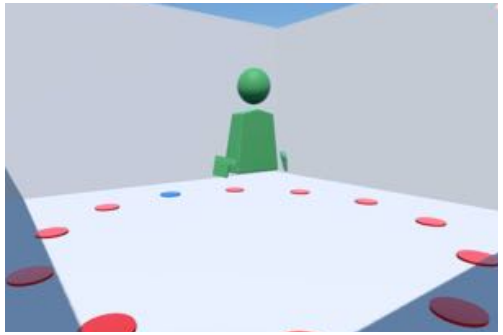
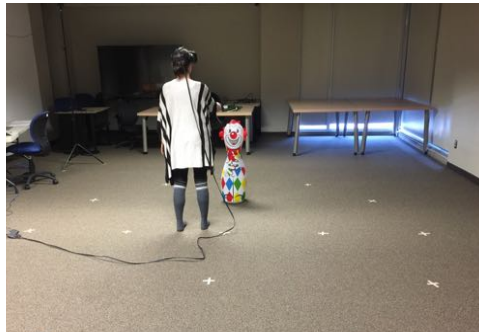
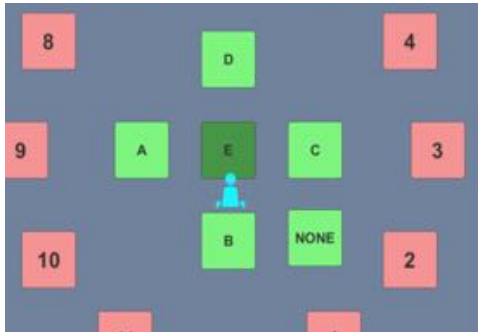


VR Collide! Comparing Collision-Avoidance Methods Between Co-located Virtual Reality Users

ANTHONY SCAVARELLI

Virtual Reality

Virtual Reality (VR) is a digital medium that focuses on providing great *immersion* and *presence*.

- **Immersion**: “a description of the technology that ... delivers an inclusive, extensive, surrounding, and vivid illusion of reality” [1][9]
- **Presence**: “a state of consciousness” [1][9]

- **Head-Mounted Displays** (HMDs) focus on providing this experience through a headset that completely covers ones vision and hearing. Most cost effective version of VR.

Multi-User Virtual Reality

Experiences that involve multiple simultaneous (concurrent) users

Often rely upon local/remote networking [2][7]

Powerful applications in education [7], virtual heritage [6], and 3D content creation [10].

Rec Room

Pool Nation VR

Tilt Brush

The Problem

What about multi-user experiences that involve co-located users – *sharing the same virtual and real space*?

why is co-location important?

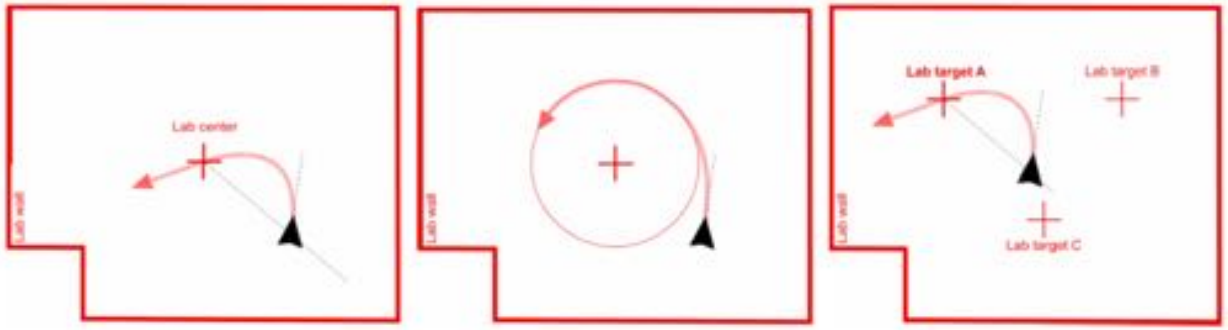
- Physical proximity helps encourage research and creativity [4]
- **What happens when VR becomes popular enough that multiple people in one household want to use VR simultaneously? Either sharing Virtual Environments or within unrelated VE's.**

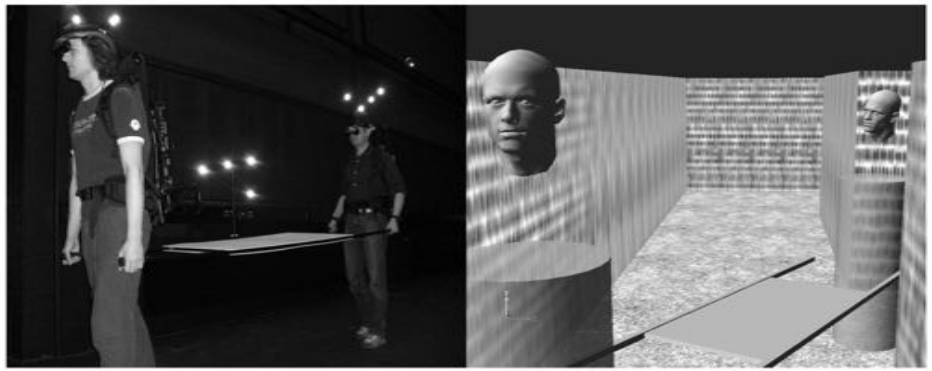
Prior Work

Redirected Walking (a subtle form of motion compression) [4]

Avatars

- Streuber, S., & Chatziastros : Multi-User Virtual Reality [9]
- Tilt Brush, Rec Room, Pool Nation VR etc.



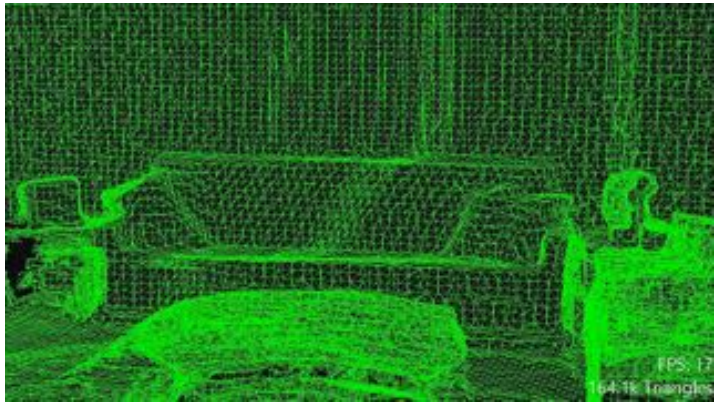


Prior Work cont.

Environmental Collisions

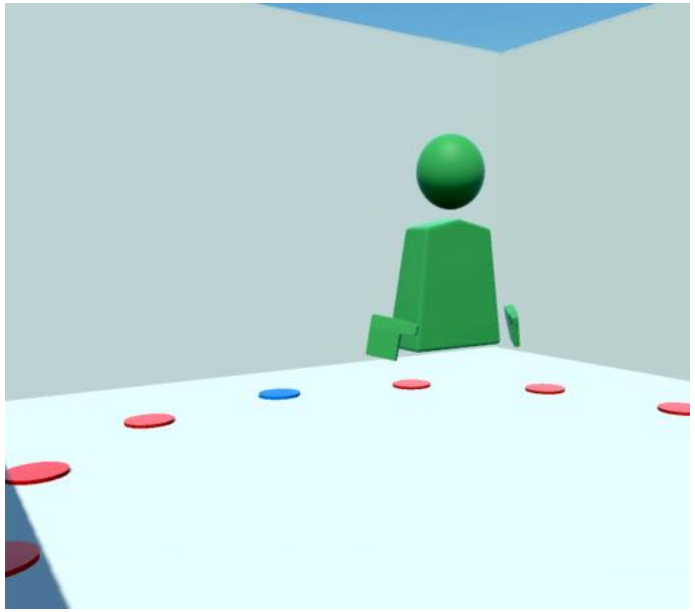
- Though not about avoiding users we can look to how other avoid collisions with environmental boundaries.
- SteamVR's "Chaperone" implementation is the most famous example
- But Hololens real-time environmental recreations in virtual space could also be useful.

Chaperone (grid)

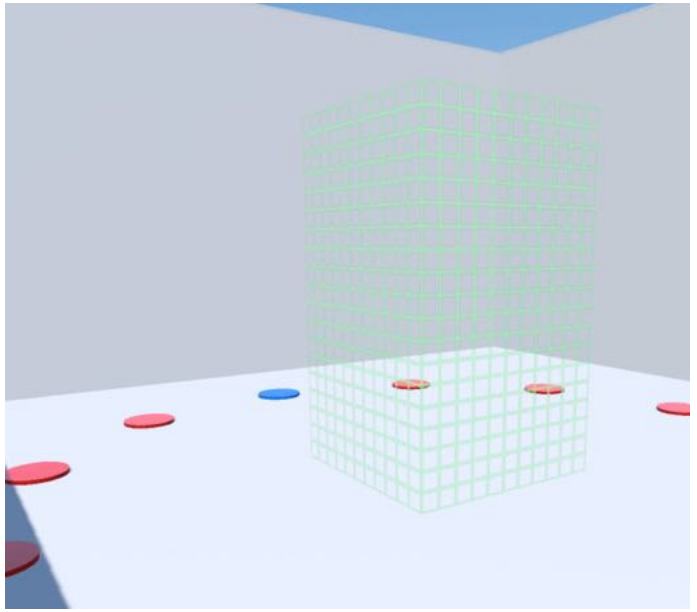


Hololens 3D scanning

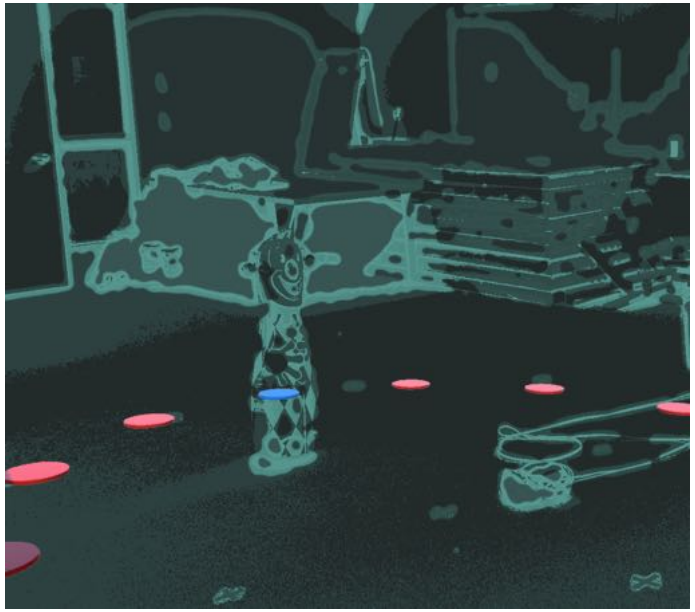
Methodology – Three Methods



Avatar

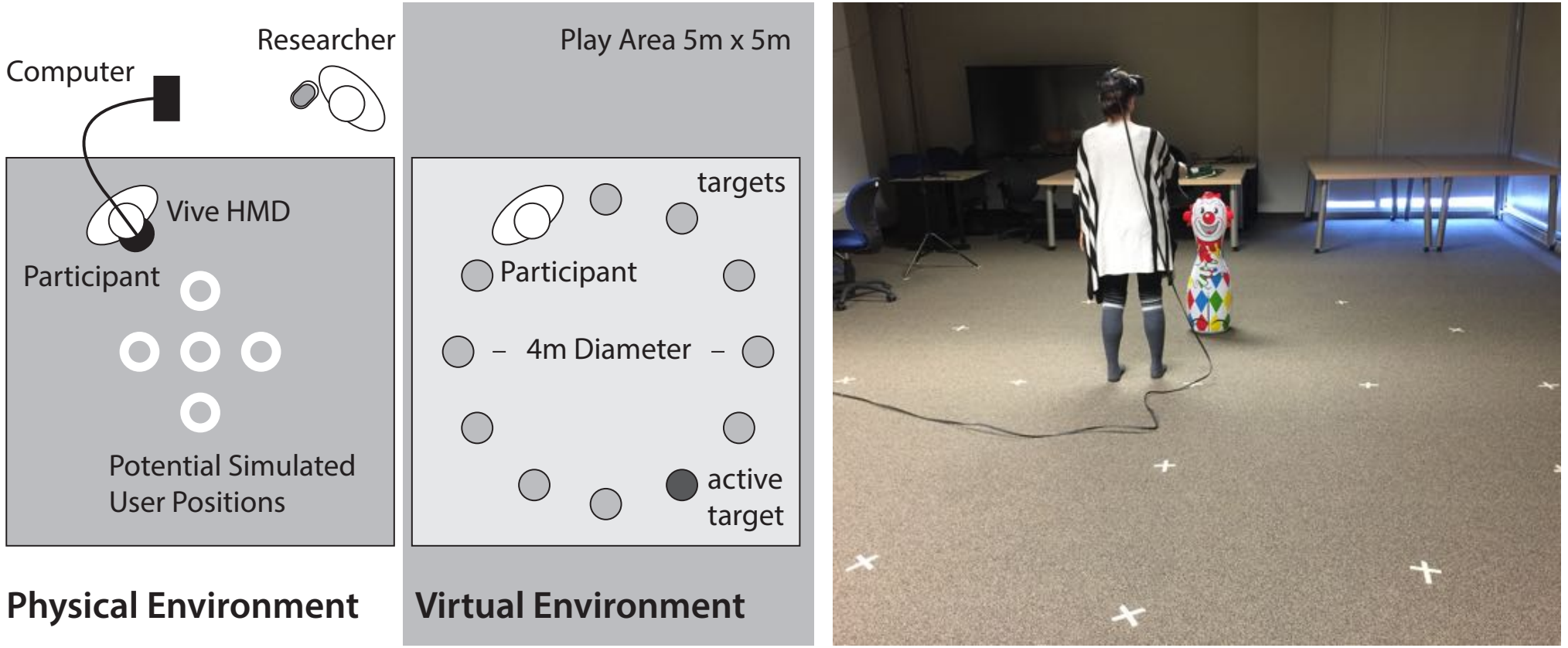


BoundingBox

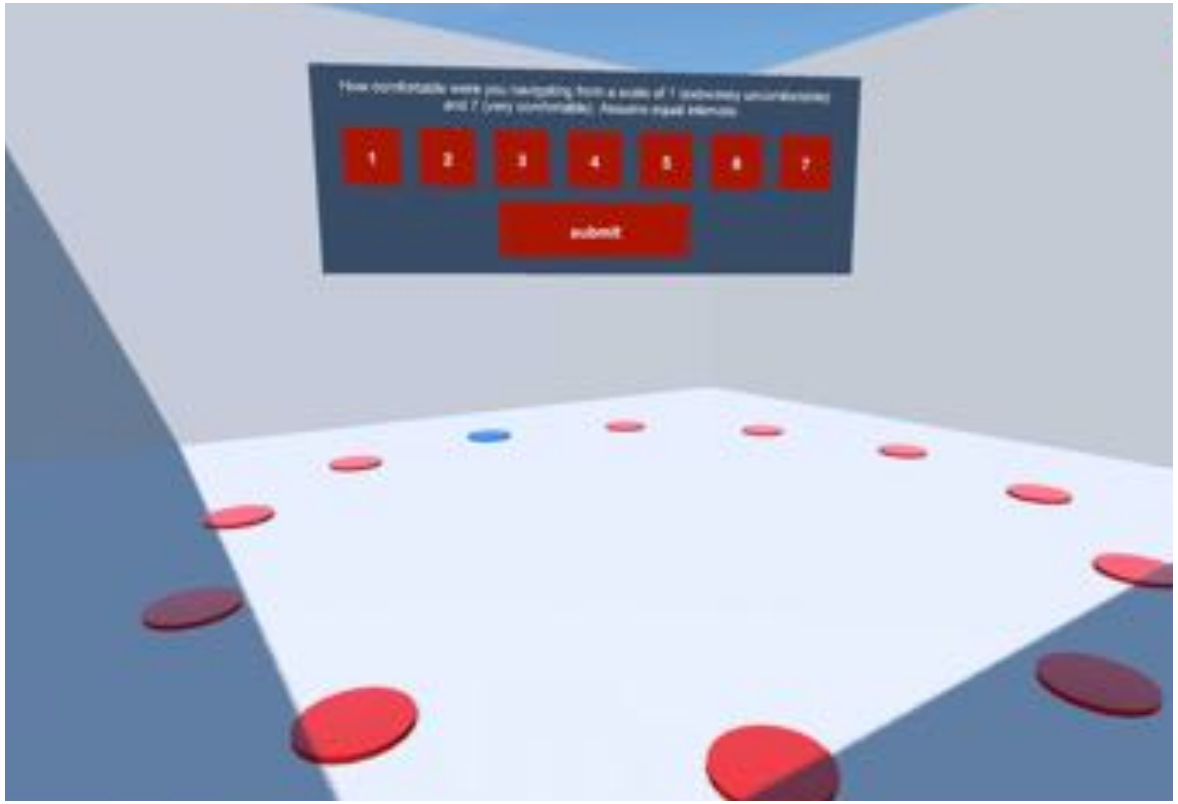


CameraOverlay

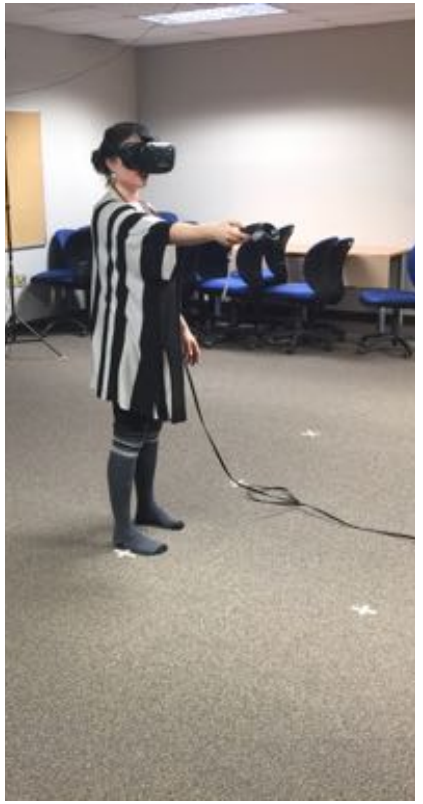
Methodology - Apparatus



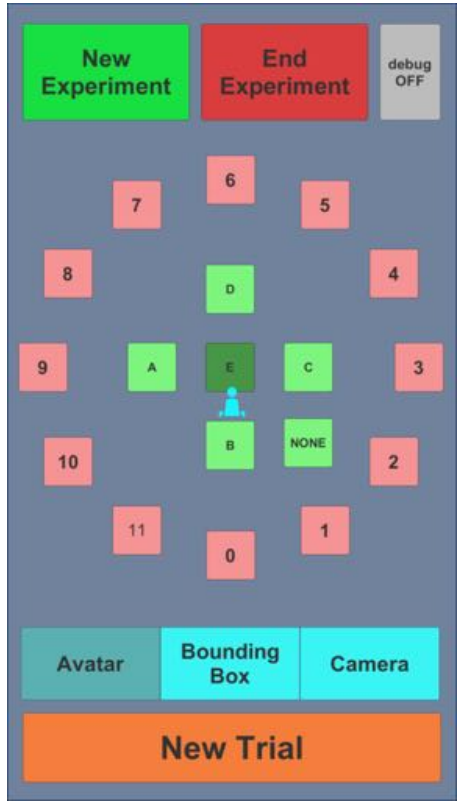
Methodology - Apparatus



Virtual View



Physical View



Mobile Control App

Methodology - Introduction

Test 3 different methods of collision avoidance (simulating an “other” user) in the human users’ VE.

3 Methods

1. ***Avatar*** - primitive human shape
2. ***BoundingBox*** - Distance dependent visible bounding grid
3. ***CameraOverlay*** - ”AR” using front camera

Data Collected

- **Movement time -** Trial end time – trial start time
- **In-app survey data -** completed after every trial.
- **Number of collisions -** between user and ”simulated user”
- **Pre and Post experiment surveys -** (effectiveness, pleasantness, safeness, suitability, open-ended question).
- **Anxiety Levels -** by tracking how hard the analog trigger on the Vive controller was pressed (*unsuccessful*).

Methodology - Design

Overview

- A within-subjects design
- 1 IV, 3 levels
- 3 DVs

Numbers

- 12 Participants (4 female, 8 male) between the ages of 18 and 35
- Prior experience not necessary (though all had none to little experience in VR).

Technology

- 1 Vive VR HMD and Win10 PC (4-core Xeon, 16GB RAM, GTX 970)
- Unity developed (efficiency of development and Valve supported VR plug-ins)

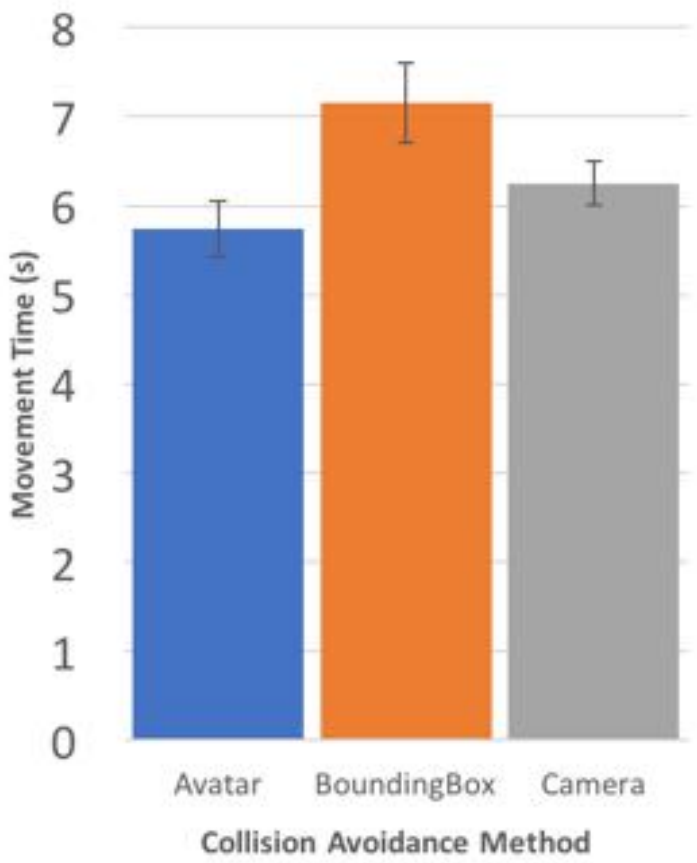
Methodology - Design

- 18 trials of each method per participant. Random but consistent order for each participant.
- Each of 6 participants follows a different order of method testing via a balanced Latin square.
- 18 * 3 = 54 trials per participant
- 54 * 12 = 648 experimental trials total

Hypothesis

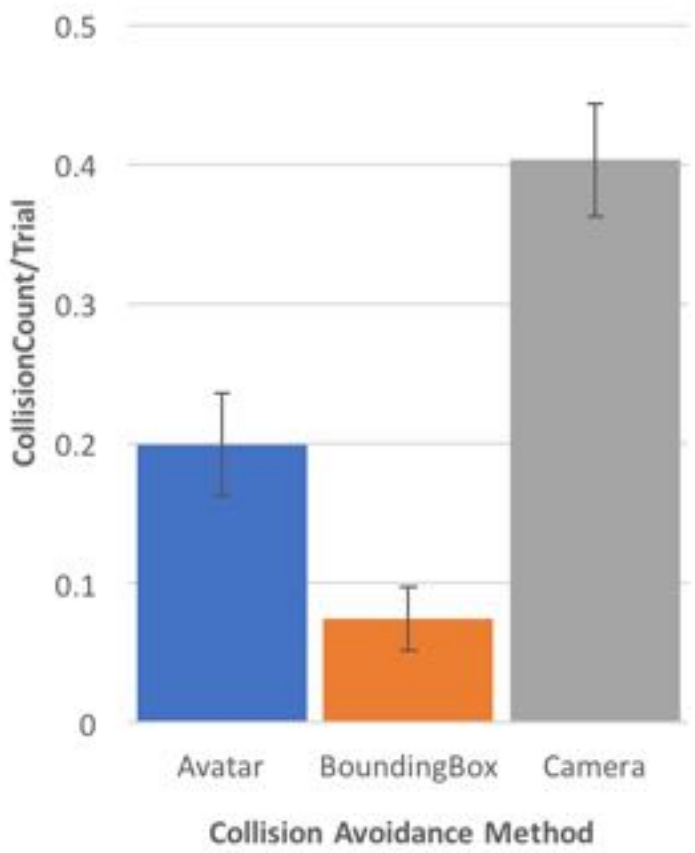
After the *CameraOverlay* control method we feel that the *Avatar* method will be the most preferred, provide faster movement through a space while avoiding the least number of collisions with other users.

Results – Movement Time



Significant differences between all methods using ANOVA and Tukey HSD post-hoc testing

Results – Number of Collisions



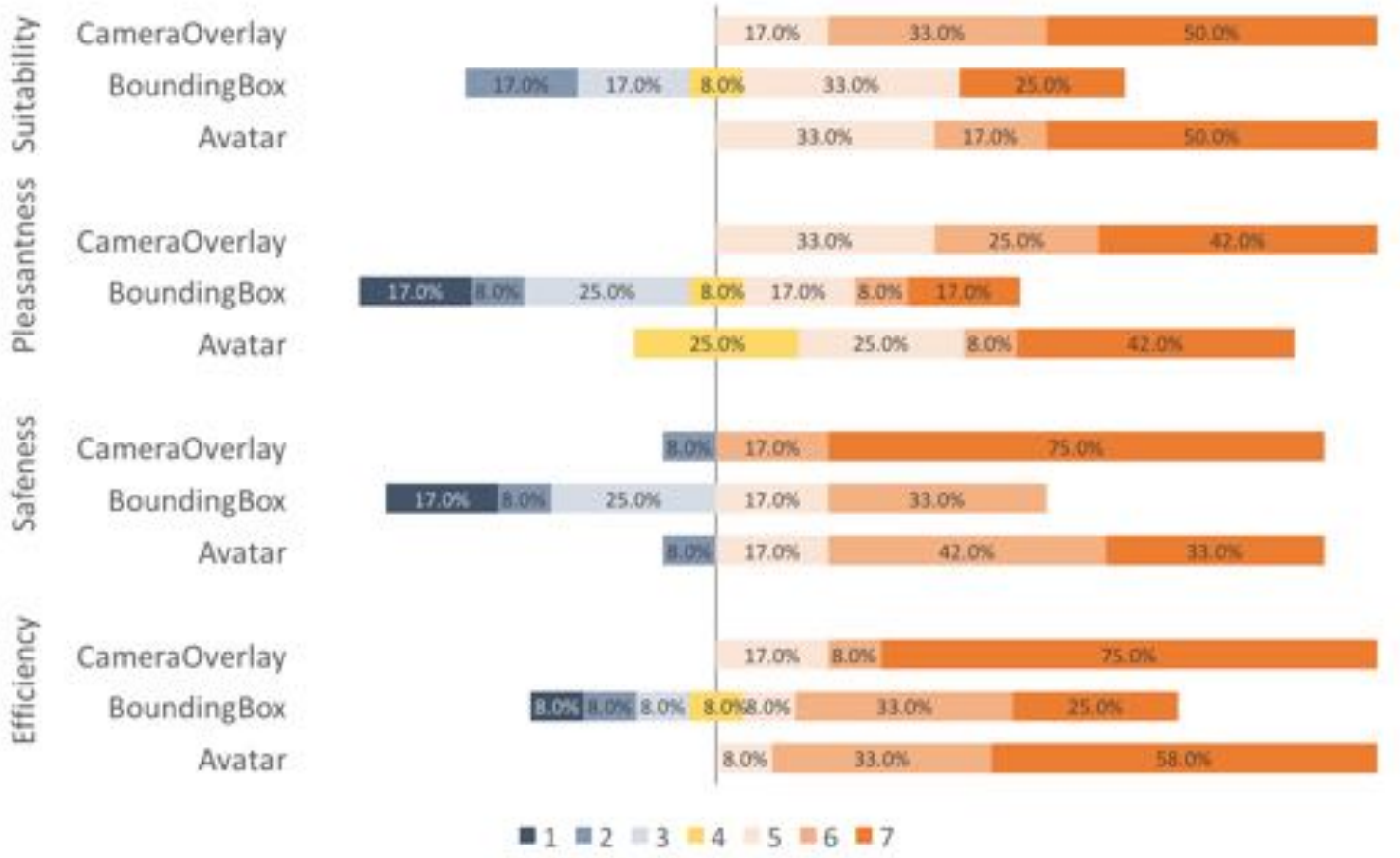
Significant differences between all methods using ANOVA and Tukey HSD post-hoc testing.

No significance detected between *Avatar* and *CameraOverlay* though.

Results – In-App Survey Responses

Post-Trial comfort levels were compared with the non-parametric Friedman test; and they were found to be non-significant.

Results – Post-Experiment Survey



Post-Experiment survey responses were found to be significant using a Friedman test. Further post-hoc analysis shows no real different between *CameraOverlay* and *Avatar* but significant differences between each of those and the *BoundingBox* method.

Discussion

- Overview
  - *BoundingBox* the safest with less collisions
  - *CameraOverlay allowed for the quickest movement across the space*
  - *Both CameraOverlay and Avatar were judged to be comfortable to navigate*

- With 6 participants there was not enough data to quantitatively analyze post-survey data but some interesting notes
  - The “surprise” element of the *BoundingBox* deemed unpleasant by most participants
  - Most were comfortable with *CameraOverlay* Method. Comfort increased when seeing physical environment.
  - *BoundingBox* movement times were significantly longer as participants were very cautious after being “surprised”
  - Avatar was personified by some participants. Was described as “cute” and “annoying”.
  - Most users were very aware of HMD wires but still found it uncomfortable to have to avoid. *CameraOverlay* was deemed useful to see these wires.
  - The *BoundingBox* is much clearer in defining personal space boundaries.

Conclusion

Preventing user collisions in virtual space is interesting!

For users within the same VE an Avatar based method should be better recognizable as another user within the space but less “safe” as users have a harder time judging personal space boundaries in VR.

For users in different VEs an always visible *Avatar* based method may break immersion/presence.

Perhaps there is room for a hybrid method that combines the *BoundingBox* and *Avatar (perhaps themed)*?

Future Work

Explore hybrid methods (*Avatar/BoundingBox*)

Increase number of participants

Explore *BoundingBox* visibility thresholds that could increase user comfort while keeping presence high.

Use multiple human participants to allow for more natural movement within the space.

Explore multiple simultaneous VEs for co-located VR users.

References

1. Bowman, D. A., & McMahan, R. P. (2007). Virtual reality: how much immersion is enough?. Computer, 40(7), 36-43.
2. Carlsson, C., & Hagsand, O. (1993, September). DIVE A multi-user virtual reality system. In Virtual Reality Annual InternationalSymposium, 1993., 1993 IEEE (pp.394-400). IEEE.
3. Lepouras, G., & Vassilakis, C. (2004). Virtual museums for all: employing game technology for edutainment. Virtual reality, 8(2), 96-106.
4. Gloor, P. A., Grippa, F., Putzke, J., Lassenius, C., Fuehres, H., Fischbach, K., & Schoder, D. (2012). Measuring social capital in creative teams through sociometric sensors. International Journal of Organisational Design and Engineering, 2(4), 380-401.
5. Holm, J. E. (2012). Collision Prediction and Prevention in a Simultaneous Multi-User Immersive Virtual Environment (Doctoral dissertation, Miami University).
6. Lepouras, G., & Vassilakis, C. (2004). Virtual museums for all: employing game technology for edutainment. Virtual reality, 8(2), 96-106.
7. Monahan, T., McArdle, G., & Bertolotto, M. (2008). Virtual reality for collaborative e-learning. Computers & Education, 50(4), 1339-1353.
8. Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. Presence: Teleoperators and virtual environments, 6(6), 603-616.
9. Streuber, S., & Chatziastros, A. (2007, December). Human Interaction in Multi-User Virtual Reality. In Proceedings of the International Conference on Humans and Computers (pp. 1-7).
10. http://www.theverge.com/2016/9/30/13122502/tilt- brush-getting-multiplayer-mode-google-virtual-reality