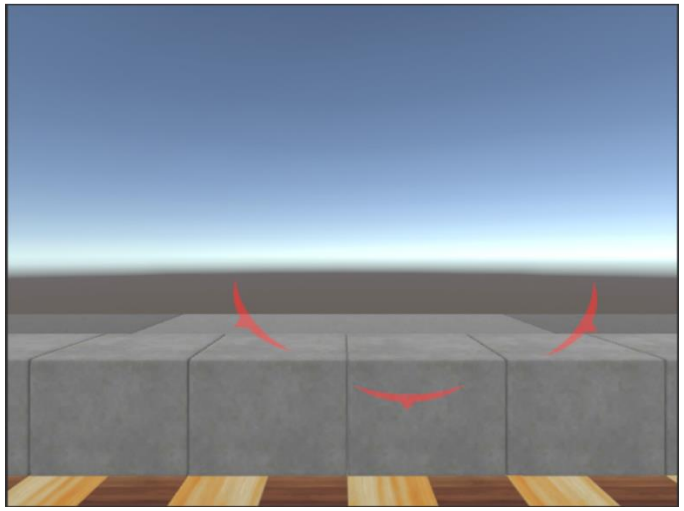
Implementation

[8]

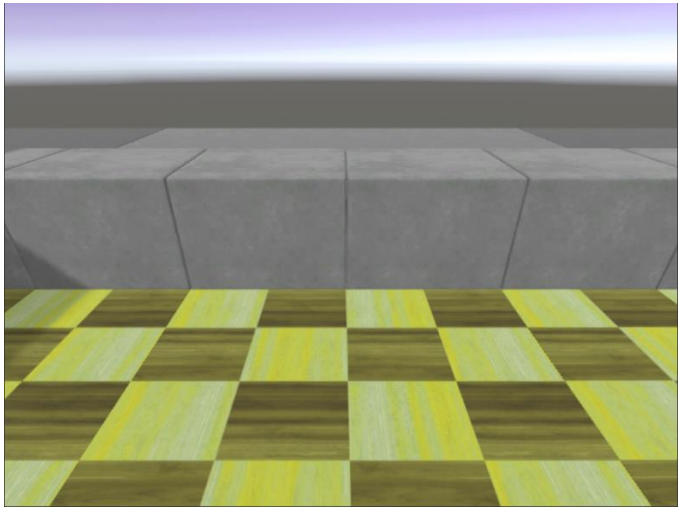
- Geiger sound effect:
  - Mimics sound of a **Geiger counter**
  - Larger discrepancy --> more frequent clicking
  - Sound played either from **local or remote** body part
- Noise sound effect:
  - Like Geiger sound effect, but constant **white static** noise
  - Larger discrepancy --> noise becomes louder
  - **Less distracting** than Geiger sound effect

Implementation

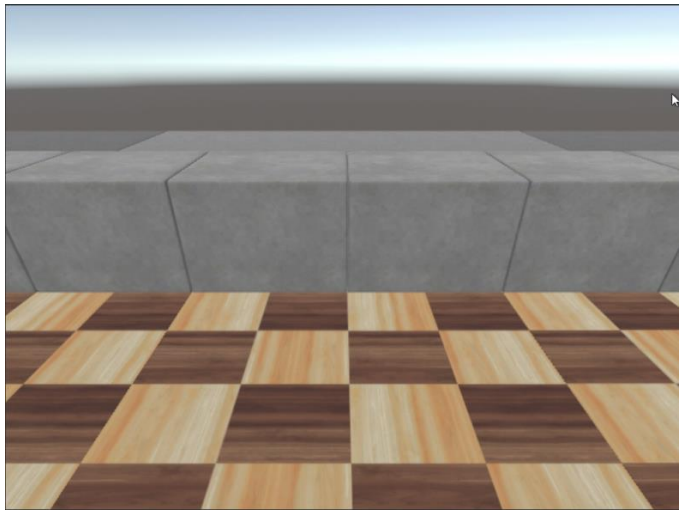
- Discrepancy indicators:



- Colour shift effect:

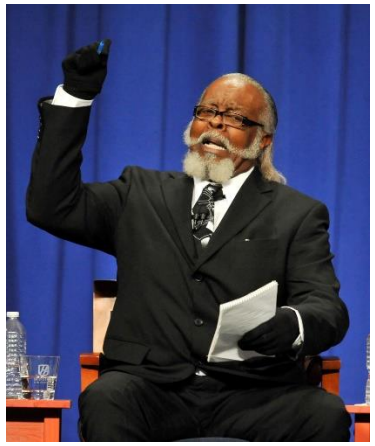


Desaturation effect:



Evaluation (User Studies, Test Runs)

- At time of testing, **latency** of remote avatar matching local avatar‘s pose **too high**
- Implemented remote avatar with colliders in Unity
- Initial test environment did not showcase feedback mechanisms well enough



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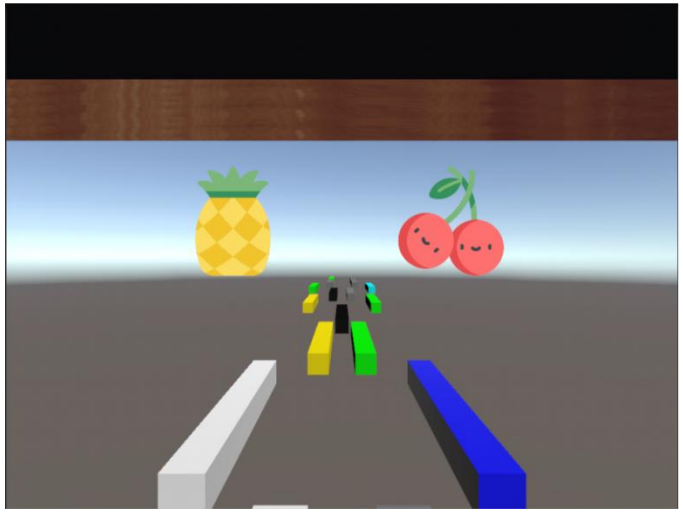
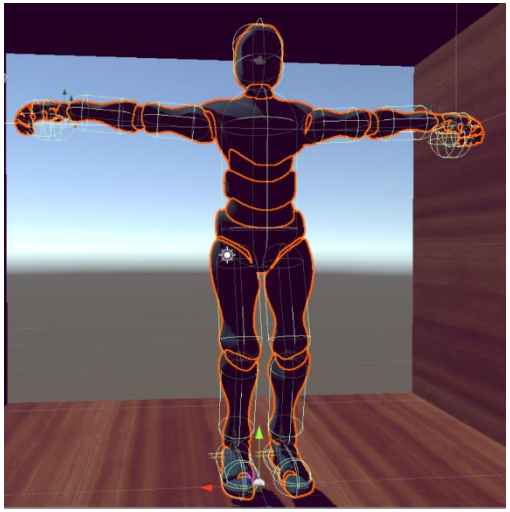
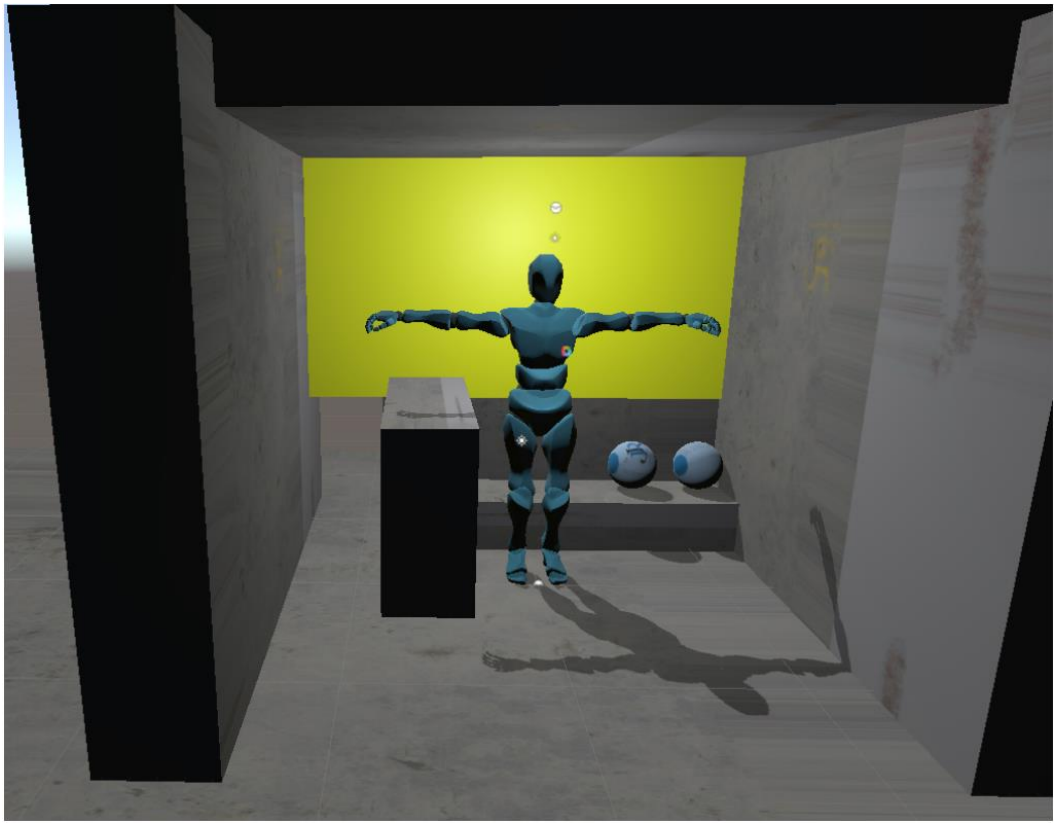




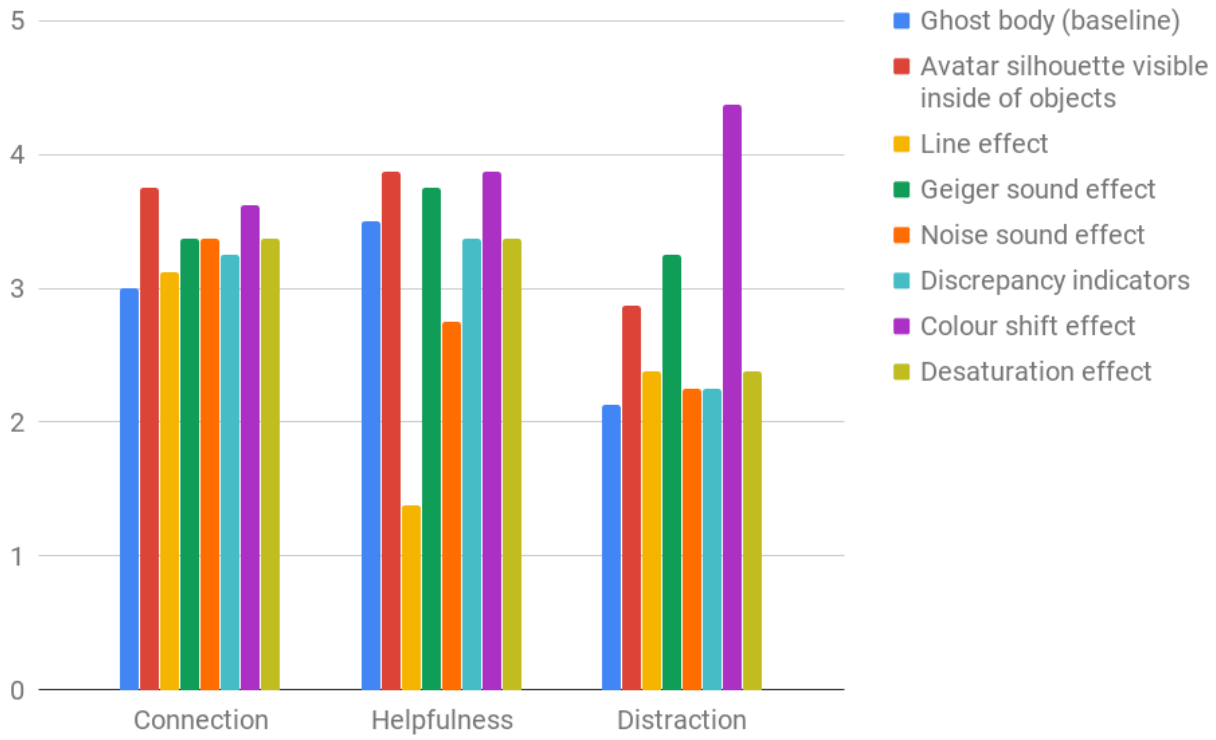
Evaluation (User Studies, Test Runs)

Final user study test environment:



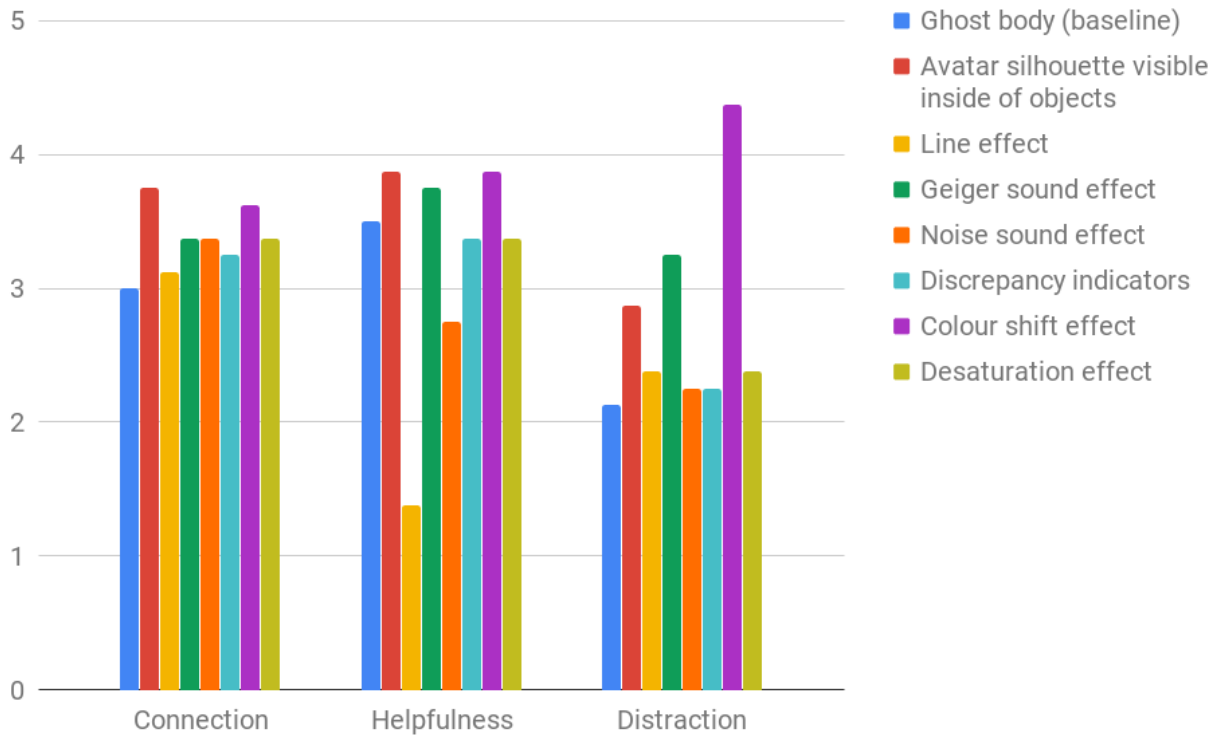
Evaluation (User Studies, Test Runs)

- Eight test subjects
- All but one age 18-30
- 62.5% female
- 75% without prior VR experience

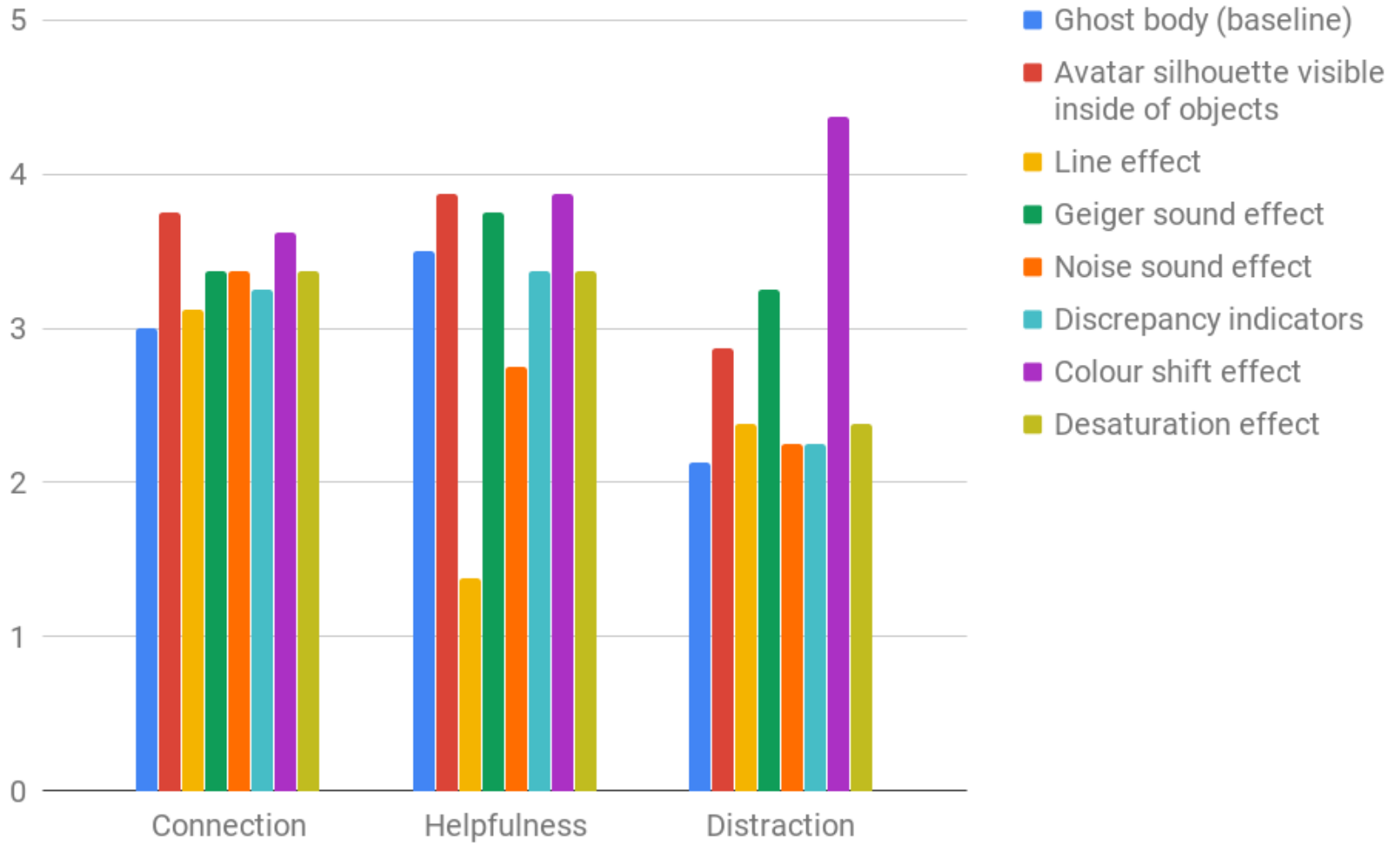


Evaluation (User Studies, Test Runs)

- **Only** tested feedback **mechanisms for** discrepancies at the **feet**
- **Ghost body** is **baseline**, as all effects were tested with it enabled



Evaluation (User Studies, Test Runs)



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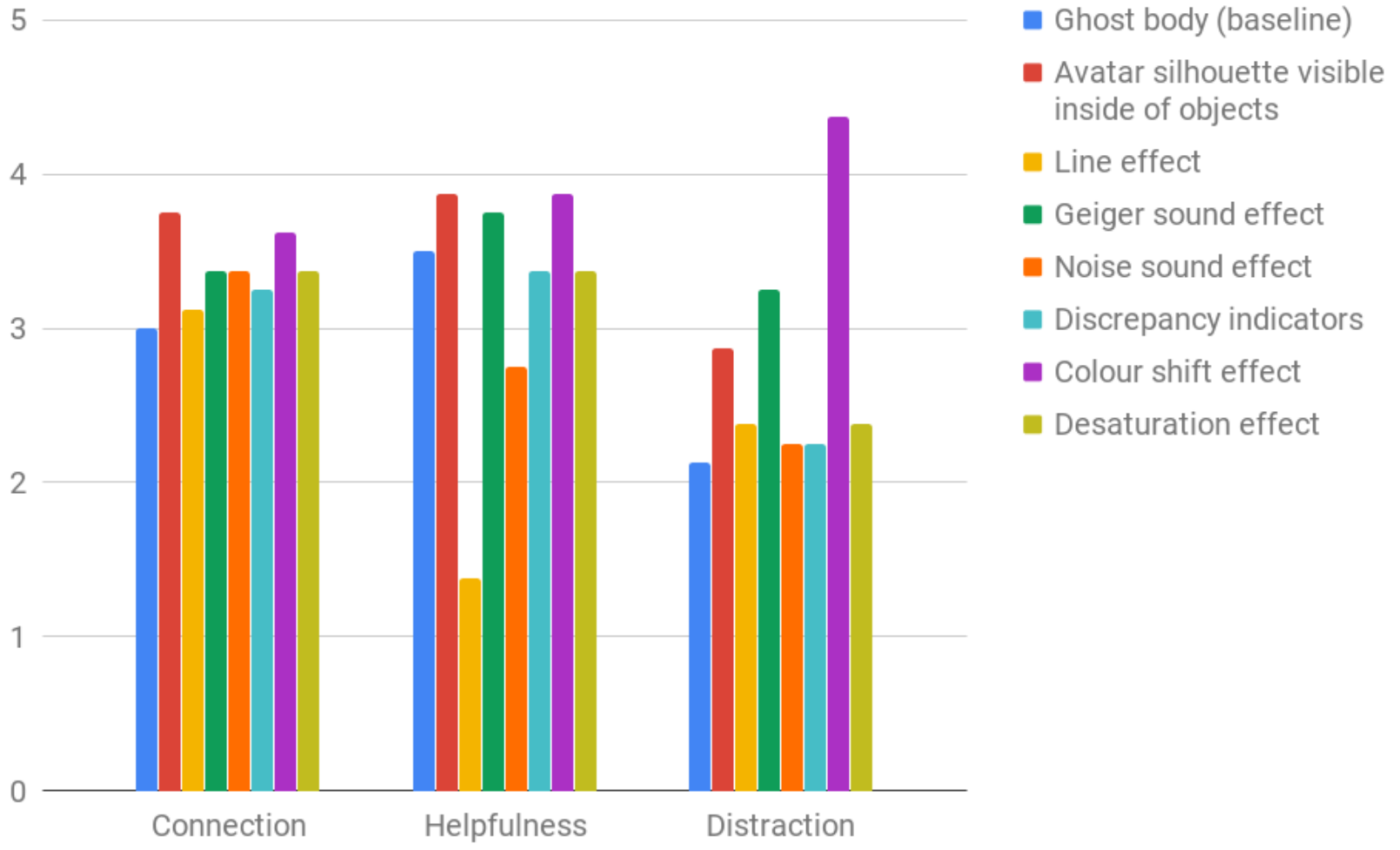

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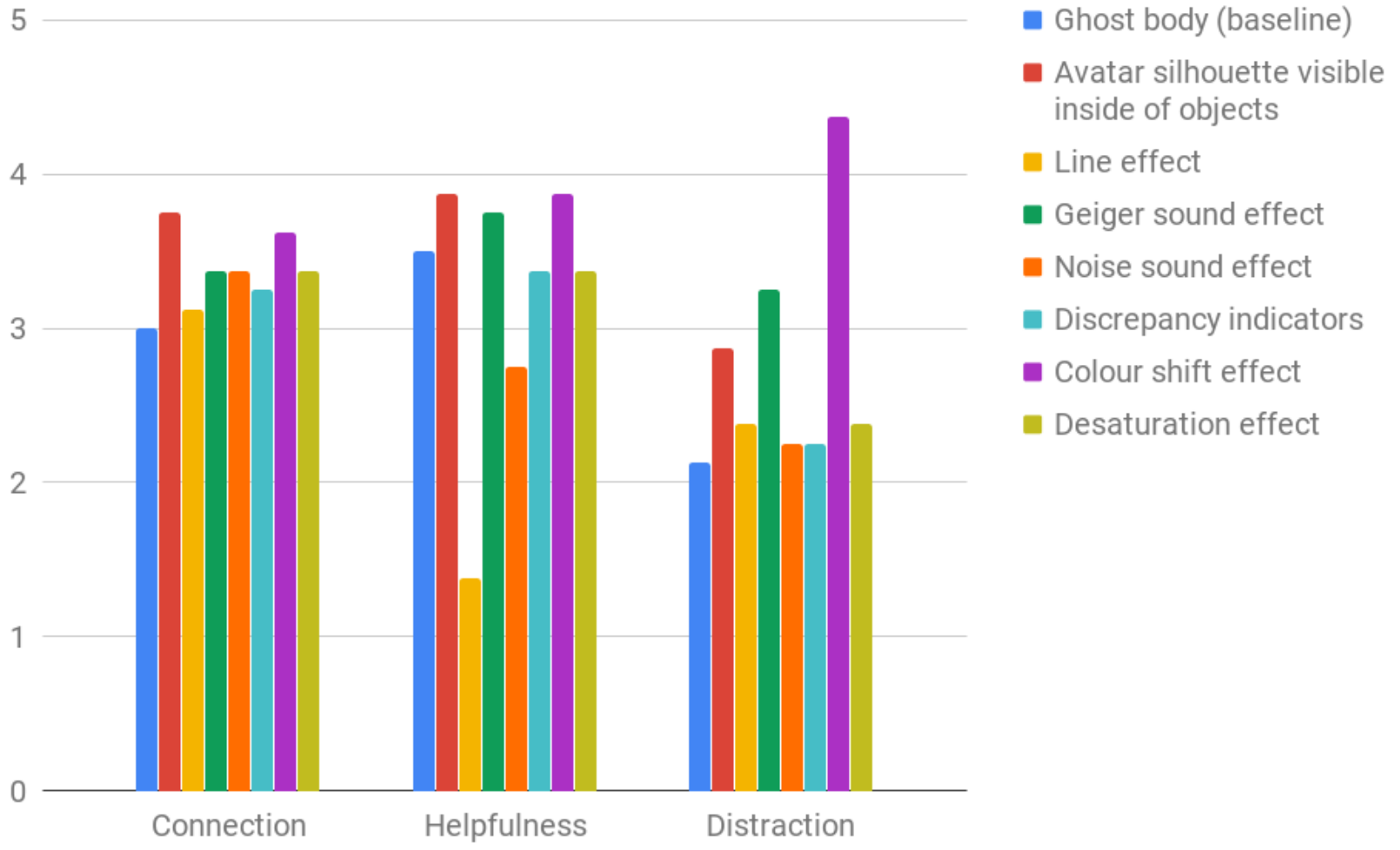

Evaluation (User Studies, Test Runs)

- Suggestions & comments by test subjects:
  - Don’t shift colours, but tint view red (red = warning)
  - Make avatar silhouette look less jarring
  - Noise sound effect too subtle, blends in with background noise
  - Combine multiple effects

Discussion / Suggested Future Work

- More **in-depth user study**
  - Combination of effects
  - For feet, hands & head
- Add **haptic** feedback to Vive Trackers
- Investigate hardware like Impacto using EMS

Conclusion

- Implemented feedback mechanisms have **positive impact** on quality of embodiment in the NRP Unity3D Client
- Investigate new hardware in future
  --> supplement current feedback mechanisms

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