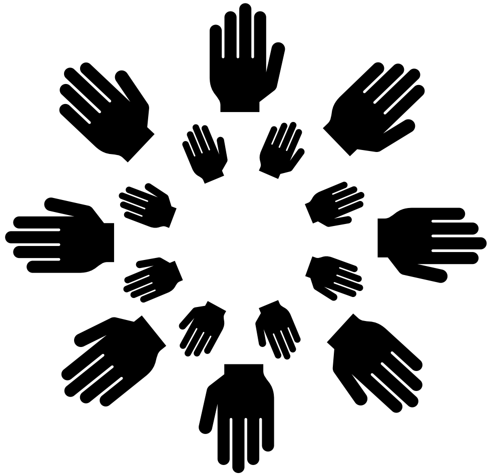
# Helping Hands

## Exploring Multimanual Interaction in Virtual Reality






Julian Karlbauer
Teresa Hirzle

# Consider.: Human Hands as a versatile tool

- Hands are the most fundamental ‘tool’ of the human. Most physical interaction relies on them.
- Hands adapt to arbitrary situations and allow us to interact in versatile environments.
- Human hands rely on versatility rather than on specificity
  - compared to other species, human hands are weak in specific domains
  - evolutionary, versatility wins over specificity (survival of the fittest)
- (Hand-) versatility supported brain development of the early homo-sapiens

**Versatile** interchange with the environment is a fundamental human property.
Hand Tracking allows to use and improve hand versatility in VR!

# Hand Tracking: Direct Consequences in VR

- digital hands become a versatile tool that (like our real hands) can adapt to **arbitrary situations** in virtual environments
- change appearance and capabilities of digital hands as desired

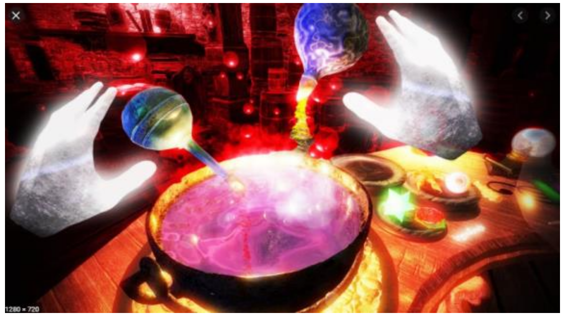
Popular Applications for Oculus Quest's inside-out hand-tracking:


https://www.youtube.com/watch?app=desktop&v=M_IJ8y9FSfM&ab_channel=Fynnpire

'Elixir'


https://sidequestvr.com/app/750/hand-physics-lab

'Hand Physics Lab'



https://www.youtube.com/watch?app=desktop&v=NSlkpNN5-4o&ab_channel=Ctop

'Waltz of the Wizard'

**Initial impulse** of developers when Hand-tracking was added to VR:

- **Augment** hand's abilities
- **Change** hand's appearance

Why is that? What are **implications in terms of future interaction design**?

Facebook Reality Labs Research, December 2020

## Constraining Dense Hand Surface Tracking with Elasticity

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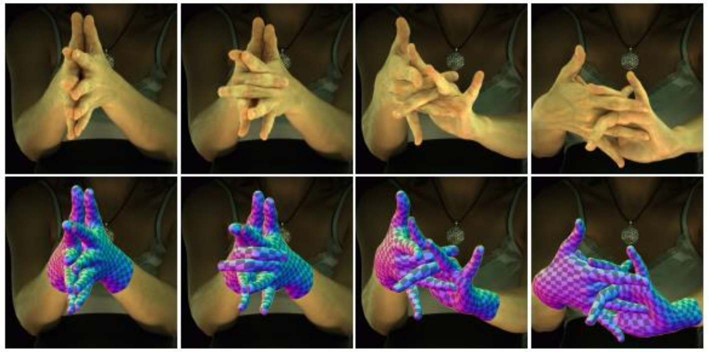

Fig. 1. A subject brings her hands together, bends her middle fingers, pivots her hands around this region of contact, intertwines her remaining fingers, and wiggles her middle fingers. Top row: Input images. Bottom row: Our tracking results. Our approach is able to track through the significant amount of self-contact and and self-occlusion induced by this two-handed performance.

Many of the actions that we take with our hands involve self-contact and occlusion: shaking hands, making a fist, or interlacing our fingers while thinking. This use of of our hands illustrates the importance of tracking hands through self-contact and occlusion for many applications in computer vision and graphics, but existing methods for tracking hands and faces are not designed to treat the extreme amounts of self-contact and self-occlusion exhibited by common hand gestures. By extending recent advances in vision-based tracking and physically based animation, we present the first algorithm capable of tracking high-fidelity hand deformations through highly self-contacting and self-occluding hand gestures, for both single hands and two hands. By constraining a vision-based tracking algorithm with a physically based deformable model, we obtain an algorithm that is robust to the ubiquitous self-interactions and massive self-occlusions exhibited by common hand gestures, allowing us to track two hand interactions and some of the most difficult possible configurations of a human hand.

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0730-0301/2020/12-ART219
https://doi.org/10.1145/3414685.3417768

CCS Concepts: • **Computing methodologies → Motion capture**.

Additional Key Words and Phrases: hand tracking, simulation, elasticity

**ACM Reference Format:**
Breannan Smith, Chenglei Wu, He Wen, Patrick Peluse, Yaser Sheikh, Jessica K. Hodgins, and Takaaki Shiratori. 2020. Constraining Dense Hand Surface Tracking with Elasticity. *ACM Trans. Graph.* 39, 6, Article 219 (December 2020), 14 pages. https://doi.org/10.1145/3414685.3417768



https://research.fb.com/publications/constraining-dense-hand-surface-tracking-with-elasticity/

### 1 INTRODUCTION

Hands are essential in our daily life: we use our hands to manipulate and interact with the world around us, and we also communicate with our hands, using *non-verbal gestures* to transmit, clarify, and emphasize our ideas and thoughts during conversation. Our hands are suited to both these functions due to their high degree of articulation, which leads to dexterity for manipulation and a high bandwidth for communicating information. However, it is precisely due to this high degree of articulation that hands exhibit frequent incidence of occlusion. This occlusion may be caused by contact with other objects, other parts of the body, and often with other parts of the hand itself. Indeed, if you consider where your hands are right now, they are almost certainly in contact with something. It is rare that hands are in a state where they are not in significant contact with another object.

[...]

Hand Tracking is becoming an **important interaction paradigm** in virtual environments.
Active field of research.

# Supernumerary Limbs: relations

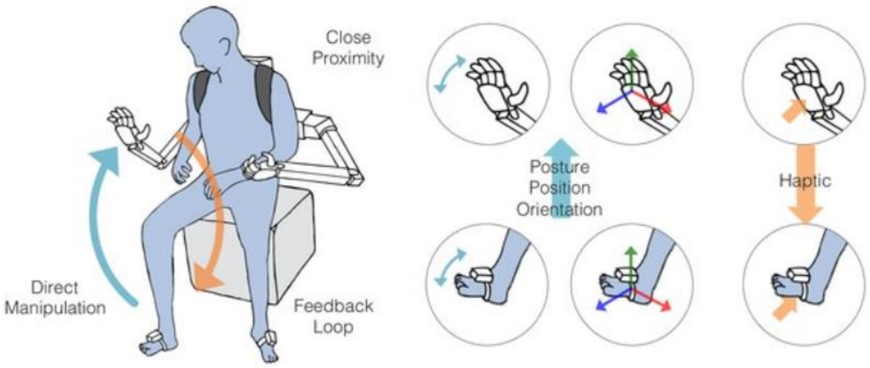
- In Hinduism, gods are represented as having multiple limbs **(power?, control?)**
- In western culture, multiple limbs are related to power as well

- However, supernumerary limbs are also linked to **danger, aversion and disgust**

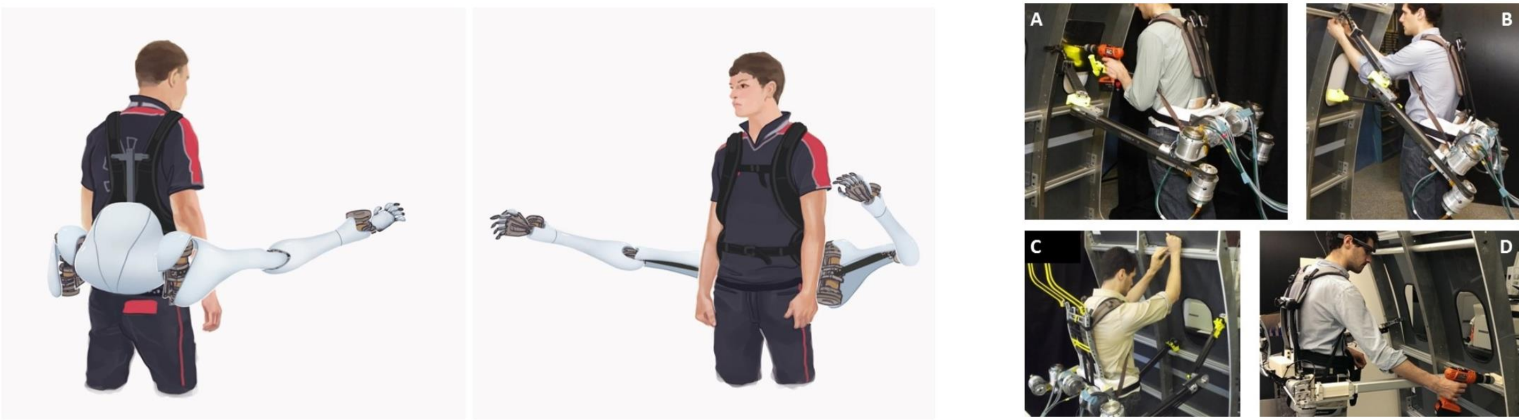
**<u>benefits</u>** power
productivity
efficiency
multi tasking

**<u>challenges</u>**
uncontrollable
unpredictable
unnatural
coordination

# Robotics



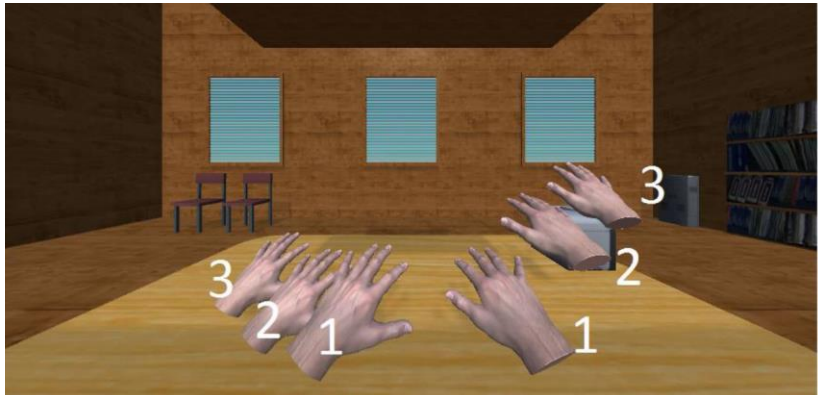

**MetaArms: Body Remapping Using Feet-Controlled Artificial Arms** [2]




**Supernumerary Robotic Limbs (SRL)** [1]

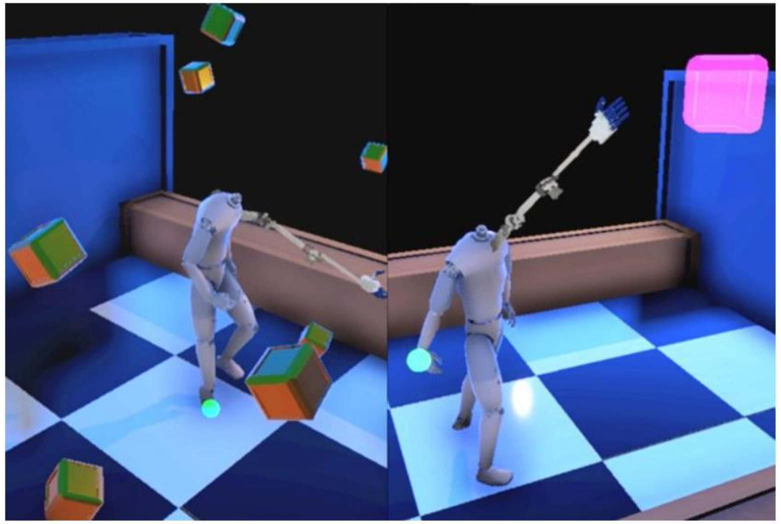
[1] http://darbelofflab.mit.edu/robotics-research/supernumerary-robotic-limbs-srl/
[2] https://www.researchgate.net/publication/327311574_MetaArms_Body_Remapping_Using_Feet-Controlled_Artificial_Arms

# Virtual Reality




**The Human Octopus: Controlling supernumerary hands with the help of virtual reality** [3]
[3] https://www.biorxiv.org/content/10.1101/056812v2.full

**Ninja Hands: Using Many Hands to Improve Target Selection in VR** [4]
[4] https://dl.acm.org/doi/pdf/10.1145/3411764.3445759



**Remapping a Third Arm in VR** [5]
[5]https://www.researchgate.net/publication/330994052_Remapping_a_Third_Arm_in_Virtual_Reality

# Multimanual Interaction in Virtual Reality:

The possibility to interact with a virtual environment using not only two but a potentially unlimited amount of virtual hands

## Research Goals:

1. Develop a **Design Space** to analyze possible interaction metaphors using supernumerary hands

2. Create and evaluate a **system for multimanual interaction in VR** to improve productivity, efficiency and enjoyment of use while being easy to use and not cognitive demanding

| | | Translation Factor | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | macro (>1) | micro (<1) | identity (=1) | macro | micro | identity | macro | micro | identity | macro | micro | identity |
| Dependency (DoF) | 6 (rotation & position) free movem. | | | | | | | | | | | | |
| | 3 (position) lock rotation | | | | | | | | | | | | |
| | 3 (rotation) lock position | | | | | | | | | | | | |
| | 0 (None) | | | | | | | | | | | | |
| | | None | | | Data (passive) | | | Information (reactive) | | | Knowledge (autonomous) | | |
| | | Intelligence | | | | | | | | | | | |

| Dependency (DoF) | | Translation Factor / Translation Sign | | | | | |
|---|---|---|---|---|---|---|---|
| | | macro (>1) | micro (<1) | identity (=1) | macro | micro | identity |
| | | + | + | + | + | + | + |
| | 6 (rotation & position) free movement | unconstrained macro control | unconstrained micro control | unconstrained identity control | unconstrained macro adjustment | unconstrained micro adjustment | unconstrained identity adjustment |
| | 3 (position) lock rotation | macro position control | micro position control | identity position control | macro position adjustments | micro position adjustments | identity position adjustments |
| | 3 (rotation) lock position | macro rotation control | micro rotation control | identity rotation control | macro rotation adjustments | micro rotation adjustments | identity rotation adjustments |
| | 0 (None) | static structures | | | automated processes | | |
| | | None | | | Data (passive) | | |
| | | Intelligence | | | | | |

**Motivation** (review)

**Related Work**

**Concept**

**Methods & Material**

Design Space

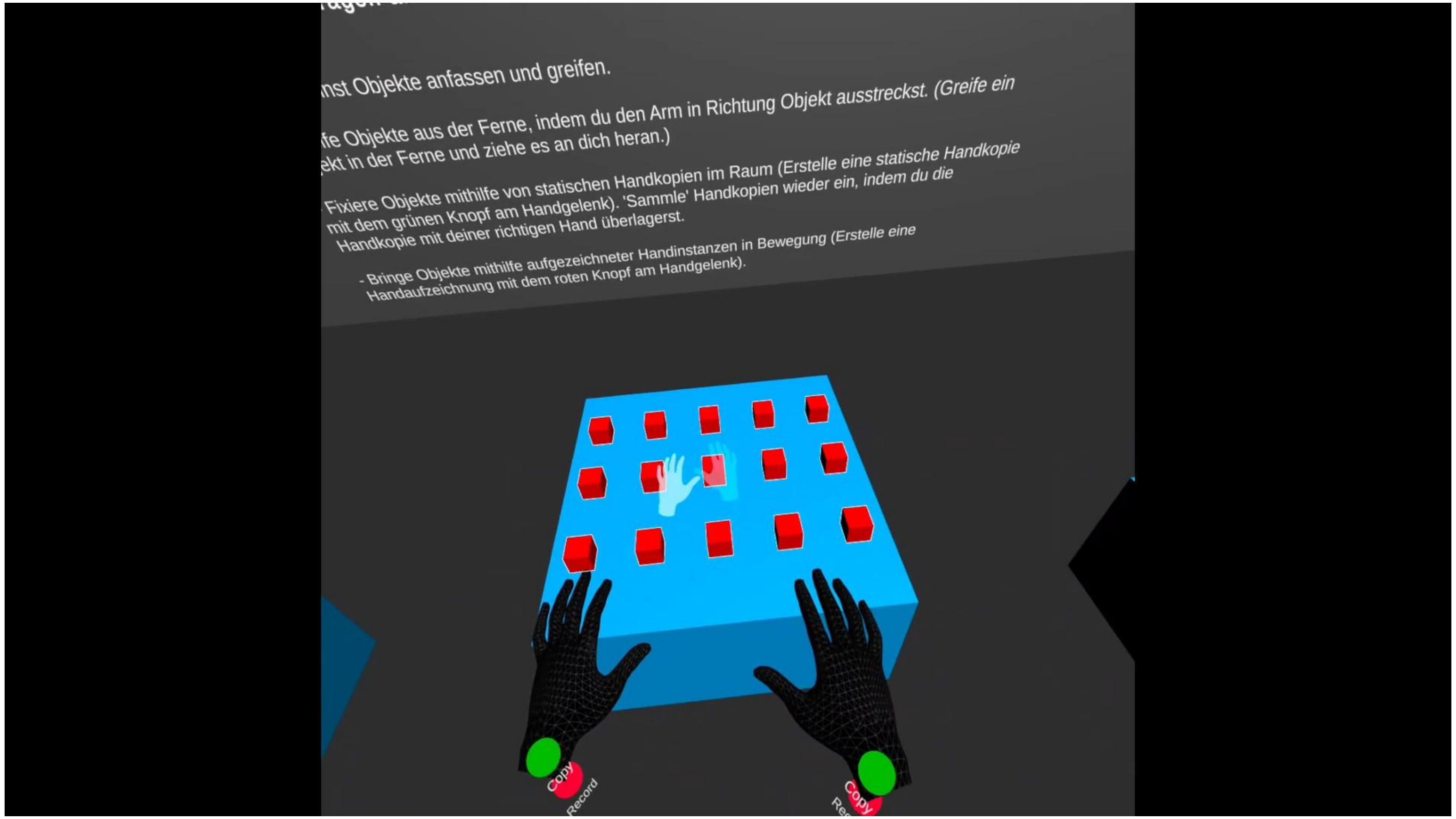
Implementation

**Evaluation**

**Conclusion**

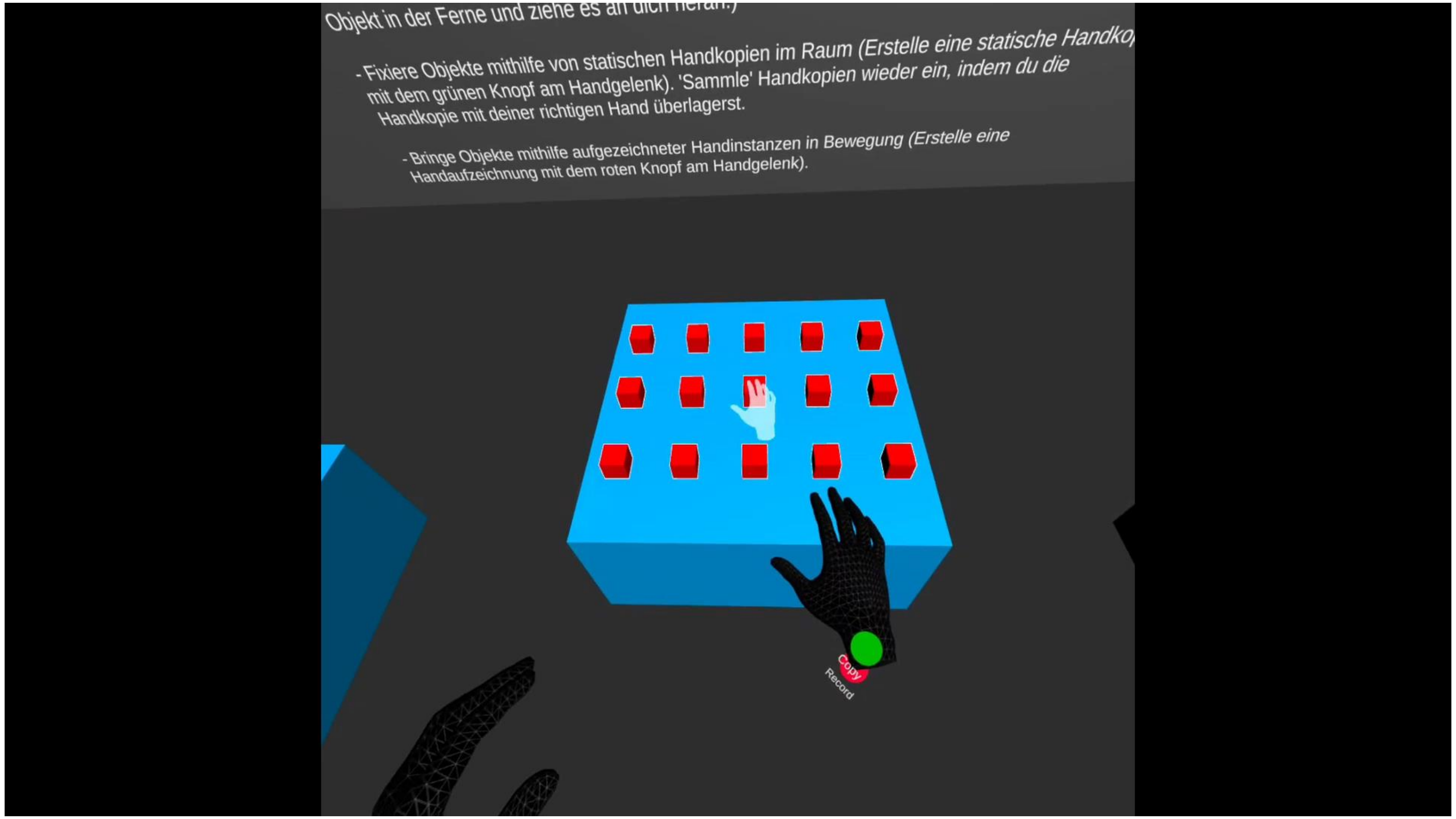
# cursor hands

Cursor hands indicate where distance hands will be placed when instantiated.



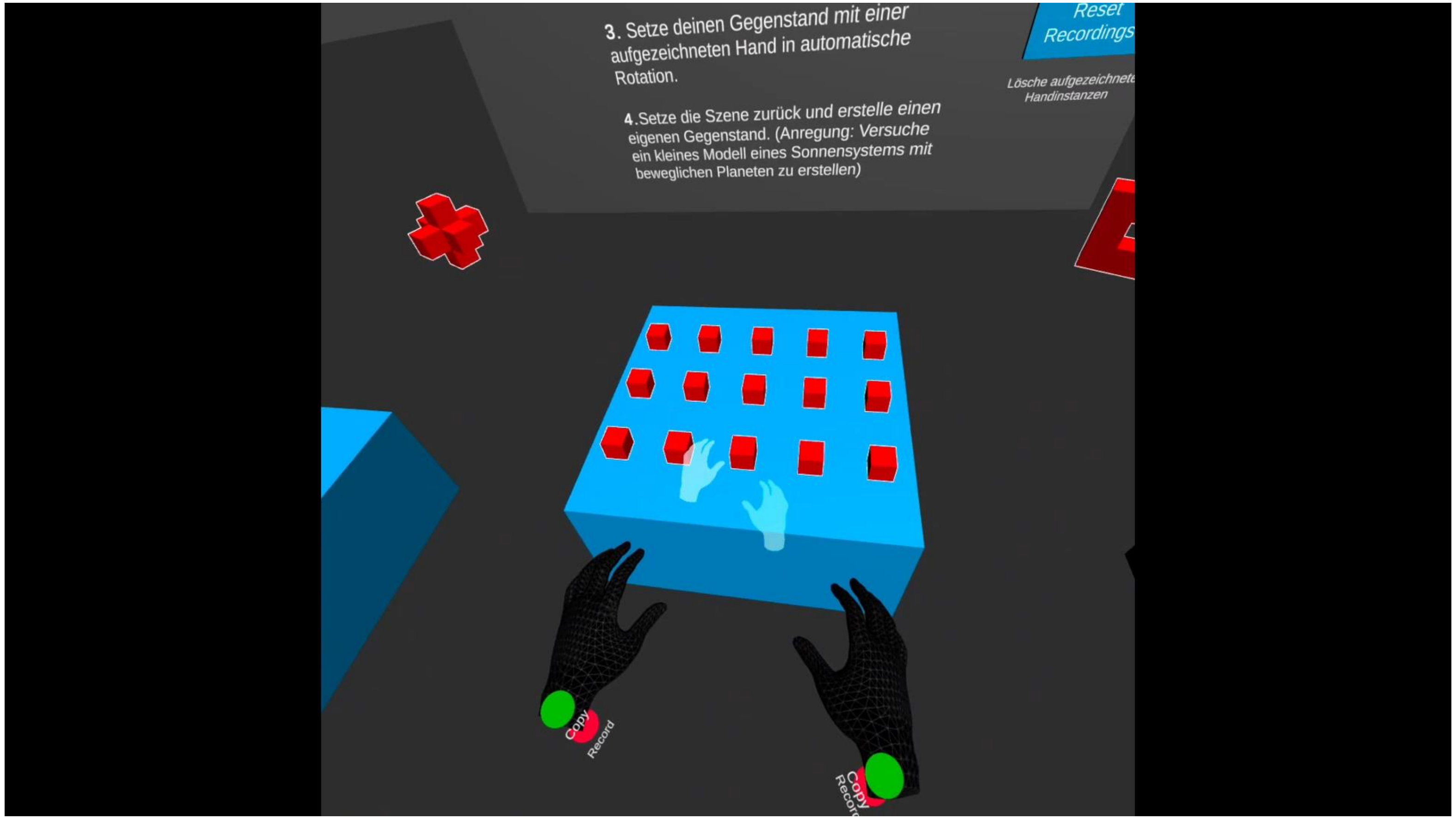
# distance hands / main hands

Implicitly create distance hands when users stretches their arm to reach an object. Users can use distance hands in the same way as main hands.



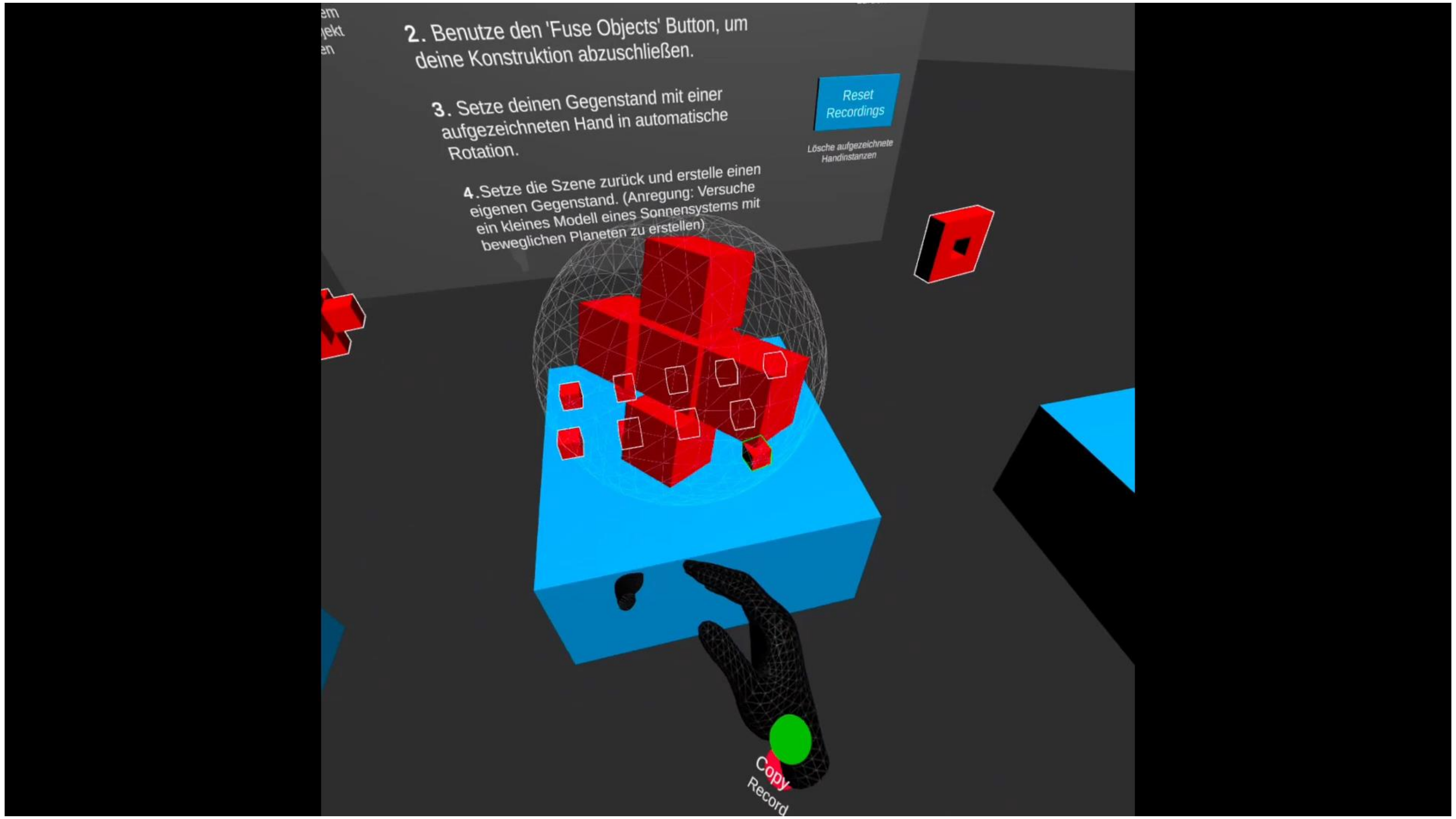
# steady hands

Steady hands passively sit in the virtual environment. On demand they can fix objects in space.



# recorded hands

Recorded hands perform predefined motions while still interacting with objects.



# User Study

Evaluate our multimanual interaction system with respect to:

**Usability**

- Easy to use and understand?
- Cognitive demanding?
- Helpful to achieve tasks?
- Identification with digital hands?

**Versatility**

- Cross Application use?
- Individual & creative use

Approach:
Build an App in which users can experiment with multimanual interaction. Let users answer questions with respect to our research goals.

# User Study

## Metrics:

1. **Questionnaires after each experiment:**
   based on Player Experience Inventory [6]

   - Immersion (user relation to copied hands)
   - Cognitive Load
   - Productivity
   - Precision of Interaction
   - Enjoyment
   - Personal Likes/Dislikes

2. **verbal user feedback during and after experiments**



[6] https://www.sciencedirect.com/science/article/pii/S1071581919301302

# User Study

## Design

**Two experiments:**

1. **Sandbox:** practical use scenario – combination of metaphors to understand interaction sequences

2. **Game:** execution under time pressure – creative use, extensive and repetitive use.

(To succeed in either experiment, it is necessary to use each of the provided interaction metaphors.)

**within subject design**

Experiment 2 requires a deeper understanding of the interaction metaphors – therefore it is **necessary for each user to first execute the easier Experiment 1**.

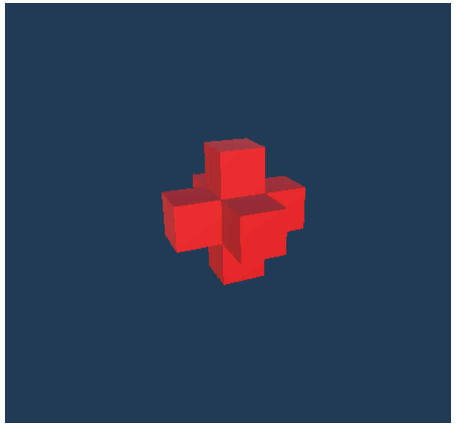
No counterbalancing: learning effects are not evaluated

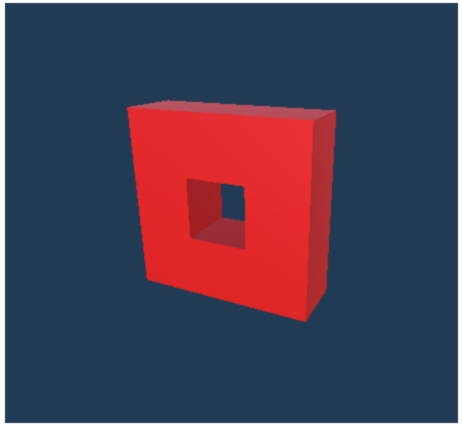
# User Study

**Experiment 1:**
Sandbox scenario with ‚Lego' like objects to stack on each other. Objects are interactable with any type of hand.

**Task:**

1. Build one of two demonstrated sample objects
2. Apply automated rotation to the finished object
3. Build a custom object containing moving objects





# User Study

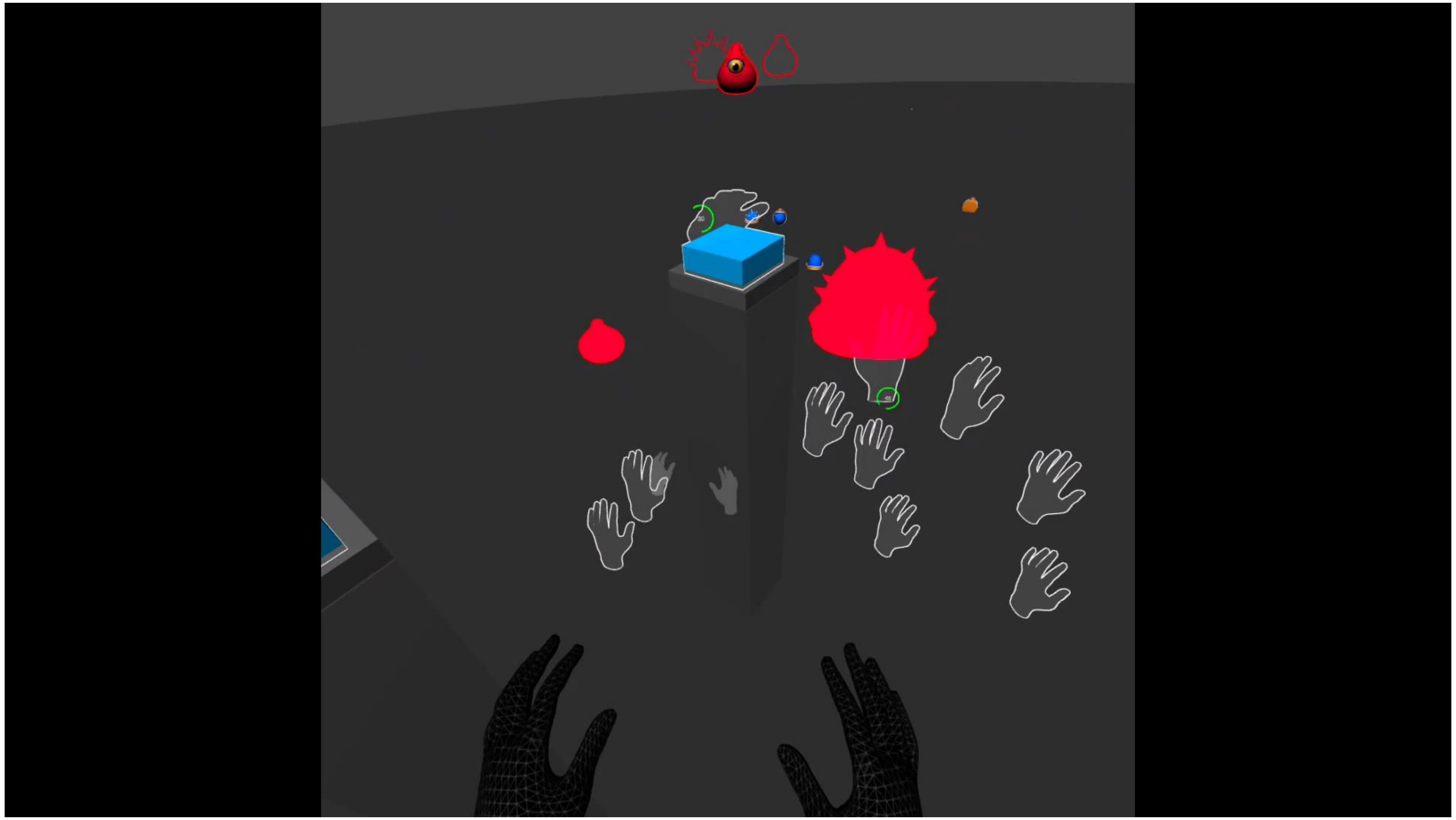
**Experiment 2:**
Player defends himself against incoming enemies using different types of hands.

**Task:**
**Defend yourself against incoming enemies using:**

- Level 1: Only ‘Distance Hands’
- Level 2: Only ‘Steady Hands’
- Level 3: Only ‘Recorded Hands’
- Level 4: All hand types

# User Study

**Experiment 2:**
Game Concept



# User Study

**Setup:**

- Oculus Quest 2
- Active hand tracking & corresponding lighting conditions
- Appr. $10m^2$ room
- VR content was streamed to a PC for observation

**Procedure:**

| 5min. | 5min. | 10min. | | 5min. | 20min. | | | | 5min. |
|---|---|---|---|---|---|---|---|---|---|
| Formal introduction | Intro | Experiment 1 | | Questionnaire | Experiment 2 | | | | Questionnaire + Demographics |
| | | Part 1: Build sample objects | Part 2: Build custom object | | Part 1: Only Distance hands | Part 2: Only Steady hands | Part 3: Only Recorded hands | Part 4: All types of hands | |

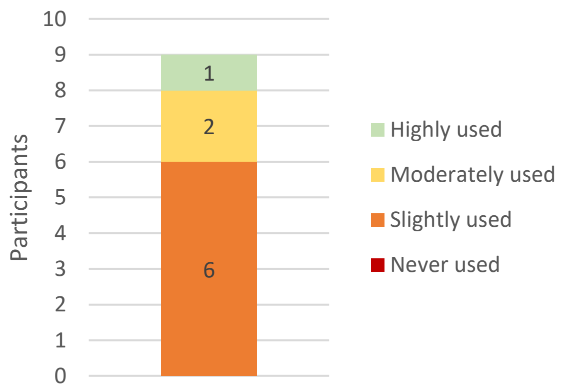
# Results (Demographics)

## Participants

**N = 9** (2F, 7M)

**Age**: 23 – 53 (Mean= 27.1, SD = 9.2)

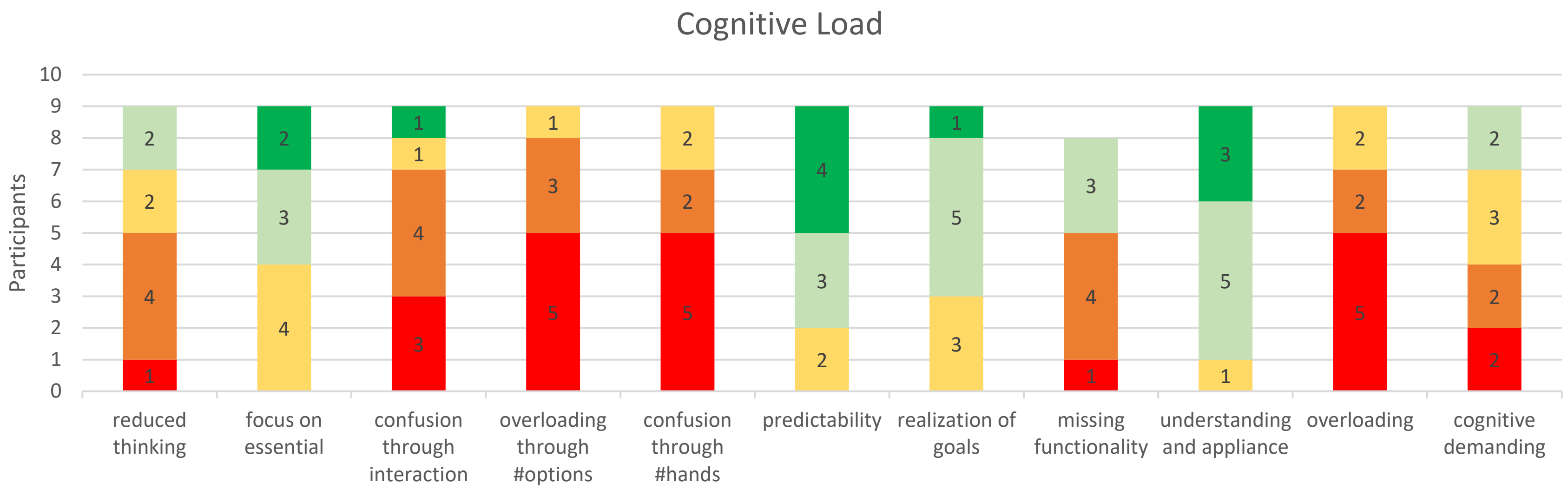
**VR Experience:**



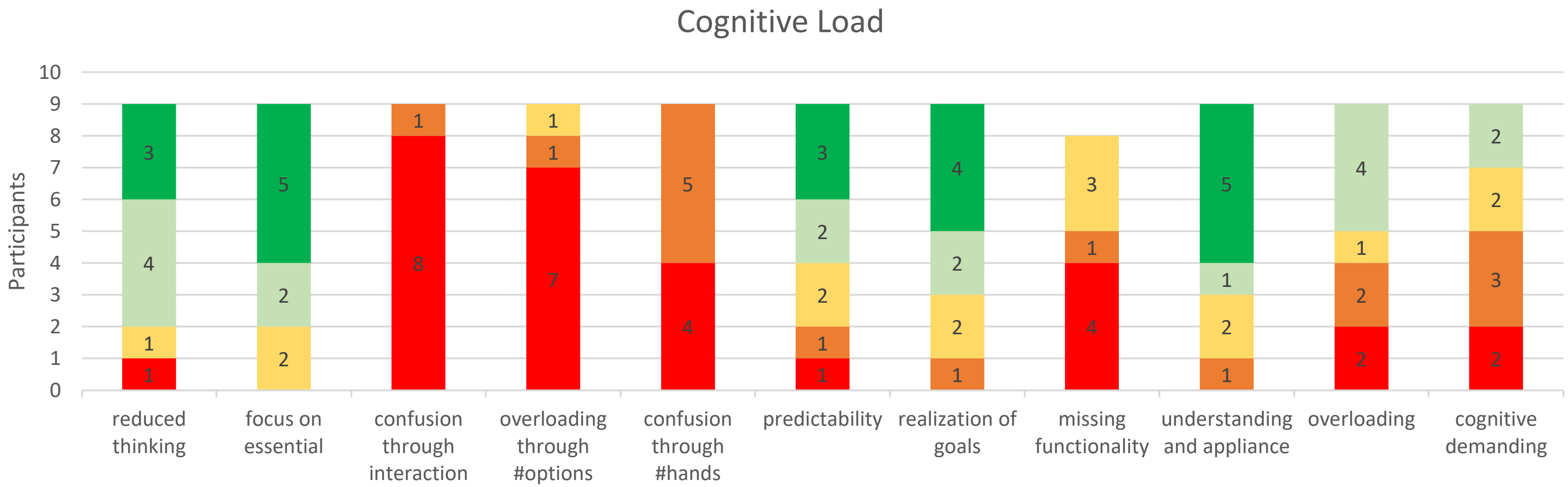
# Results (Cognitive Load)

strongly agree
agree
neutral
disagree
strongly disagree

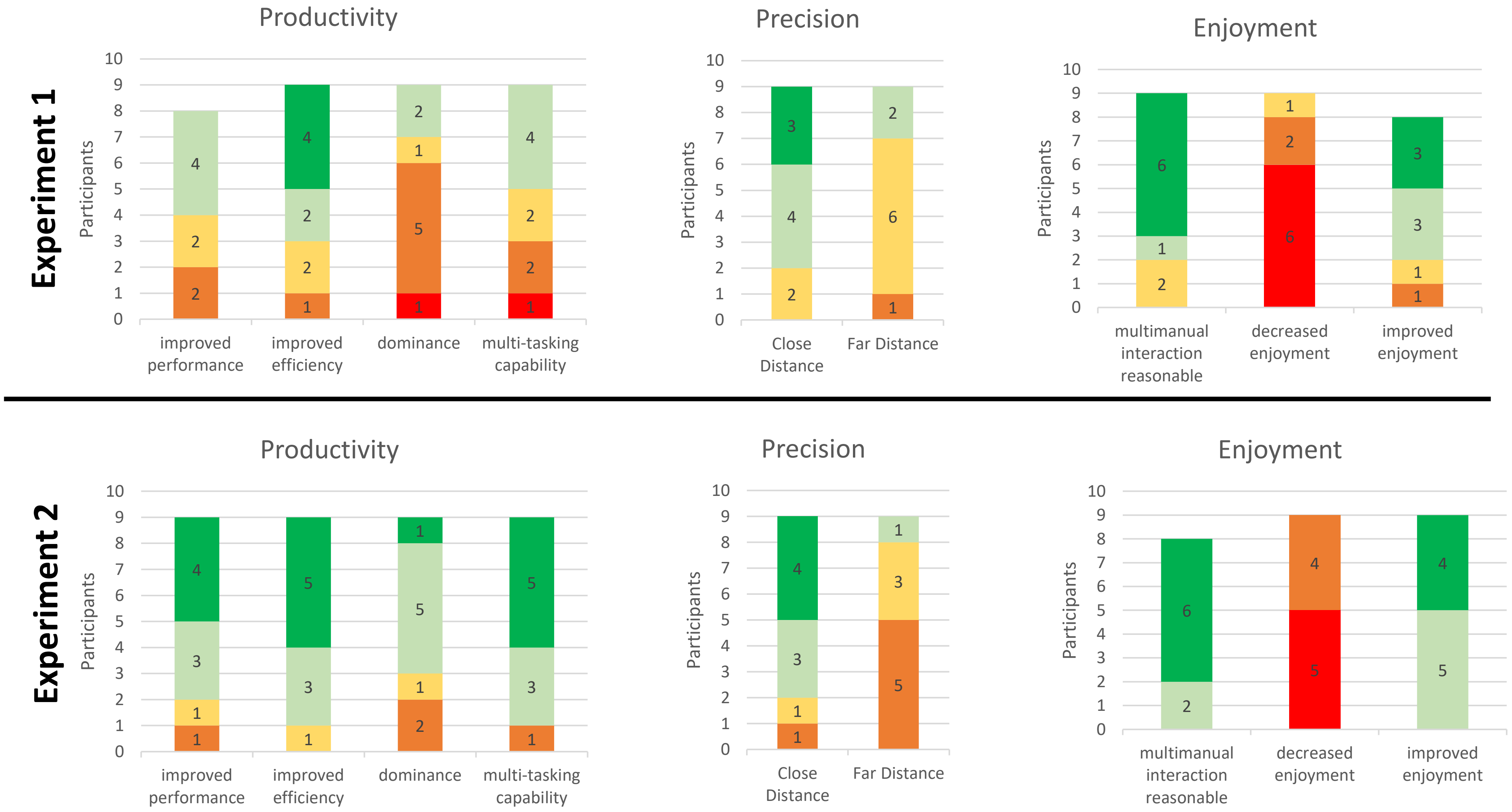
**Experiment 1**




**Experiment 2**



# Results (Productivity, Precision, Enjoyment)




**Motivation** (review)

**Related Work**

**Concept**

**Methods & Material**

Design Space

Implementation

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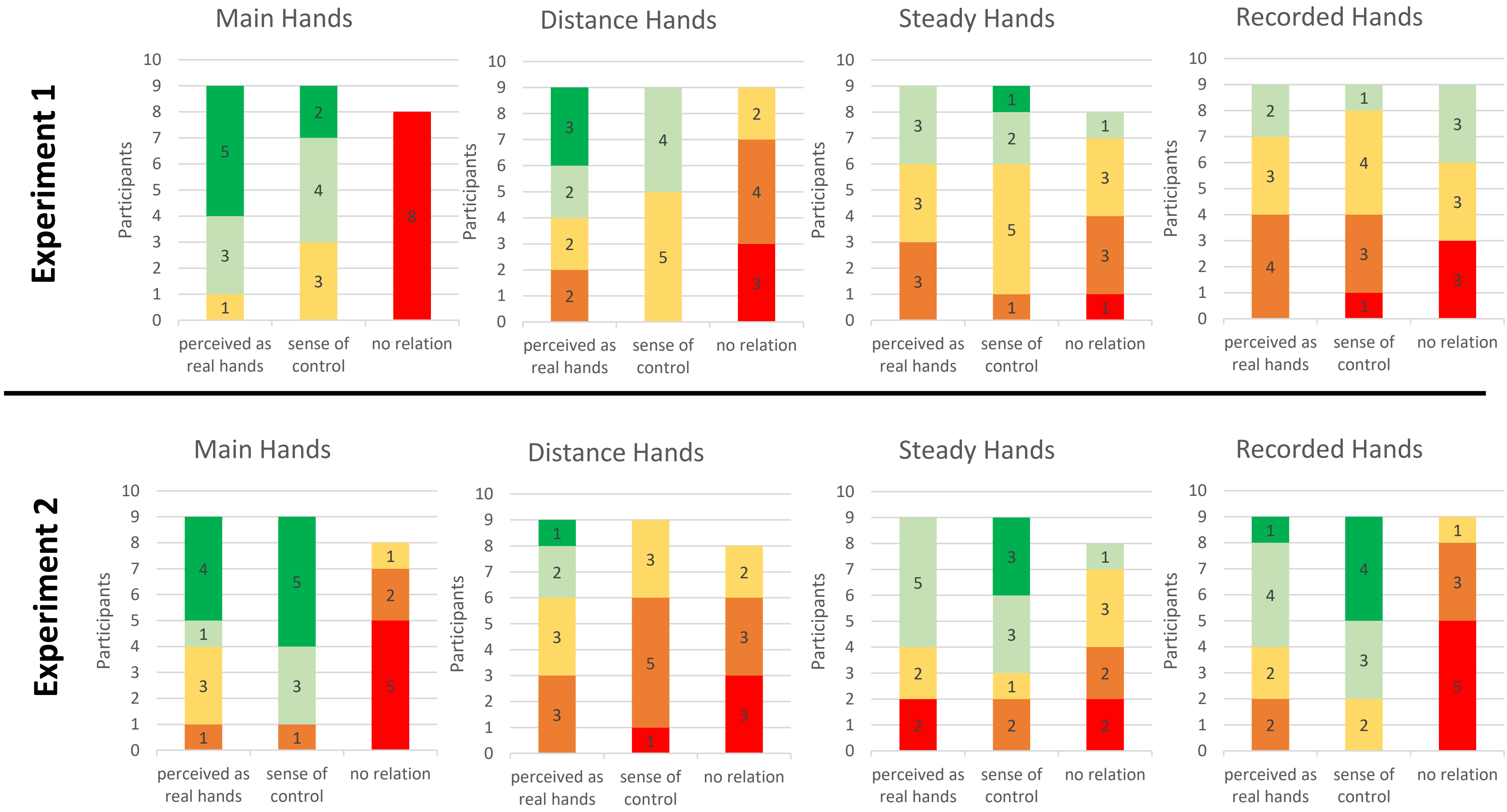
**Conclusion**

# Results (Immersion)

- strongly agree
- agree
- neutral
- disagree
- strongly disagree





**Motivation** (review)

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# Results (Individual User Feedback)

**What aspects of multimanual interaction did you notice negatively?**

**What aspects of multimanual interaction did you notice positively?**

**What functionality was missing to enhance user experience?**

**What functionality did you find unnecessary?**

# Results (Individual User Feedback)

**What aspects of multimanual interaction did you notice negatively?**

- Hand tracking partially inaccurate
- Distance interaction partially unprecise
- Sometimes hard to reach hand buttons
- Preferred gesture interaction instead of buttons

**Technical**

- Maintain overview of hands

**Cognitive Load**

**What aspects of multimanual interaction did you notice positively?**

- Interacting with objects from a distance
- Hand copies are usable in a versatile manner – not restricted to a certain setup
- Easy and understandable interaction metaphors / good realization and easy to handle

**Interaction**

- Hand copies did a lot of work for me / Automatization of simple processes
- Availability of hand copies reduce pressure (Game)

**Multi-tasking**

**What functionality was missing to enhance user experience?**

- Gesture interaction

**What functionality did you find unnecessary?**

- none

# Conclusion

- **Multimanual Interaction** is a plausible way to improve versatility of our digital hand representations
- Adding abilities to our virtual body representations is promising when thinking of the **progressive fusion of virtual and digital world** through rapidly developing MR technology
- Enhanced abilities in virtual environments might soon also be practical in real environments
- Complete fusion of real and digital world: **The Ultimate Display** [7]
    - Improved digital abilities directly affect real abilities



[7] SUTHERLAND, Ivan. The ultimate display. 1965.
http://papers.cumincad.org/cgi-bin/works/BrowseTreefield=seriesorder=AZ/Show?c58e

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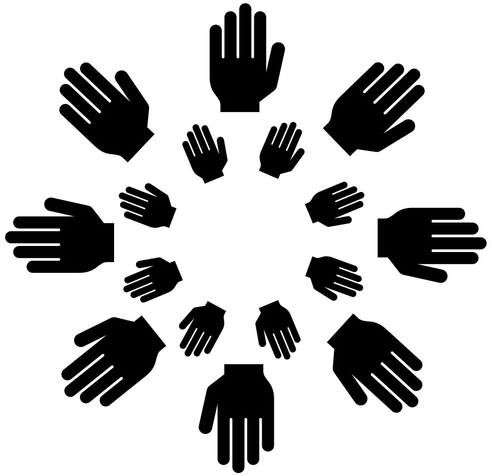



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