Why Human-Scale Mobile Manipulators Will Eventually Be In Homes

Charlie Kemp
https://charliekemp.com

Associate Professor, Department of Biomedical Engineering
Adjunct in the Schools of Interactive Computing and Electrical & Computer Engineering

Georgia Tech
Wallace H. Coulter Department of Biomedical Engineering
Emory University

I Believe It's Likely

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Millions Of

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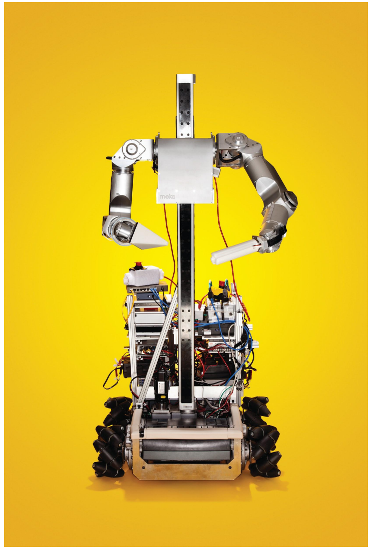
Charlie's Conflict of Interest Statement

Dr. Kemp is both an associate professor at Georgia Tech and the chief technology officer (CTO) of Hello Robot Inc. where he works part time. **He owns equity** in Hello Robot Inc. and is an inventor of Georgia Tech intellectual property (IP) licensed by Hello Robot Inc. Consequently, **he receives royalties** through Georgia Tech for sales made by Hello Robot Inc. He also benefits from increases in the value of Hello Robot Inc.

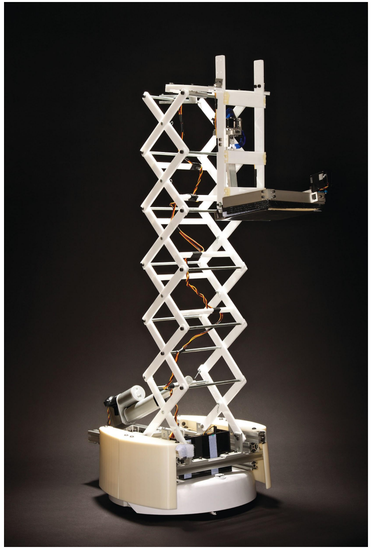
Summary: If Hello Robot does well, Charlie does well.

I’ve focused on mobile manipulation since 2006

EL-E (2008)



Cody (2009)



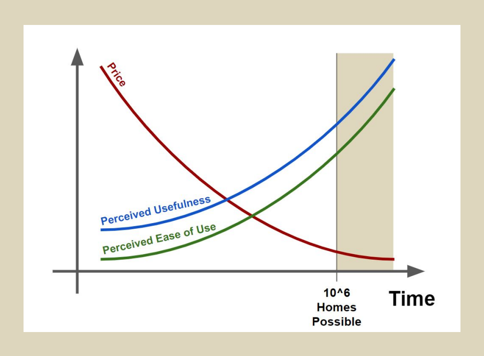
Dusty (2010)

Stretch (2020)

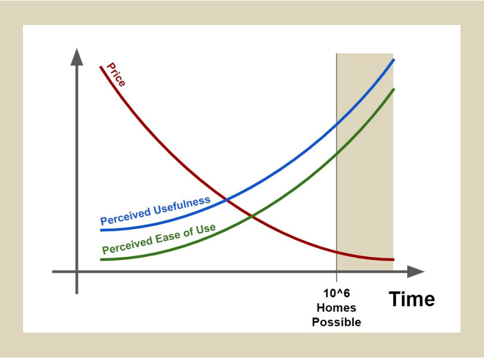
Commercialized by Hello Robot

Human-Scale Mobile Manipulators in Homes

- A Simple Model of Technology Adoption
- People with Disabilities Could be Early Adopters
- Progress Toward Broader Use and Affordability



A Simple Model of Technology Adoption



Why will human-scale mobile manipulators eventually be in millions of homes?

Perceived Usefulness

Perceived Ease of Use

Photo from https://ahs.illinois.edu/rogers

Prof. Wendy Rogers introduced me to this model back in 2010 when we began collaborating on home robots.

https://en.wikipedia.org/wiki/Technology_acceptance_model

Why will human-scale mobile manipulators eventually be in millions of homes?

Perceived Usefulness

Perceived Ease of Use

Price

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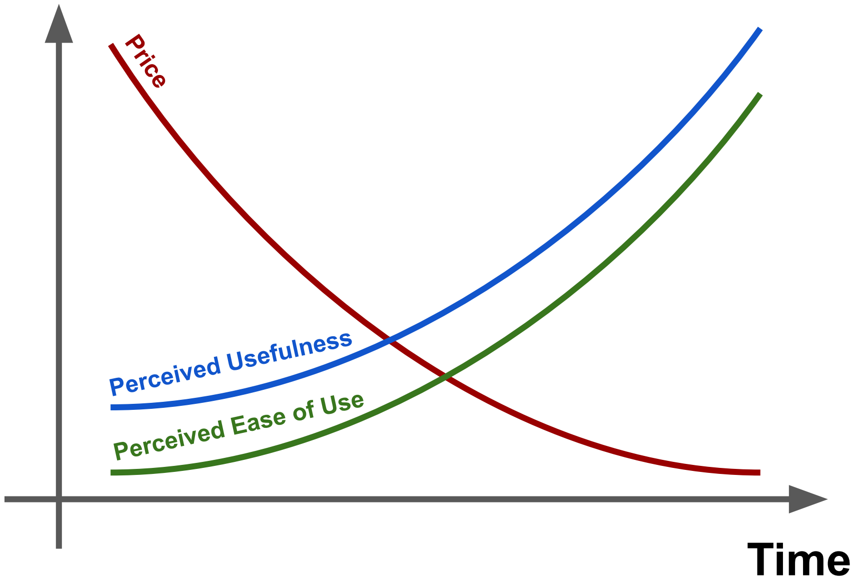
Perceived Usefulness

Perceived Ease of Use

Price



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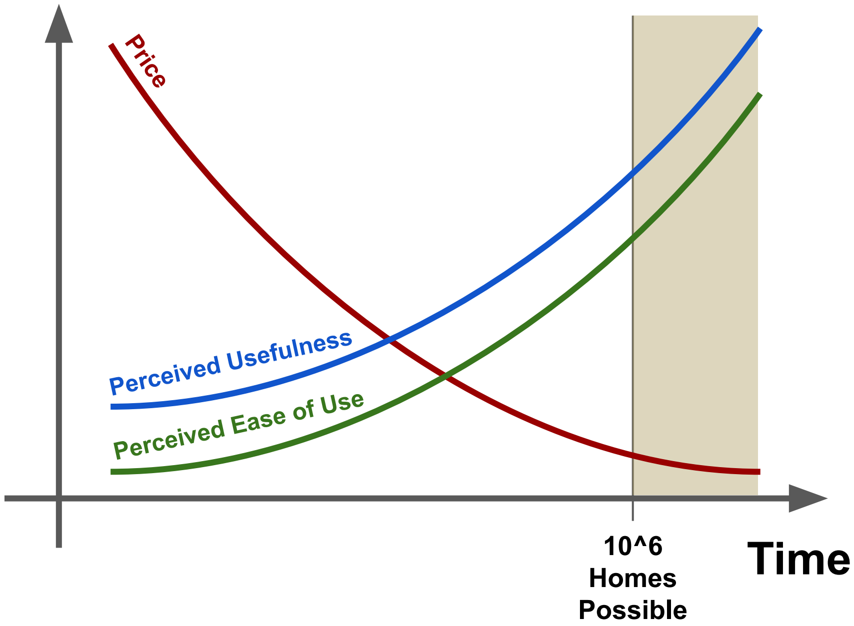
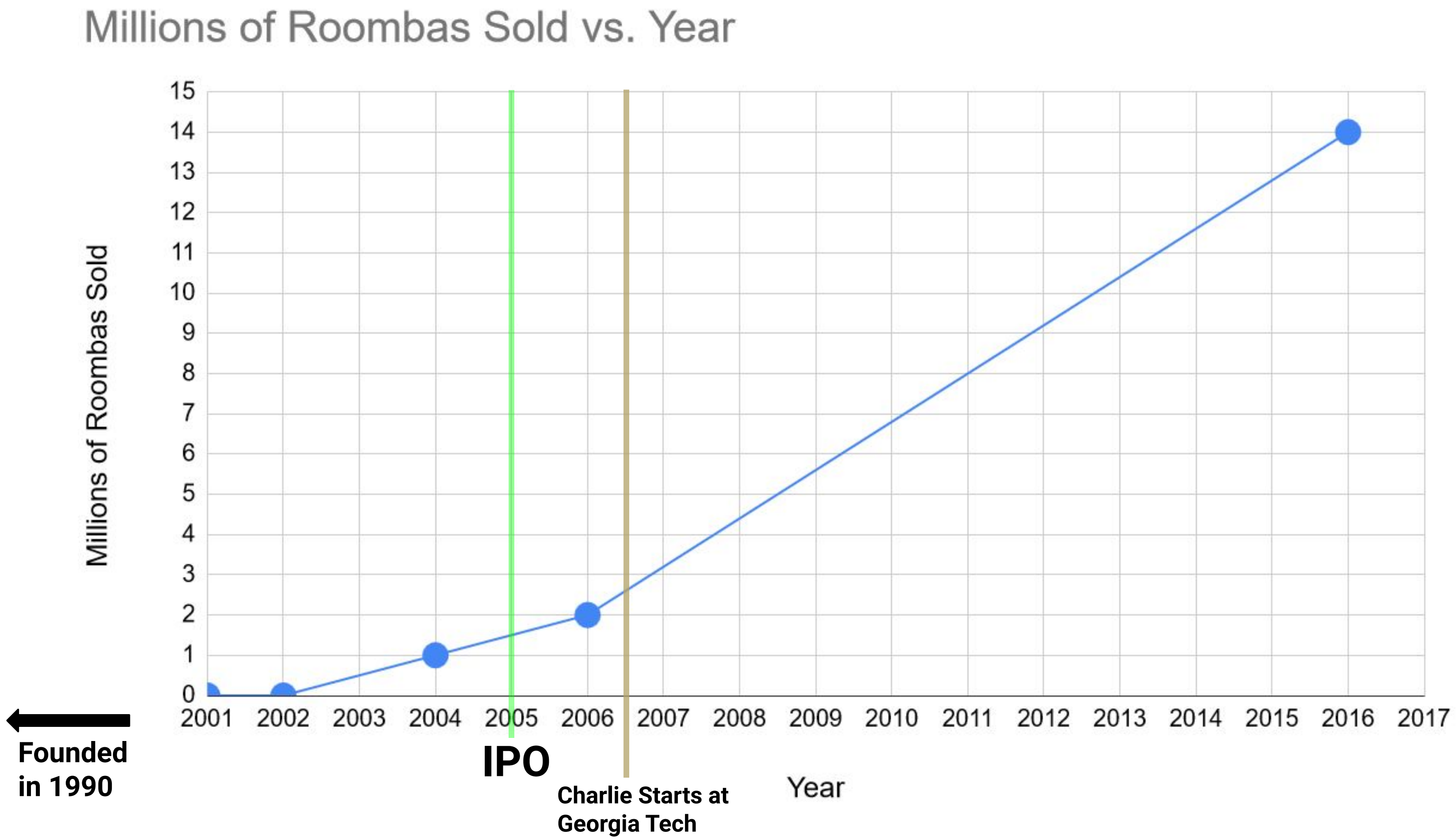


It’s Happened Before

Photo Credit: *Larry D. Moore, CC BY-SA 3.0, Wikimedia Commons*.
from https://en.wikipedia.org/wiki/Roomba

The first Roomba from 2002.

20 years ago!


Millions of Roombas Sold vs. Year
Millions of Roombas Sold
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Year
Founded in 1990
IPO
Charlie Starts at Georgia Tech

Why is the Roomba in millions of homes?

- **Perceived Usefulness** - Autonomously cleans floors
- **Perceived Ease of Use** - Small, easy to move, 3 buttons
- **Price** - $200 at launch (~$300 in 2022 dollars)

Rod Brooks has emphasized the importance of a low price. iRobot wanted a person to be comfortable buying a Roomba without permission from a life partner.

Photo from https://www.edge.org/memberbio/rodney_a_brooks

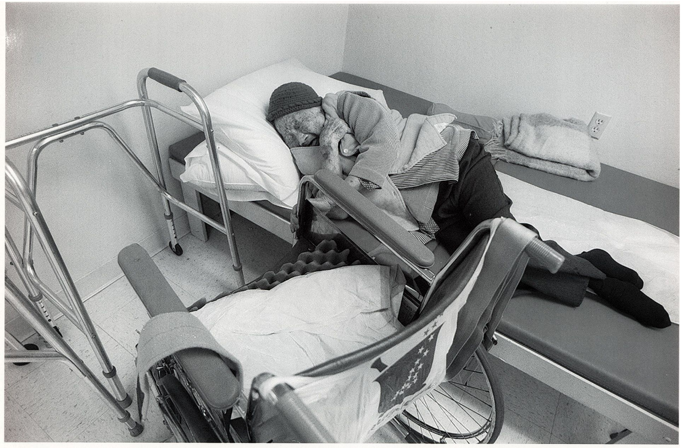
People with Disabilities Could be Early Adopters

Mobile Manipulators Can Provide Meaningful Assistance

research from the Healthcare Robotics Lab (healthcare-robotics.com) at Georgia Tech

Long-term Disabilities

- In the US, 12,000,000 people with disabilities need assistance with daily activities [1]
- Causes include
    - Disease
    - Injury
    - Aging



[1] Brault, Matthew W. "Americans with disabilities: 2010." Current population reports 7 (2012): 0-131.
Photo from https://en.wikipedia.org/wiki/Elderly_care

Short-term Disabilities

- In the US by 2030
    - 635,000 total hip replacement surgeries per year
    - 1.28 million total knee replacement surgeries per year

"*median time to recovery of independence in walking was **12 days** and to ability to perform household chores was **49 days***" [2]

[1] Sloan, Matthew, Ajay Premkumar, and Neil P. Sheth. "Projected volume of primary total joint arthroplasty in the US, 2014 to 2030." JBJS 100.17 (2018): 1455-1460.
[2] Hamel, Mary Beth, et al. "Joint replacement surgery in elderly patients with severe osteoarthritis of the hip or knee: decision making, postoperative recovery, and clinical outcomes." Archives of internal medicine 168.13 (2008): 1430-1440.
Photo from https://en.wikipedia.org/wiki/Knee_replacement

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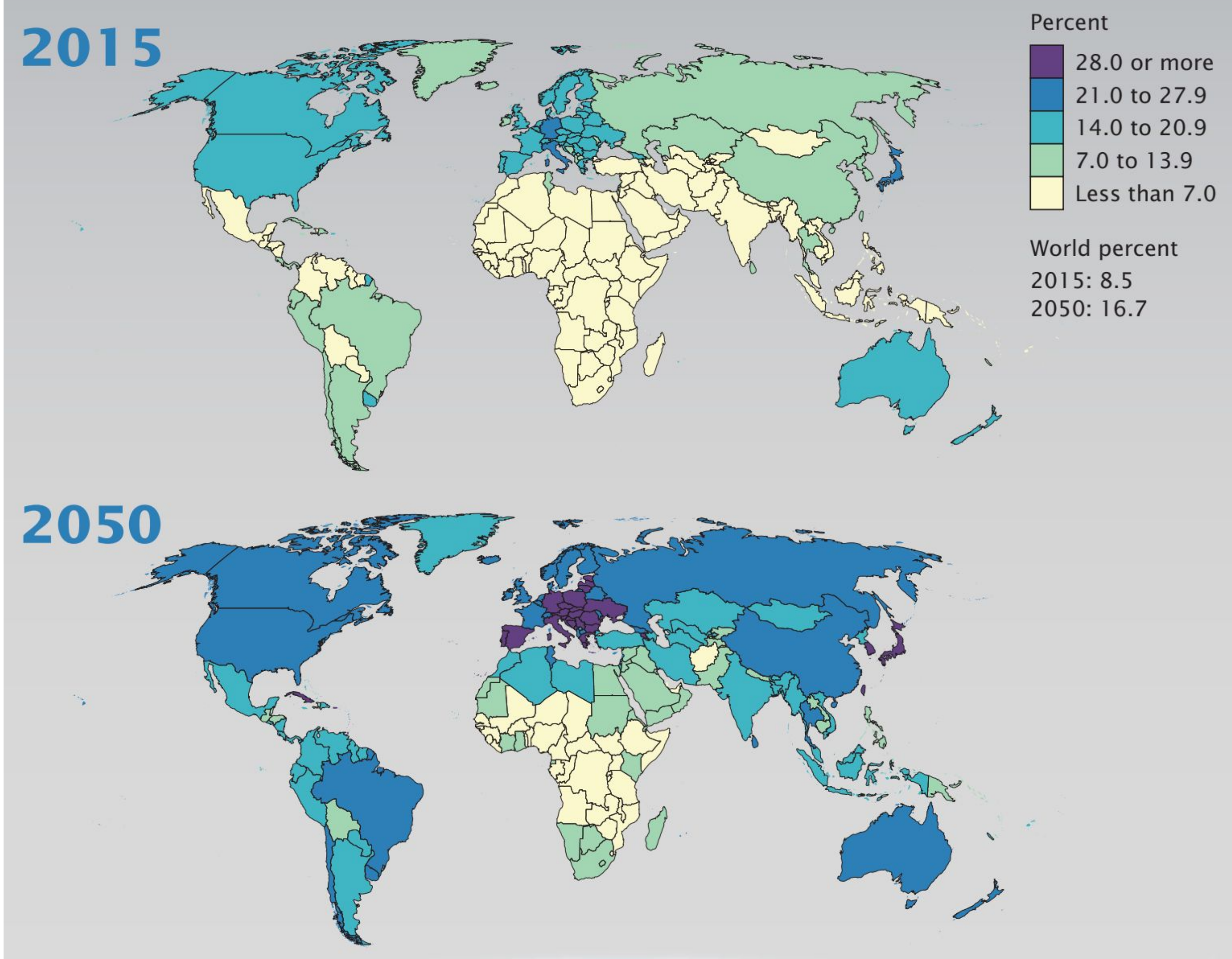
Aging Societies will Increase Demand

Percentage of Population Age 65+



From https://www.census.gov/library/visualizations/2016/comm/cb16-54_aging_world.html

Types of Tasks

- **Activities of Daily Living (ADLs)**
  - Feeding, toileting, transferring, dressing, and hygiene
- **Instrumental Activities of Daily Living (IADLs)**
  - Housework, food preparation, taking medications, …

Types of Tasks

- **Activities of Daily Living (ADLs)**
  - Feeding, toileting, transferring, dressing, and hygiene
  - Manipulation near the person’s body
- **Instrumental Activities of Daily Living (IADLs)**
  - Housework, food preparation, taking medications, …
  - Manipulation of objects in the environment

Robotic Opportunities

- Provide **independence**
- Robots preferred for some tasks [1]
- 24/7 personalized assistance

[1] *Domestic robots for older adults: Attitudes, preferences, and potential*, Cory-Ann Smarr, Tracy L. Mitzner, Jenay M. Beer, Akanksha Prakash, Tiffany L. Chen, Charles C. Kemp, and Wendy A. Rogers. International Journal of Social Robotics, 6(2):229–247, 2014.
[image] from Willow Garage

Commercial Assistive Robots

- On a wheelchair
- On a table or desk
- On the body

JACO by Kinova

DynamicArm by Ottobock

My Spoon by SECOM

Myomo by Myomo Inc.

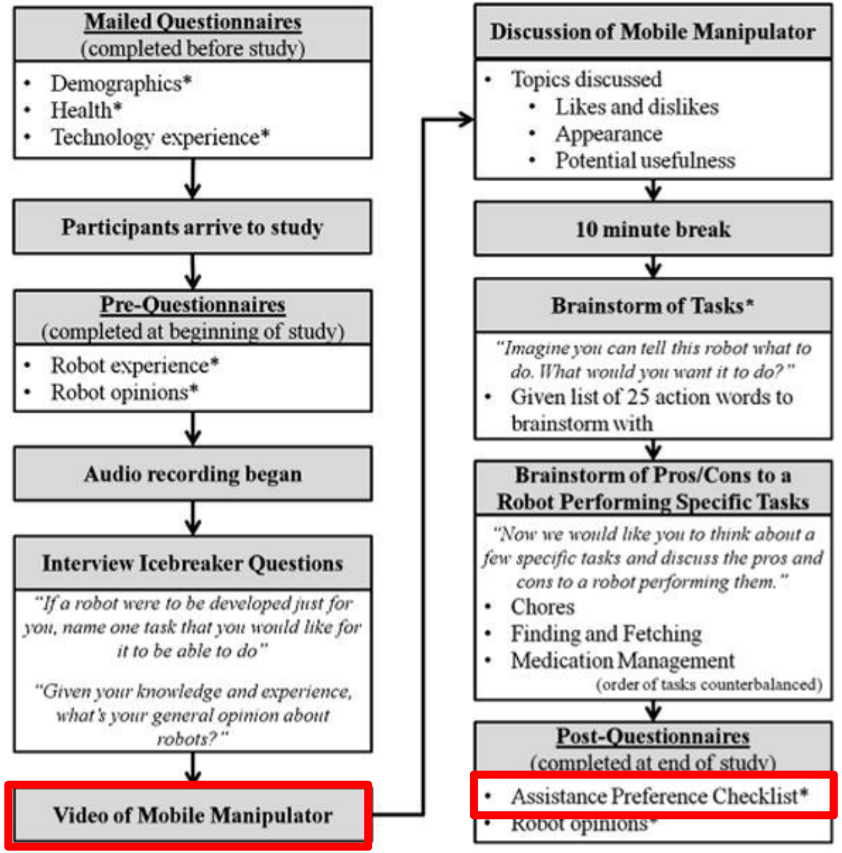
Advantages of Mobile Manipulators

- Operate independently from the user
- No don/doff
- Assist diverse users

People are Open to Assistance from Mobile Manipulators

- Hundreds of participants since 2007
  - People with disabilities
  - Older adults
  - Nurses

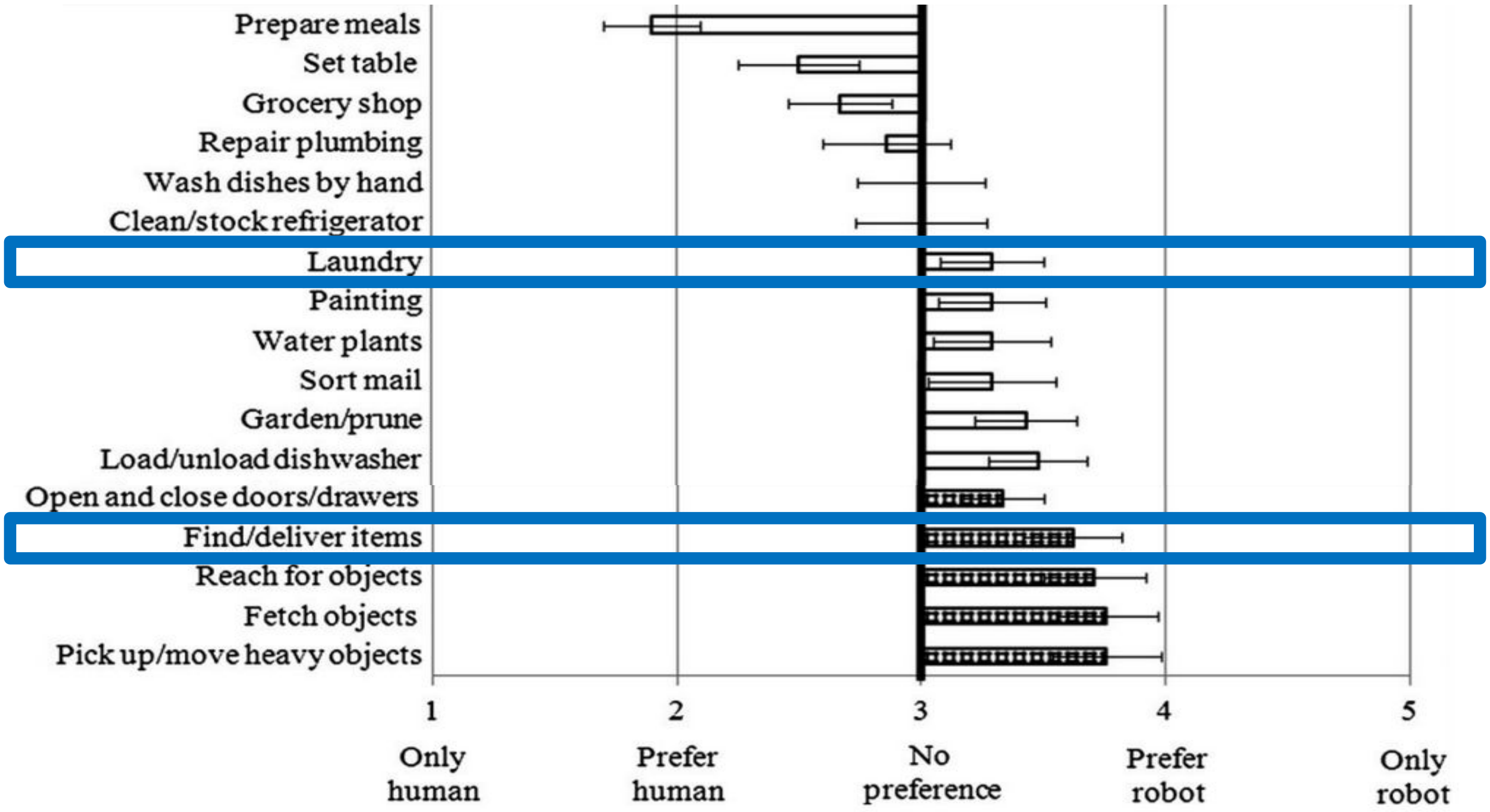
Structured Group Interview and Questionnaires with Older Adults (N=21)



Domestic robots for older adults: Attitudes, preferences, and potential, Cory-Ann Smarr, Tracy L. Mitzner, Jenay M. Beer, Akanksha Prakash, Tiffany L. Chen, Charles C. Kemp, and Wendy A. Rogers. International Journal of Social Robotics, 6(2):229–247, 2014.

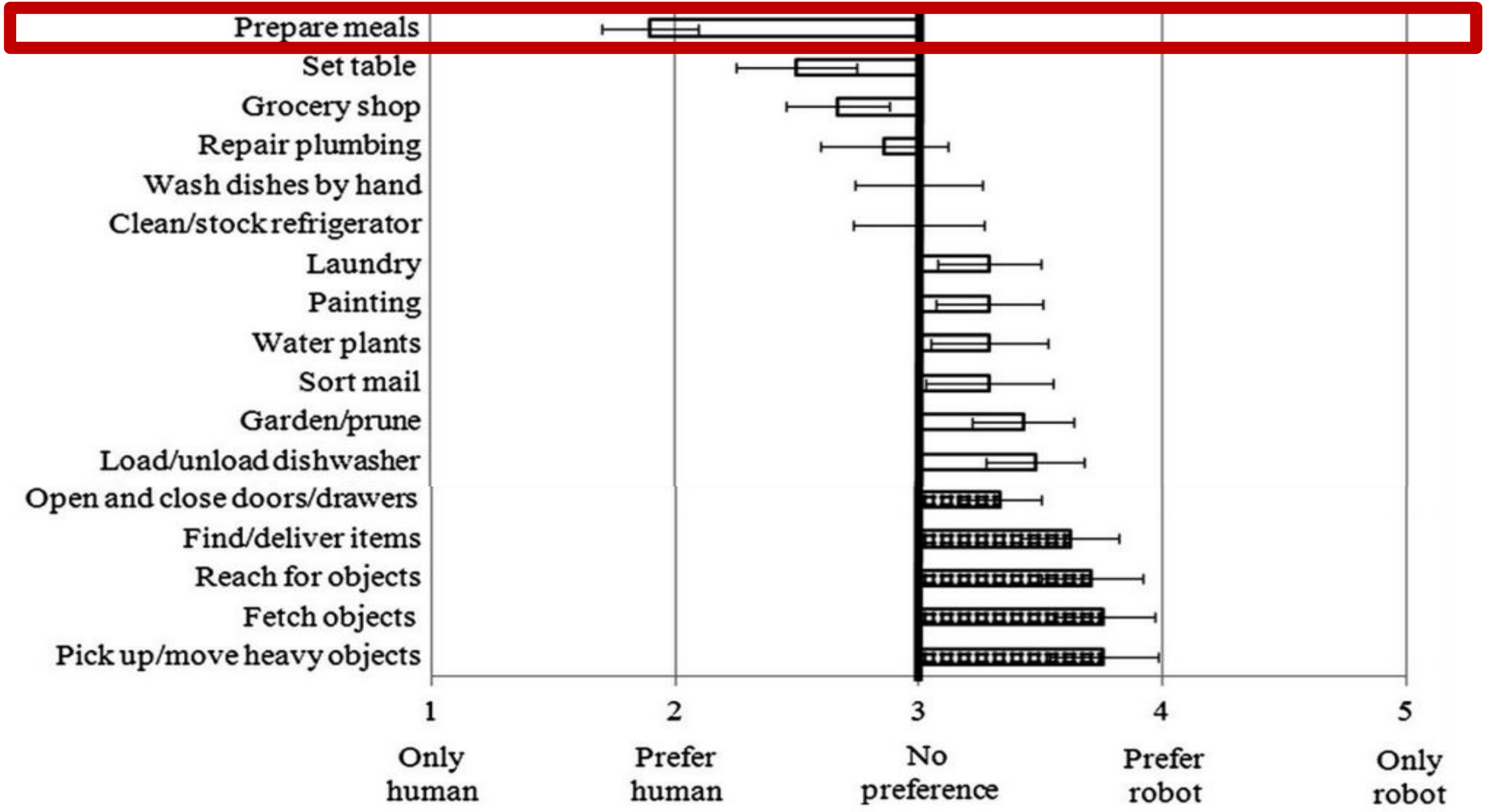
Preferred Robots for Some Tasks

(N=21, results after PR2 video and structured group interview)



Preferred Humans for Others

(N=21, results after PR2 video and structured group interview)



Autonomous Delivery of Medicine to Older Adults at the Aware Home via RFID (N=12)

Older Adults Medication Management in the Home: How can Robots Help? Akanksha Prakash, Jenay M. Beer,Travis Deyle, Cory-Ann Smarr, Tiffany L. Chen, Tracy L. Mitzner, Charles C. Kemp, and Wendy A. Rogers, 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI), 2013

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More Open to Robotic Assistance After Using the PR2

(N=12, POST is after PR2 autonomously delivered medicine to them)

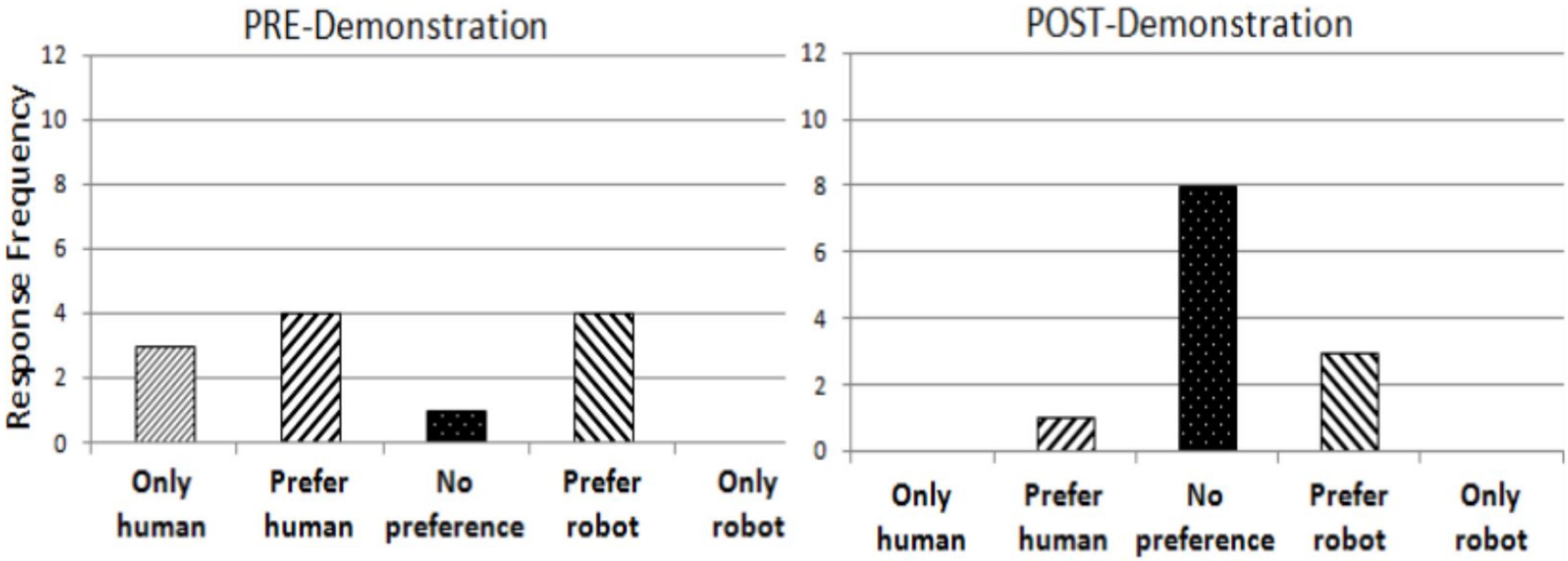

Fig. 4. Human versus robot assistance with delivering medication.

Older Adults Medication Management in the Home: How can Robots Help? Akanksha Prakash, Jenay M. Beer,Travis Deyle, Cory-Ann Smarr, Tiffany L. Chen, Tracy L. Mitzner, Charles C. Kemp, and Wendy A. Rogers, 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI), 2013

But Not for Everything

(N=12, POST is after PR2 autonomously delivered medicine to them)

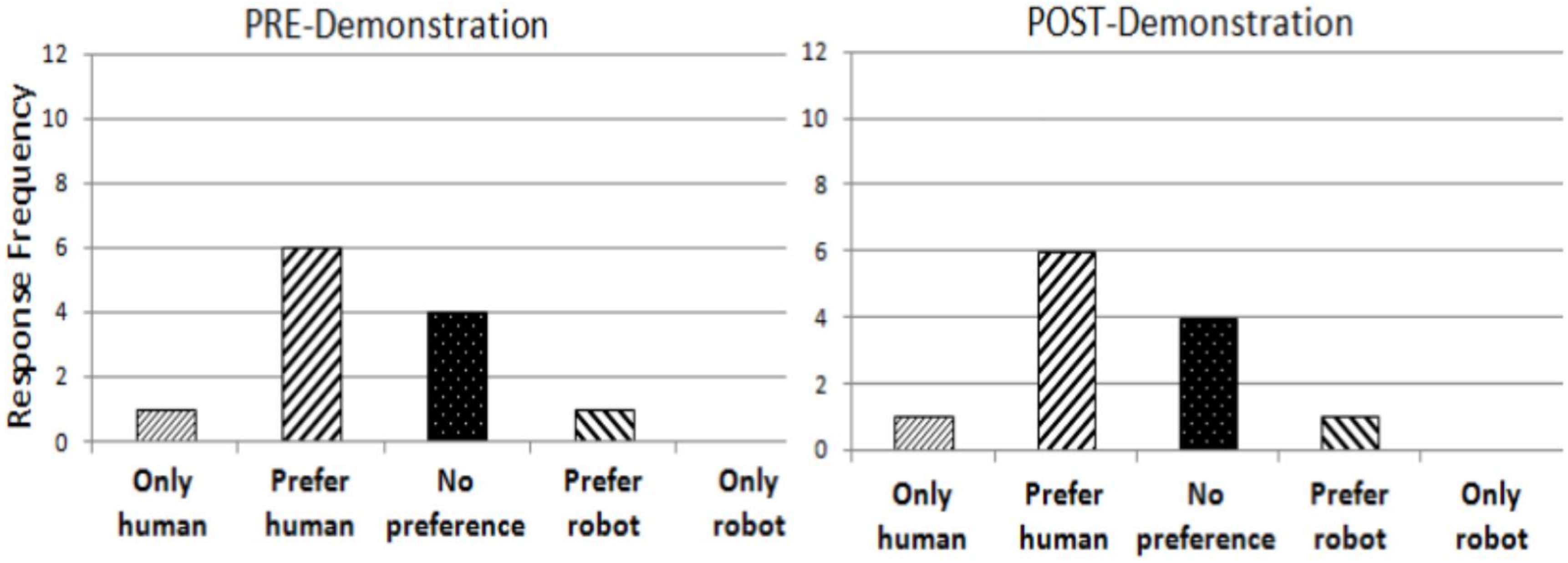

Fig. 5. Human versus robot assistance with taking medication.

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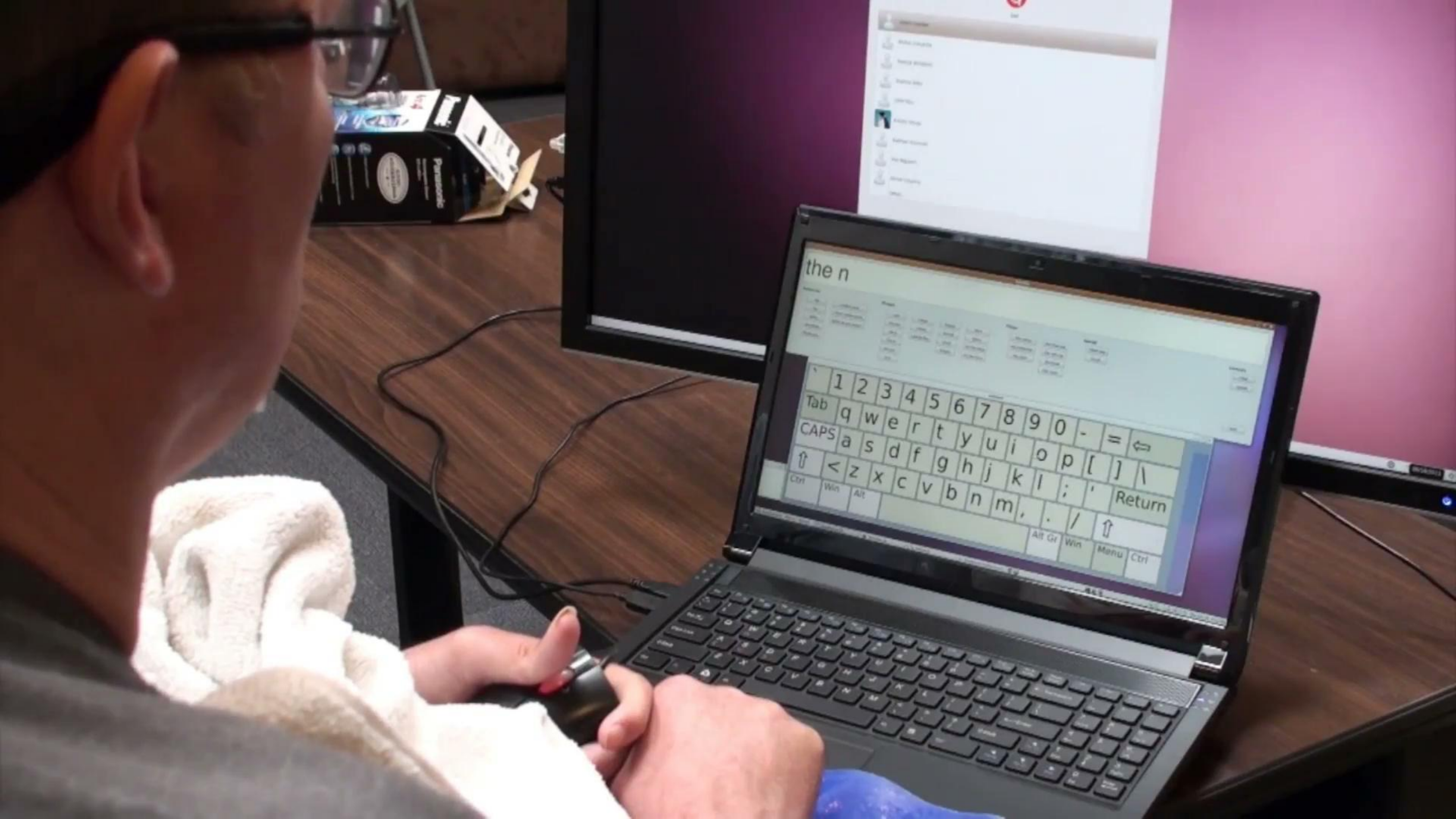
Mobile Manipulators Can Provide Meaningful Assistance

research from the Healthcare Robotics Lab (healthcare-robotics.com) at Georgia Tech

Mobile Manipulators Can Provide Meaningful Assistance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Assistive Mobile Manipulation for Self-Care Tasks Around the Head, Kelsey Hawkins, Phillip M. Grice, Tiffany L. Chen, Chih-Hung King, and Charles C. Kemp, 2014 IEEE Symposium on Computational Intelligence in Robotic Rehabilitation and Assistive Technologies, 2014.

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In-home and remote use of robotic body surrogates by people with profound motor deficits, Phillip M. Grice and Charles C. Kemp, PLoS ONE 14(3), 2019.

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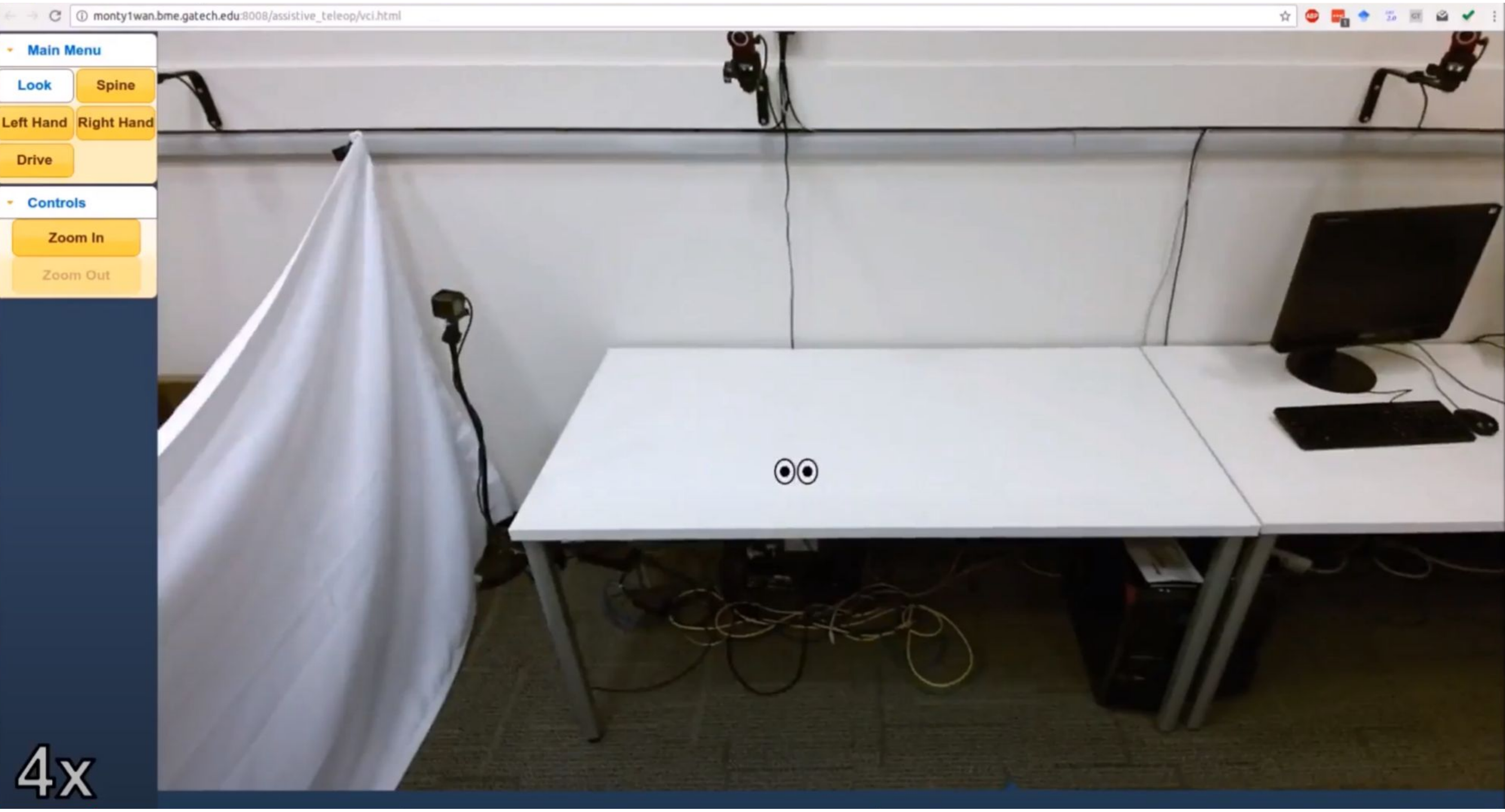
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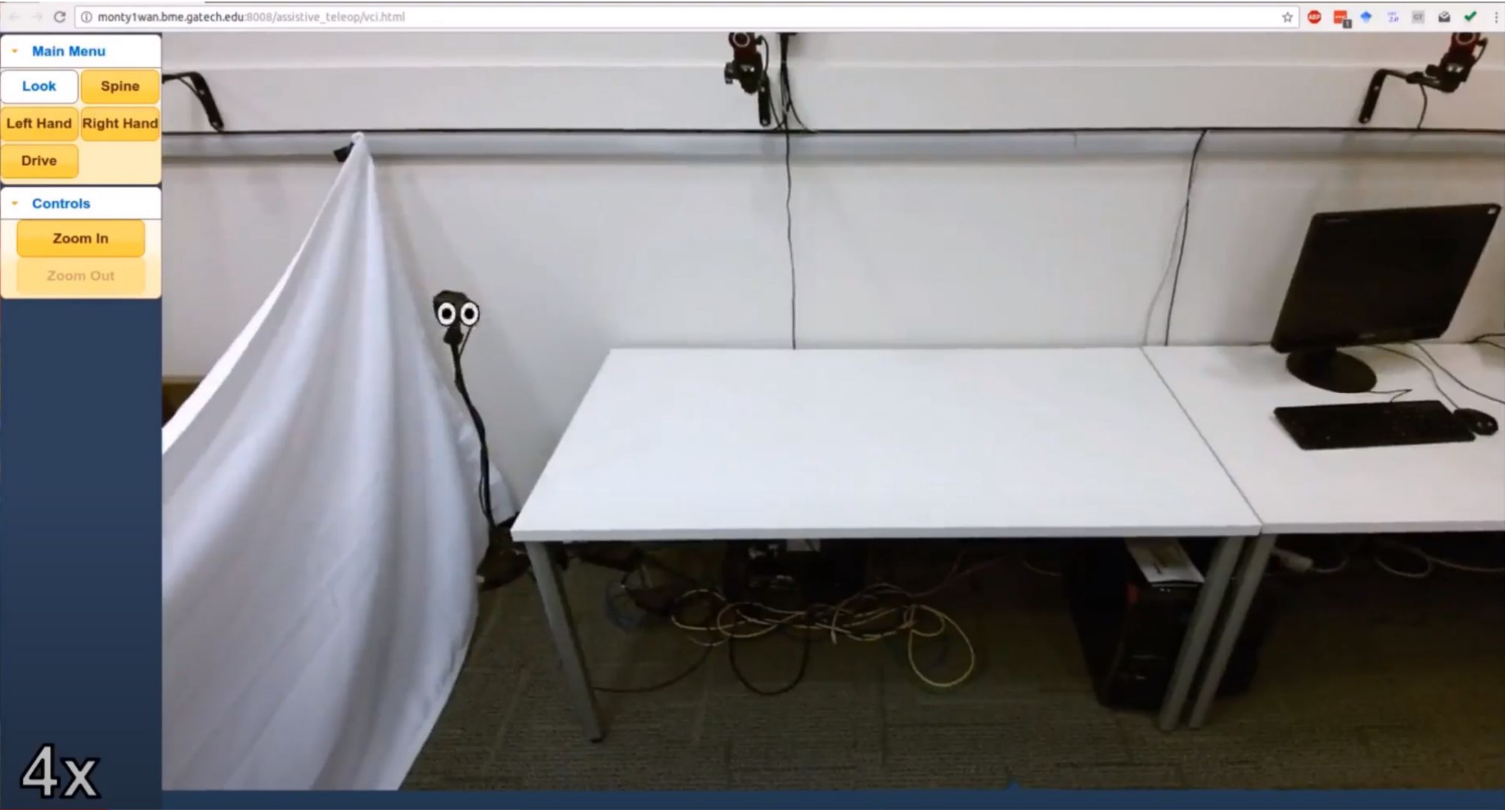
Main Menu
Look
Spine
Left Hand
Right Hand
Drive
Controls
Zoom In
Zoom Out
4x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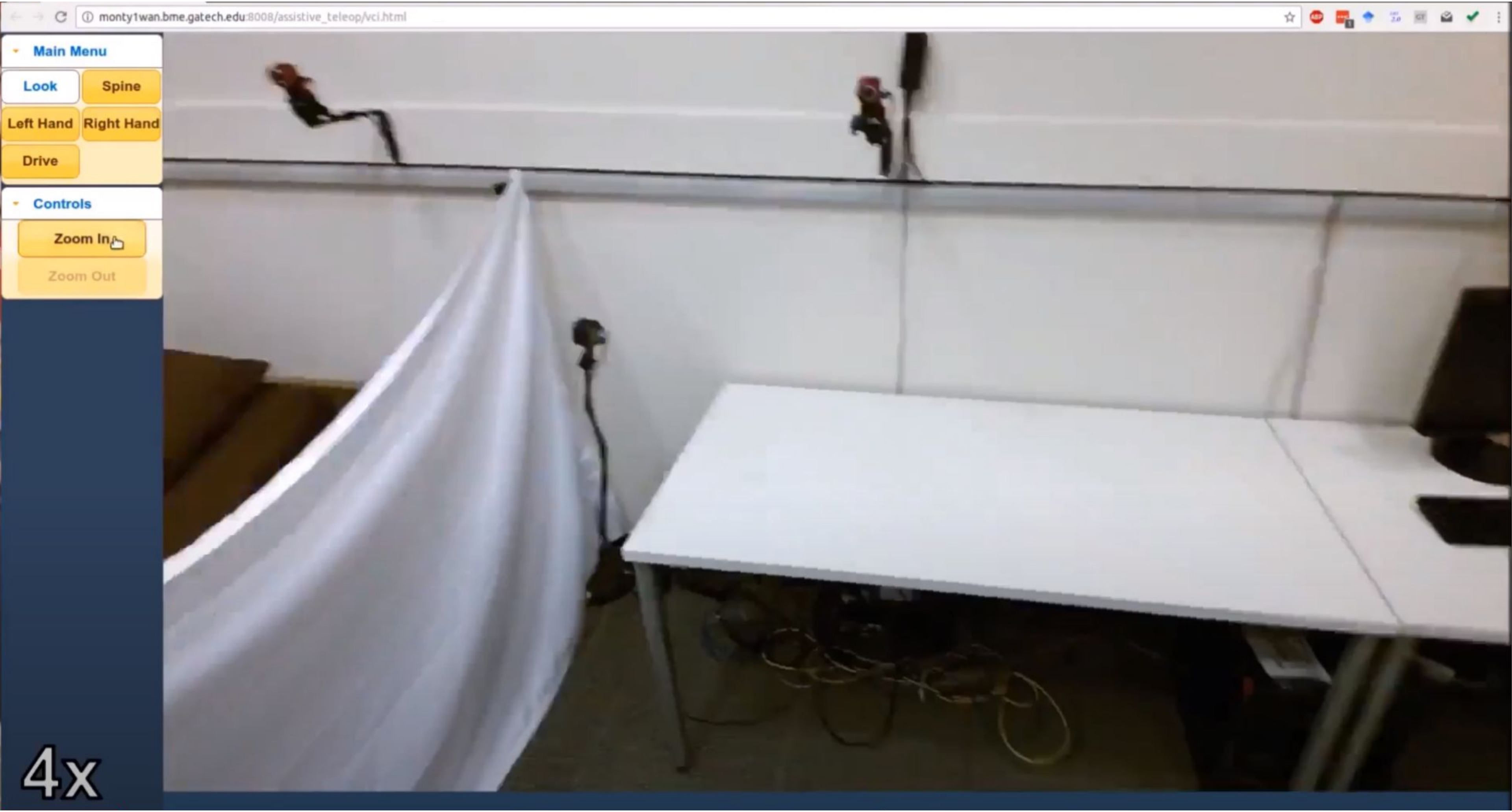
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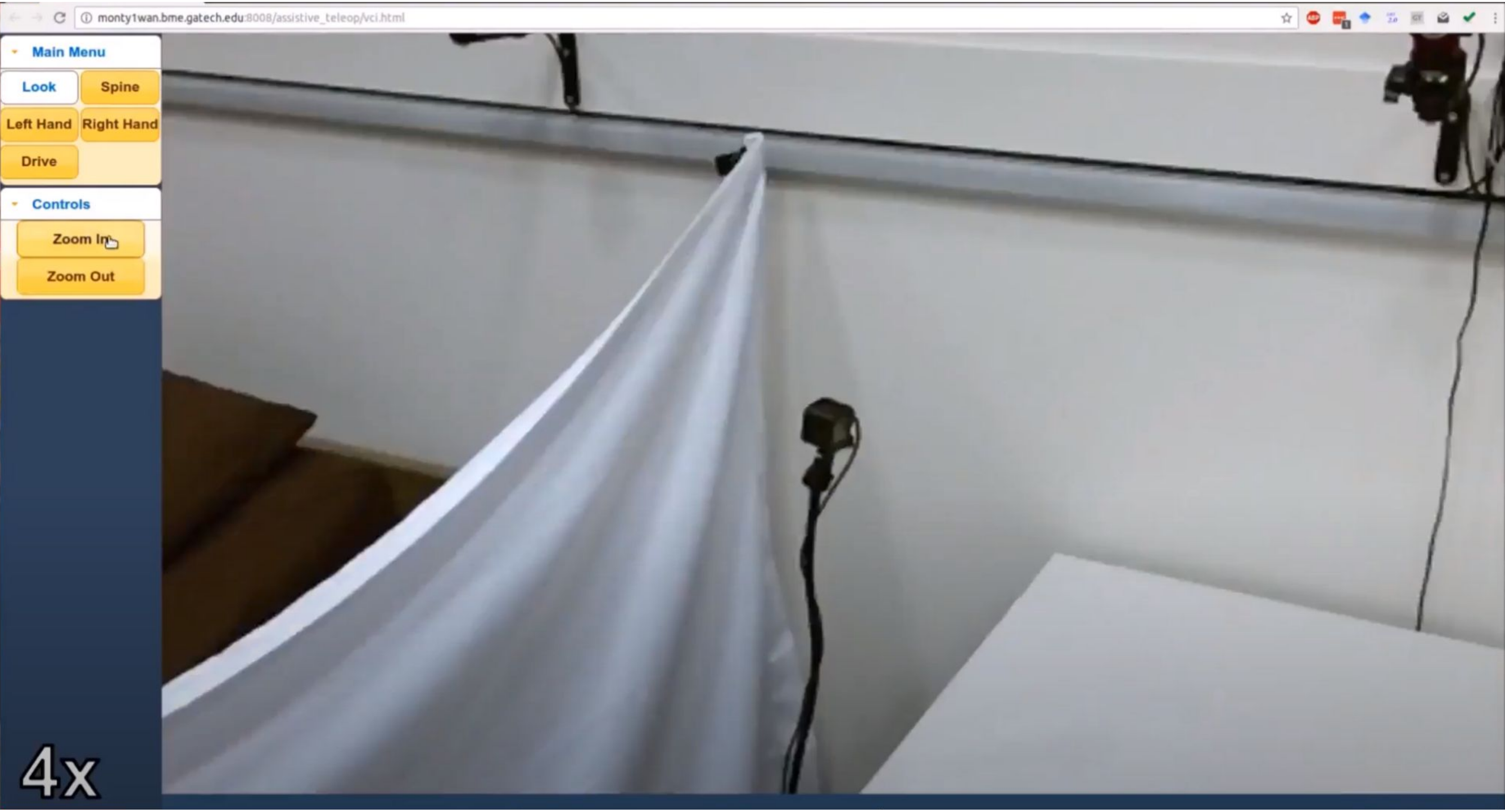
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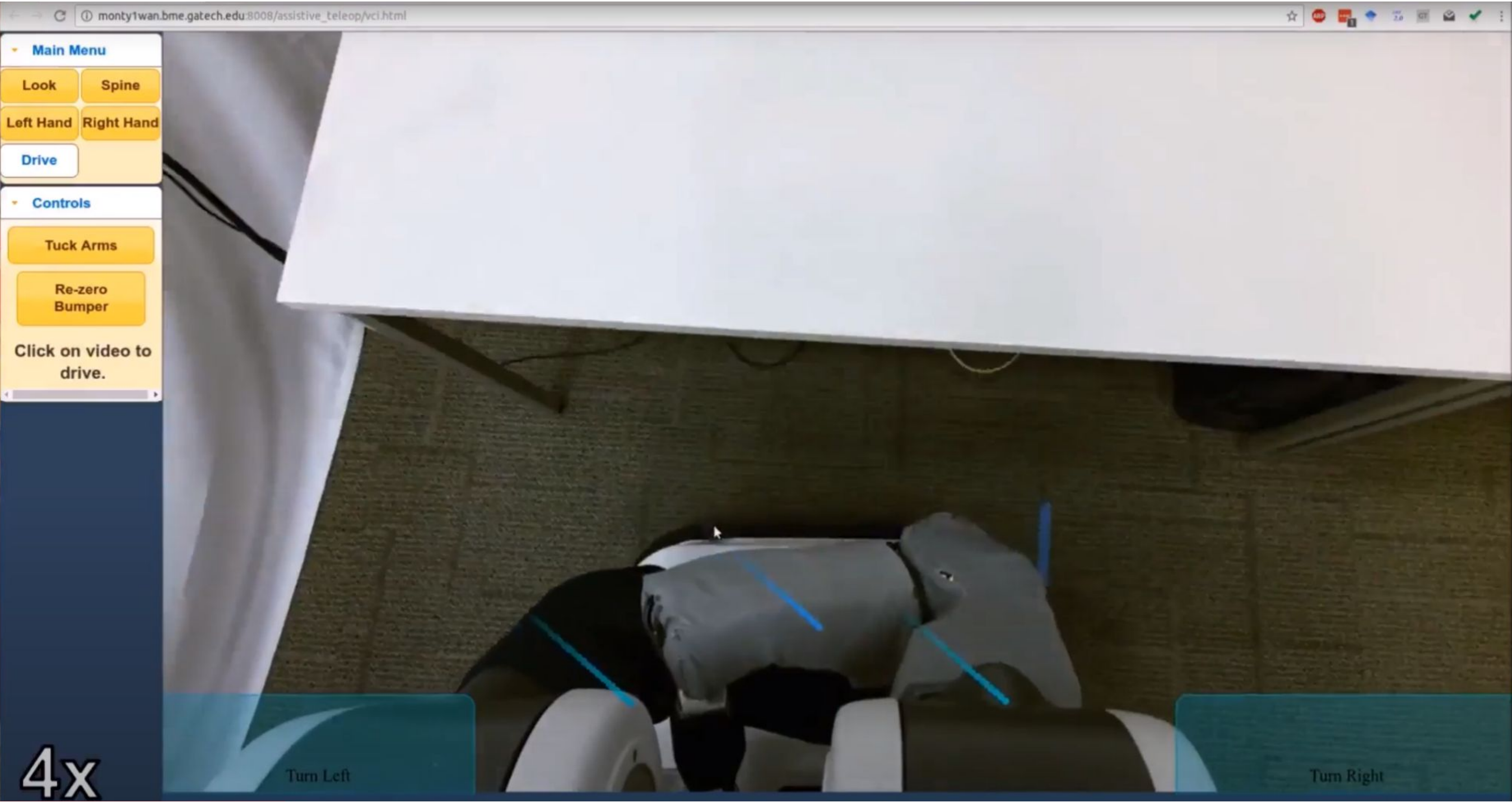
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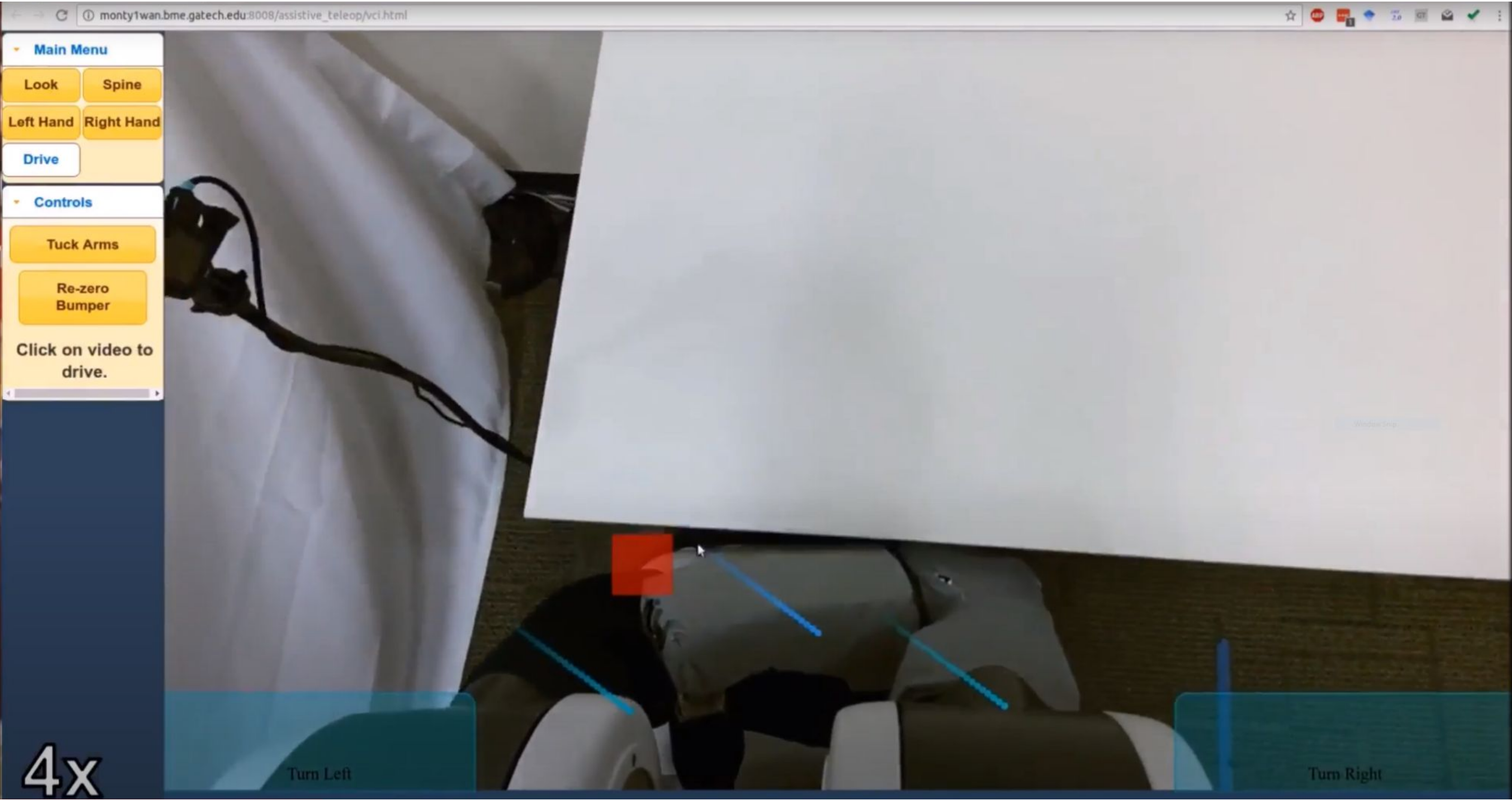
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Move Aside
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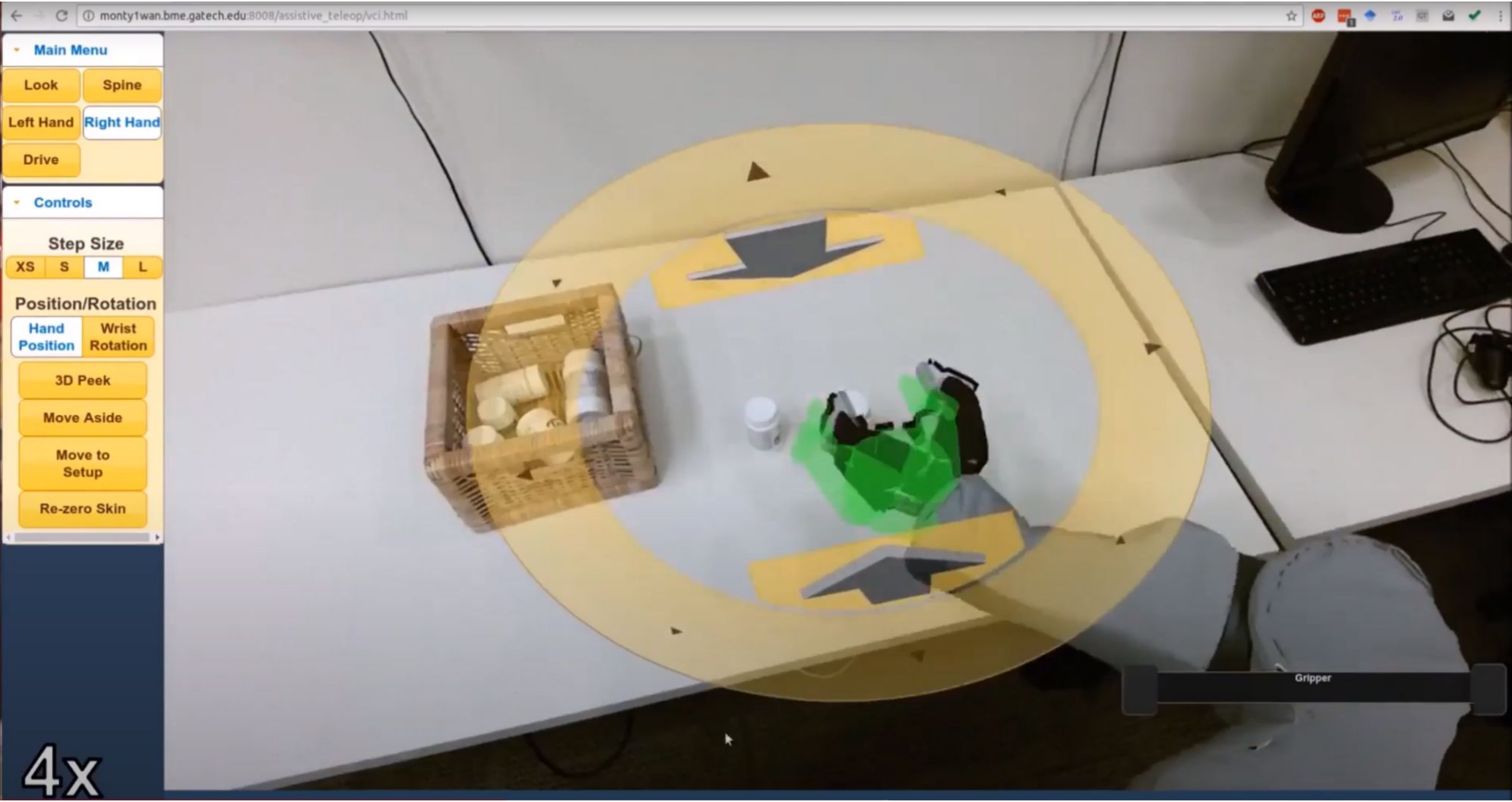
Gripper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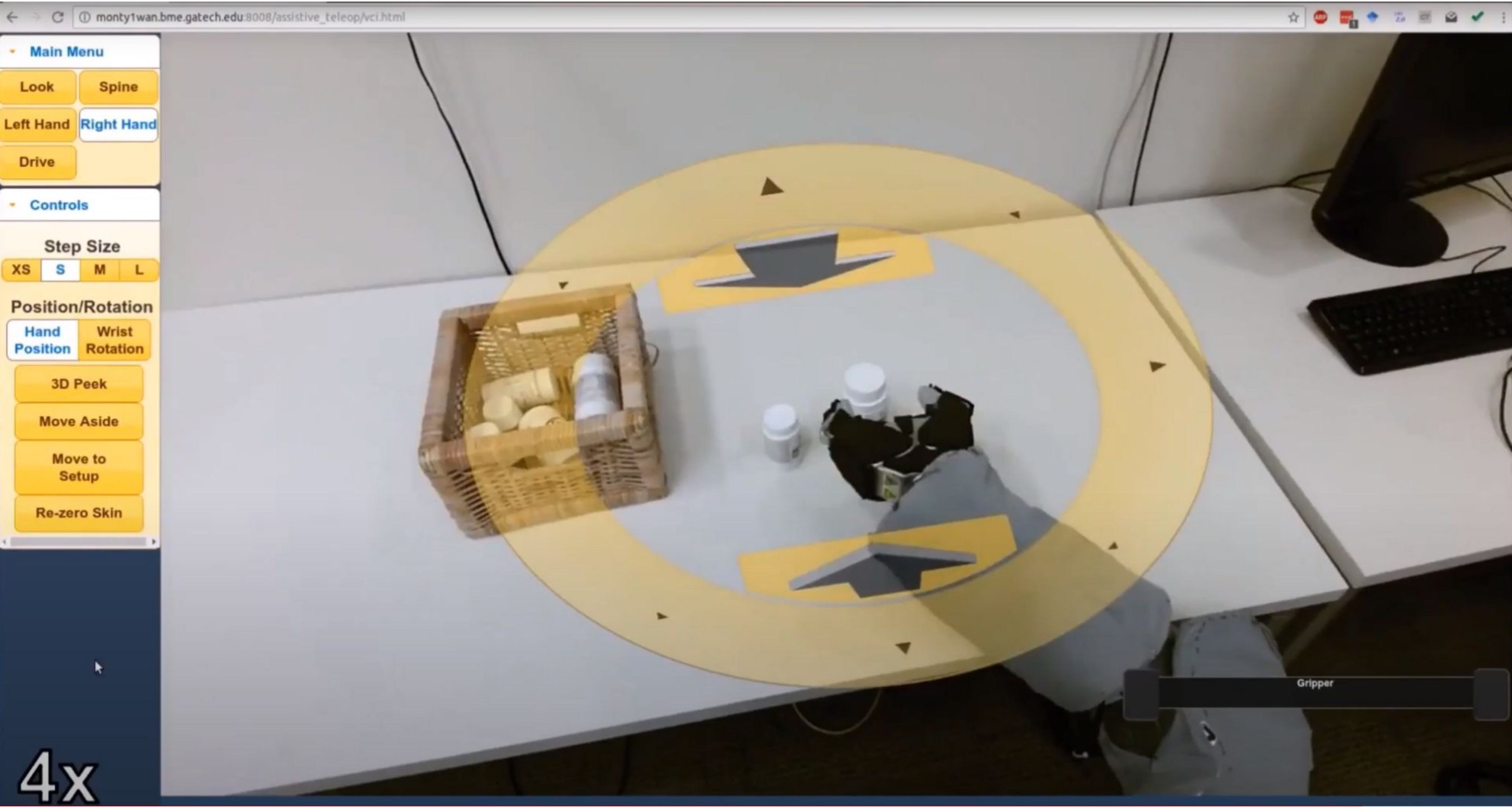
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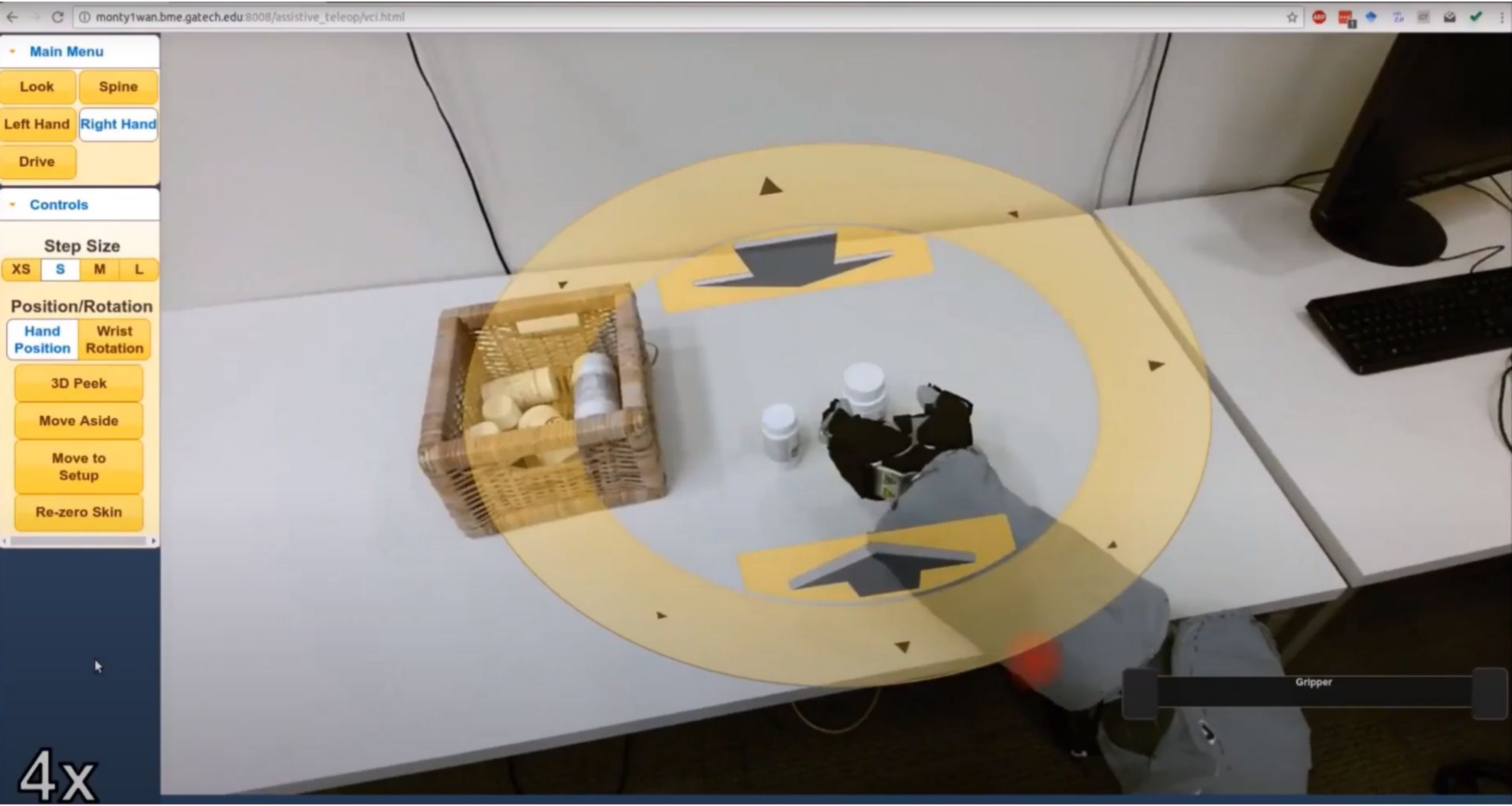
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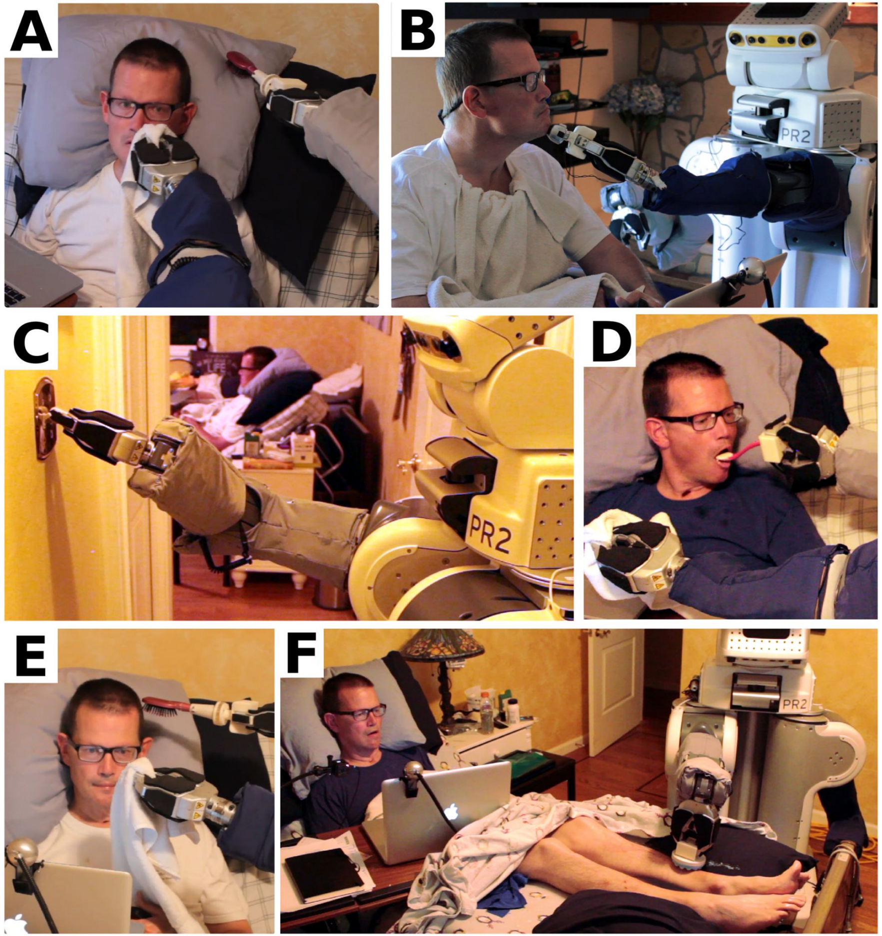

In-home and remote use of robotic body surrogates by people with profound motor deficits, Phillip M. Grice and Charles C. Kemp, PLoS ONE 14(3), 2019.

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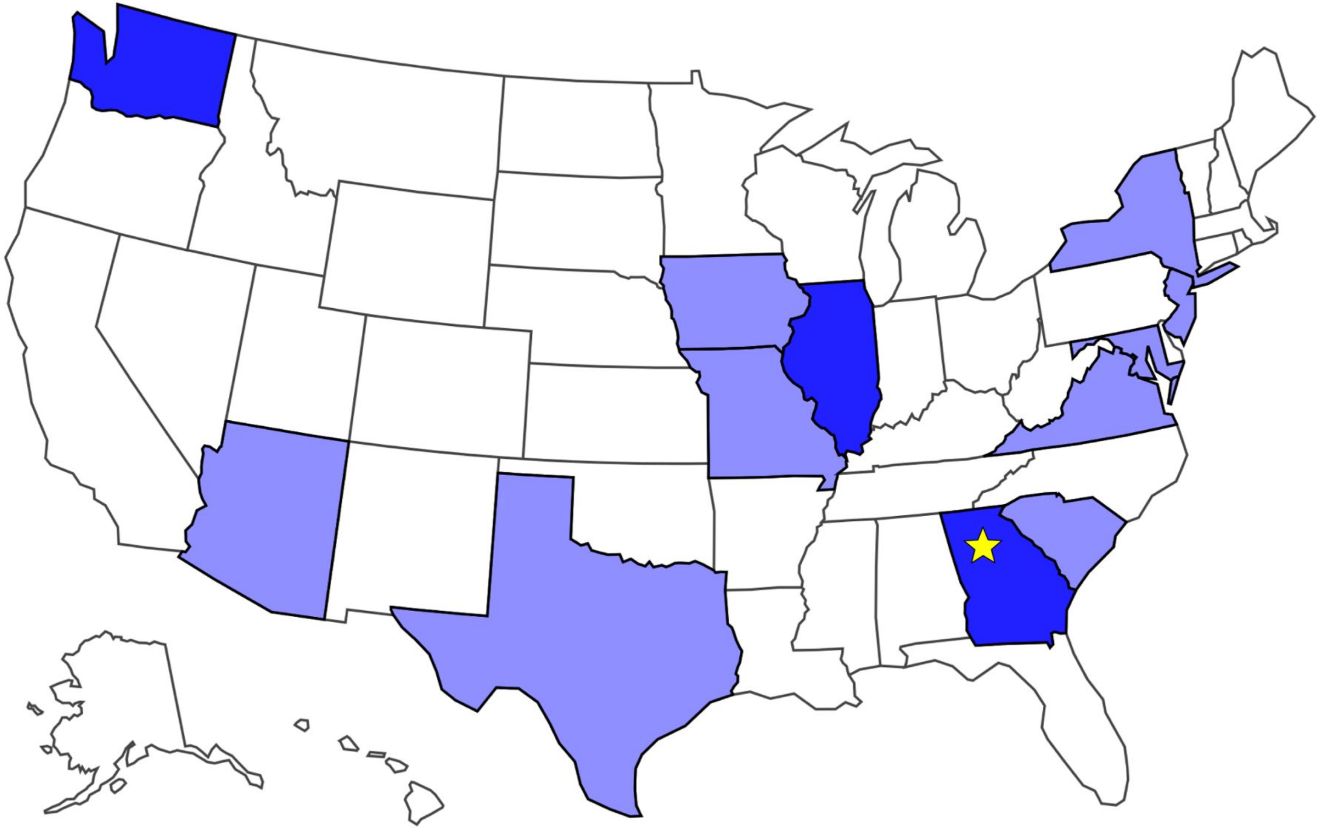
15 Participants



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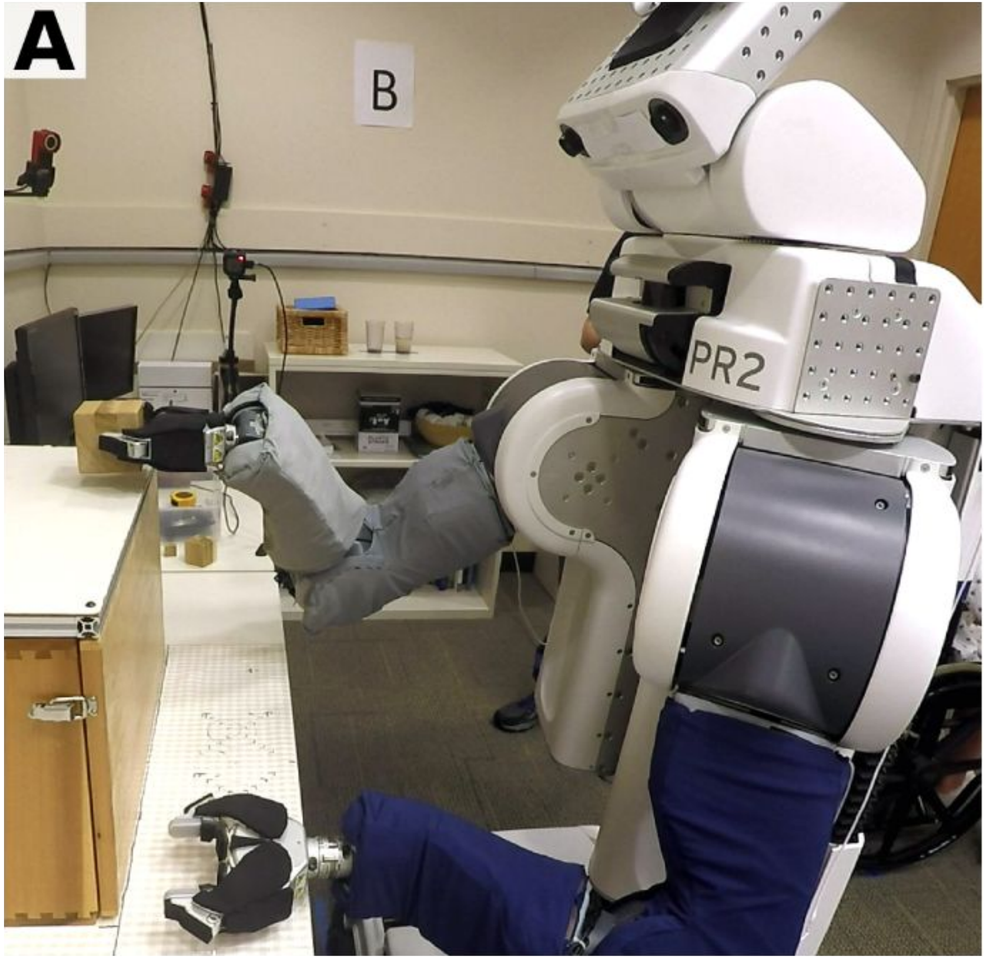

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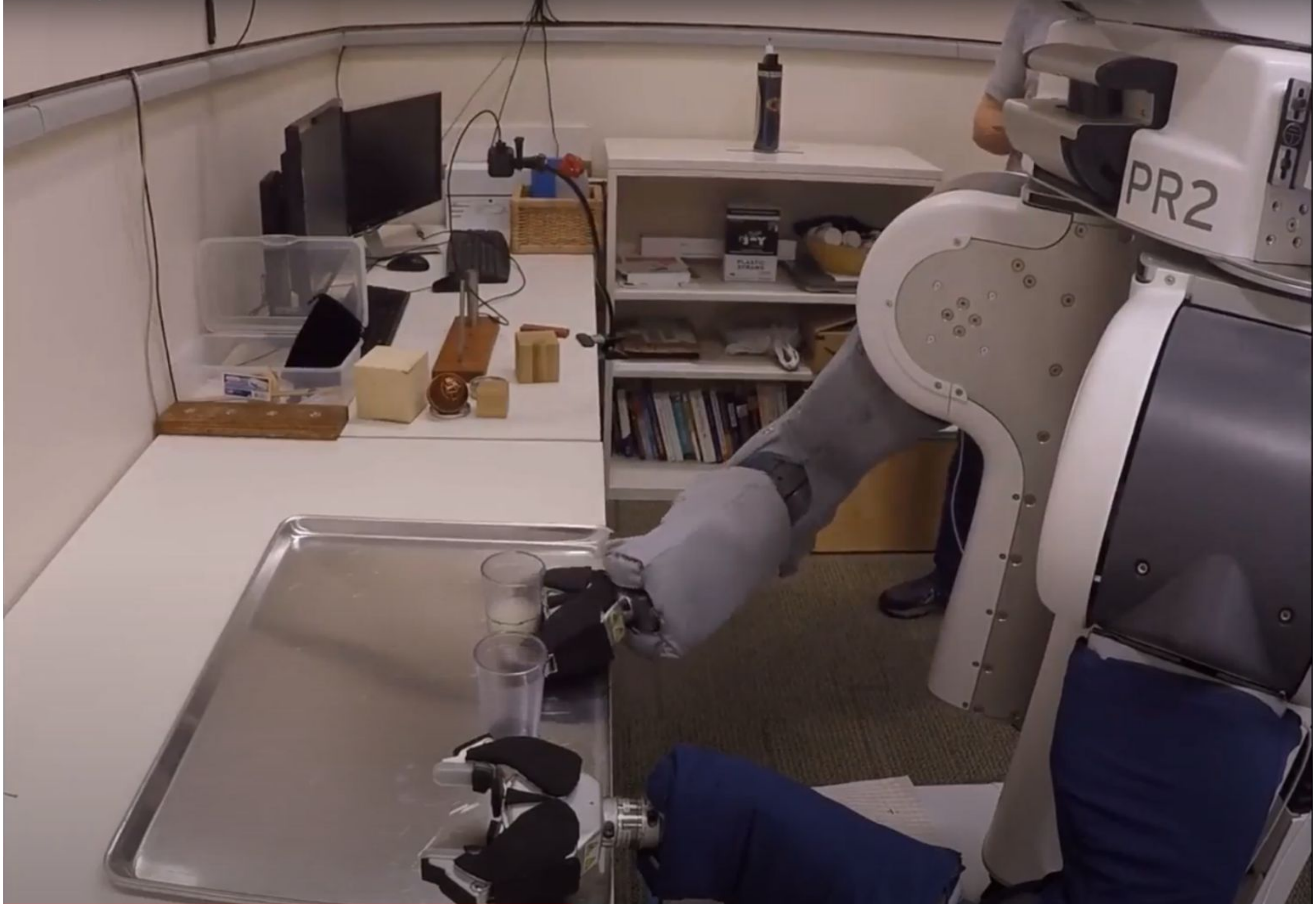
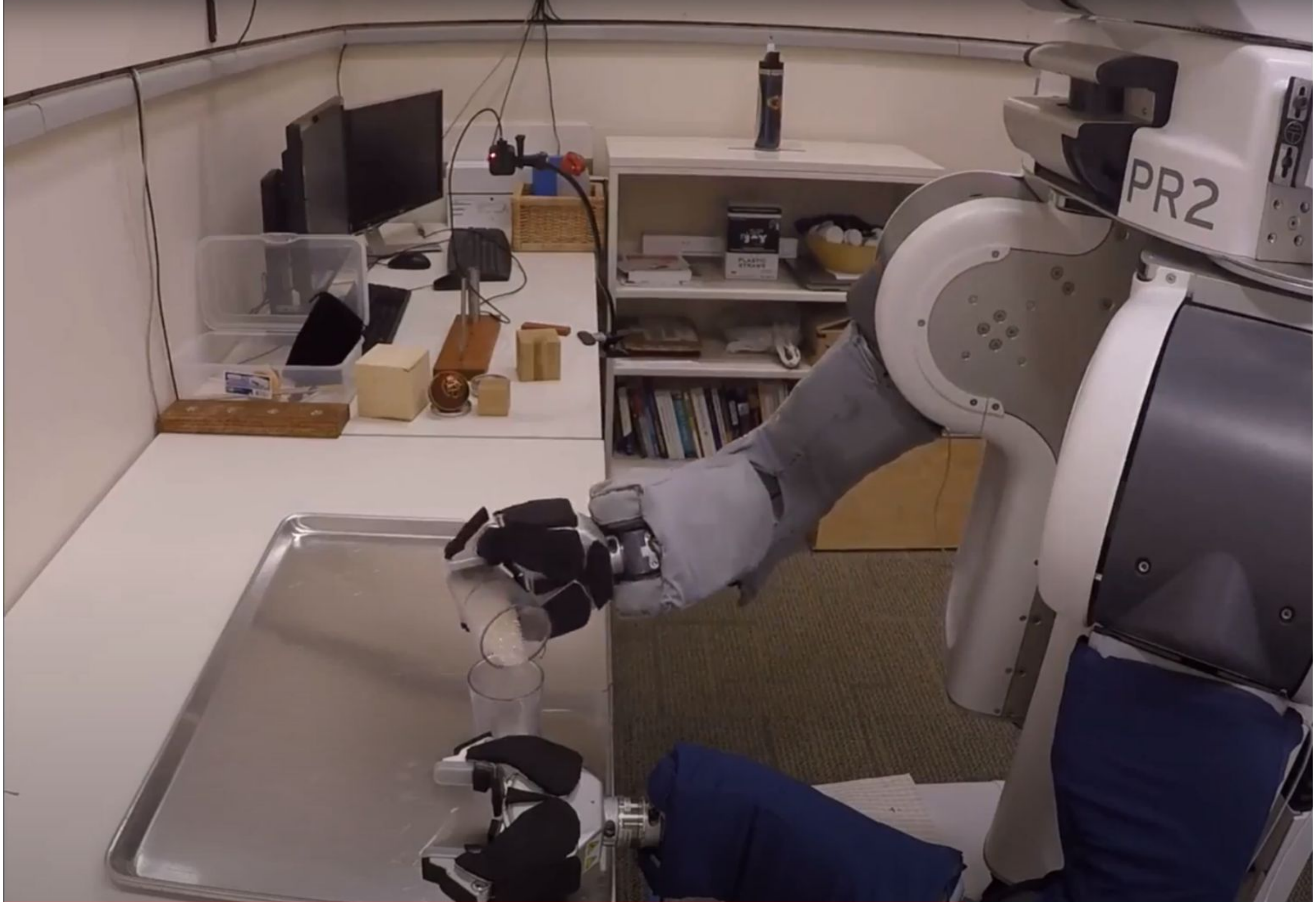

PR2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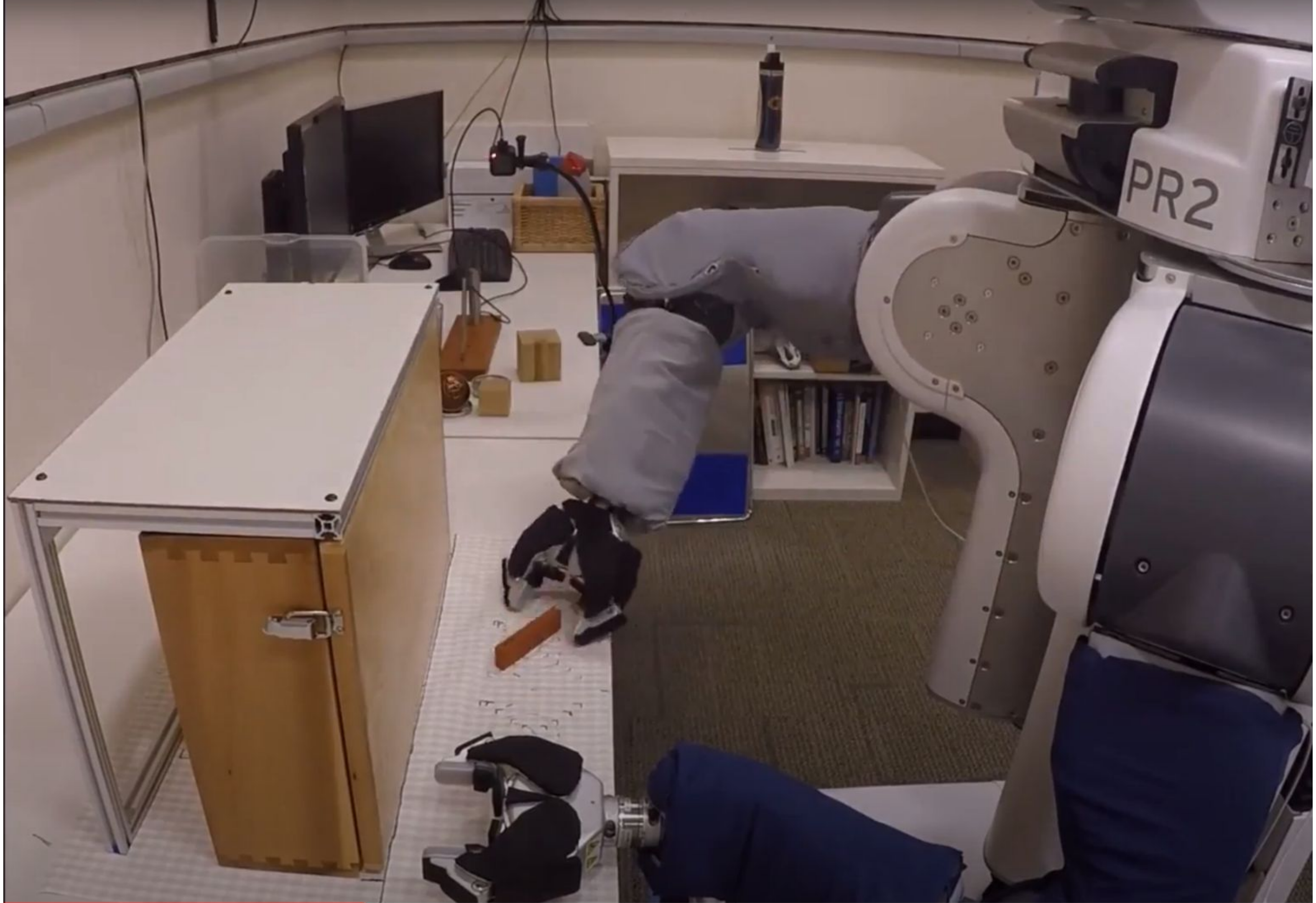
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PR2


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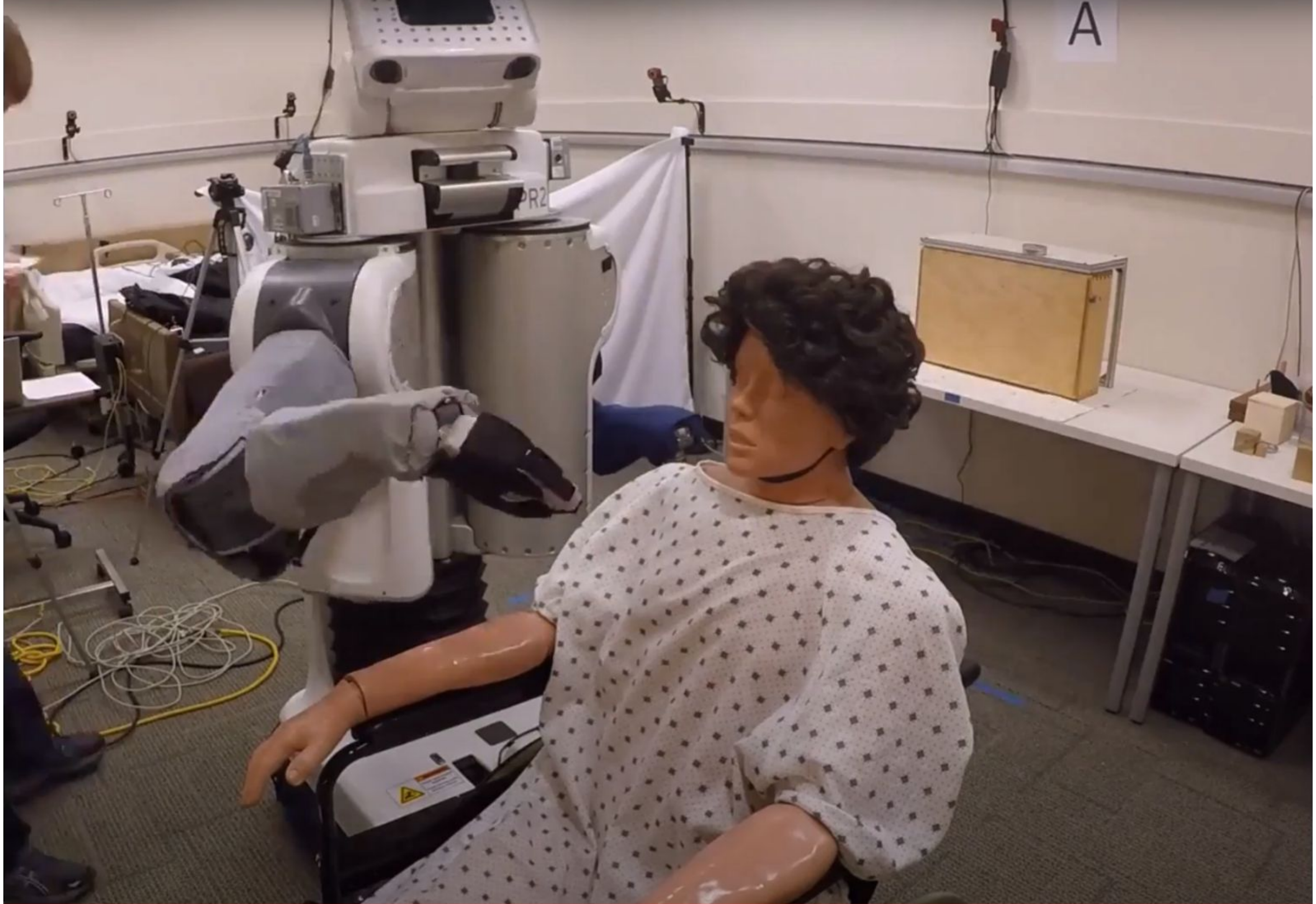
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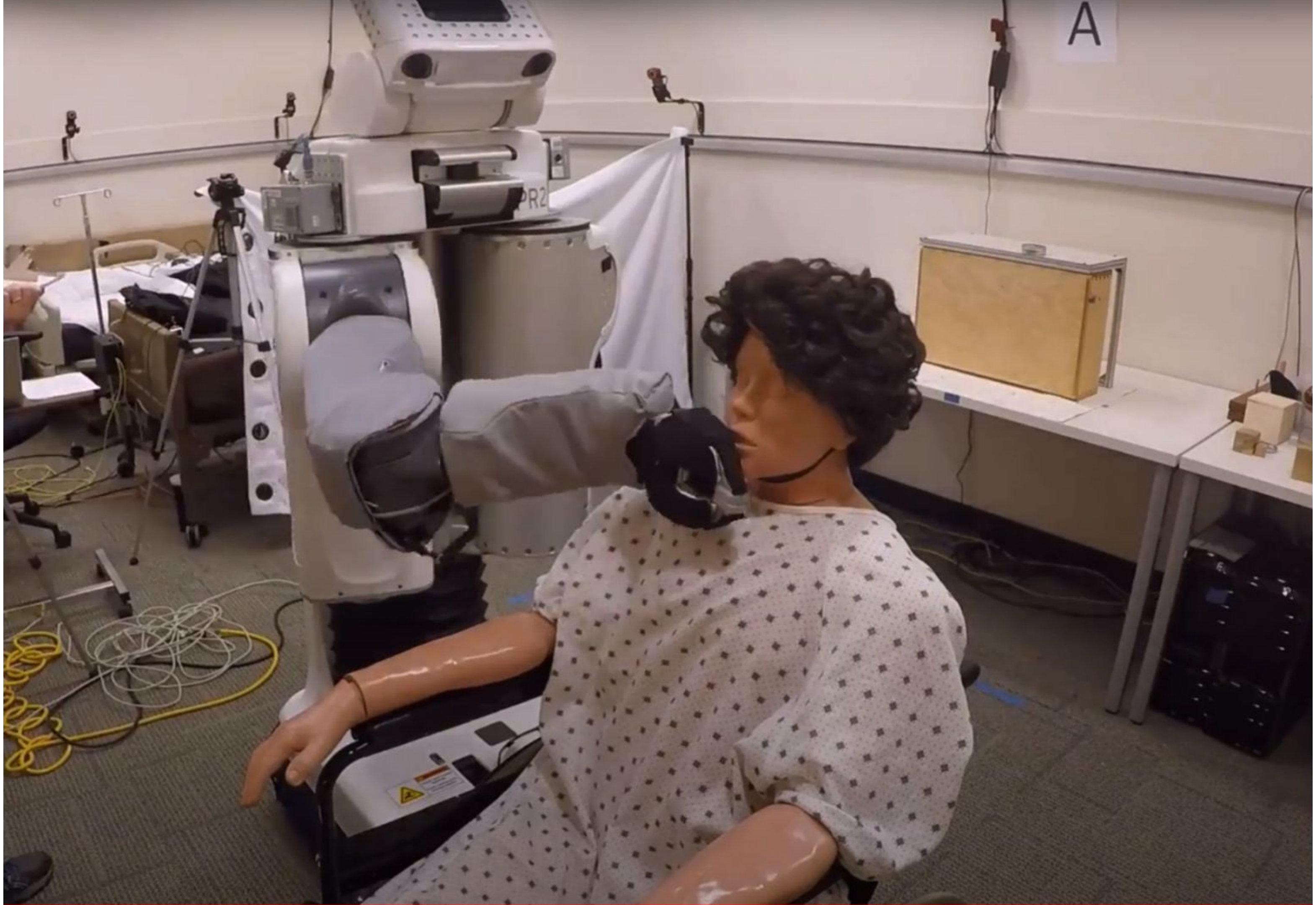
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Causes of Motor Impairment

6 Spinal Muscular Atrophy (SMA)

3 Muscular Dystrophy (Duchenne/Becker)

3 Spinal Cord Injury

1 Amyotrophic Lateral Sclerosis (ALS)

1 Arthrogryposis

1 Dejerine-Sottas

ARAT Threshold: 9/57 with best arm

Computer Access Devices

4 – Trackball

3 – Touchpad

3 – Head-mouse (TrackerPro, 2x HeadMouse Extreme)

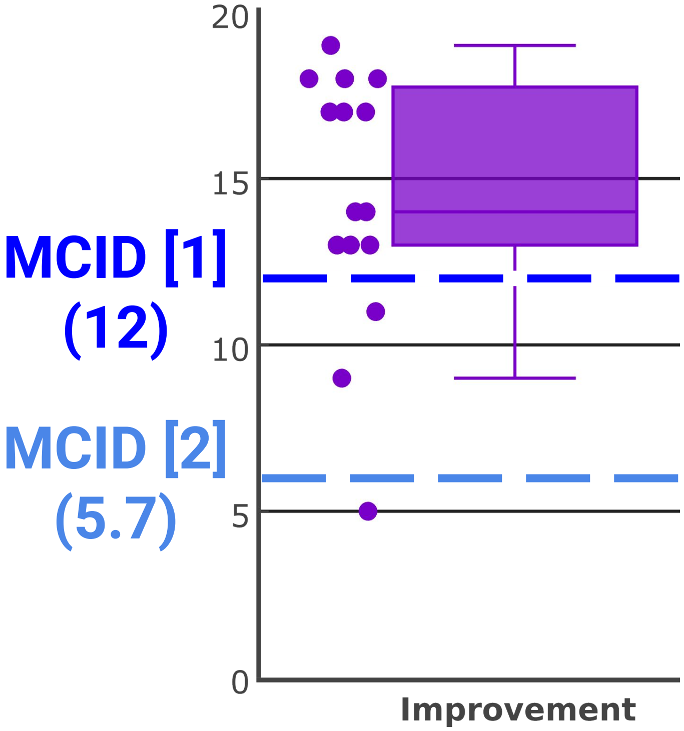
2 – Standard mouse

1 – Eye-gaze (Tobii)

1 – Touchpad w/Stylus held in mouth

1 – Speech (Dragon MouseGrid)

Improvement Exceeded Conservative Minimal Clinically Important Difference (MCID)

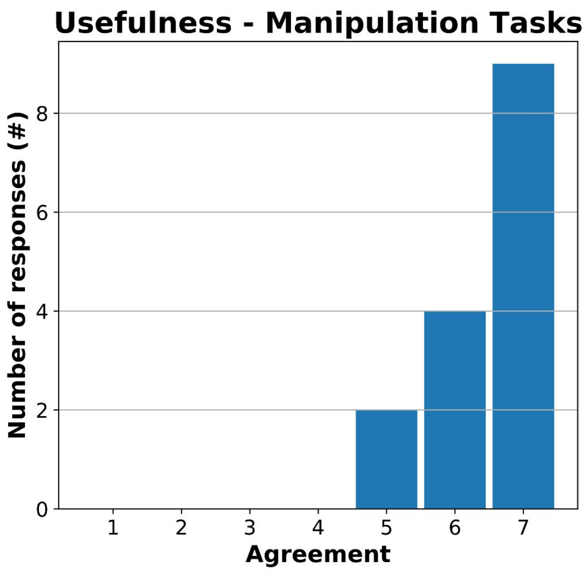


[1] C. E. Lang, D. F. Edwards, R. L. Birkenmeier, and A. W. Dromerick, **"Estimating minimal clinically important differences of upper-extremity measures early after stroke,"** Archives of physical medicine and rehabilitation, vol. 89, no. 9, pp. 1693– 1700, 2008.

[2] J. H. Van der Lee, V. De Groot, H. Beckerman, R. C. Wagenaar, G. J. Lankhorst, and L. M. Bouter, **"The intra-and interrater reliability of the action research arm test: A practical test of upper extremity function in patients with stroke,"** Archives of physical medicine and rehabilitation, vol. 82, no. 1, pp. 14–19, 2001.

1-tailed Wilcoxon signed-rank test vs MCID: W=96, **p=.021**

Perceived Usefulness

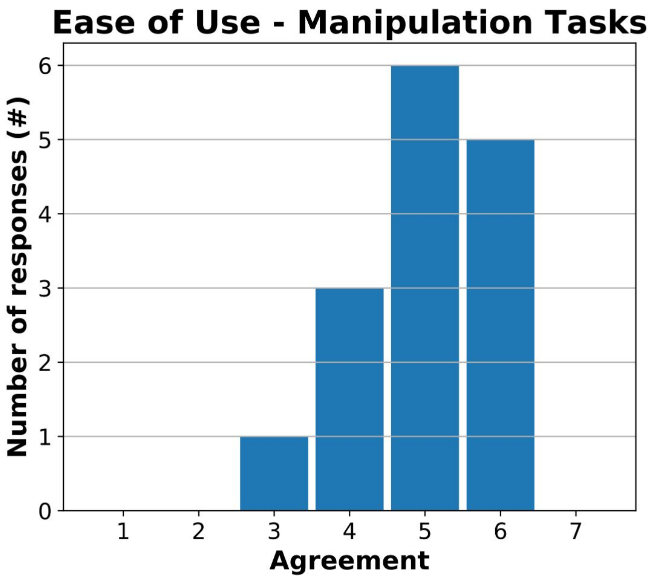


Wilcoxon signed-rank test vs neutral:
W=120, p=.000258

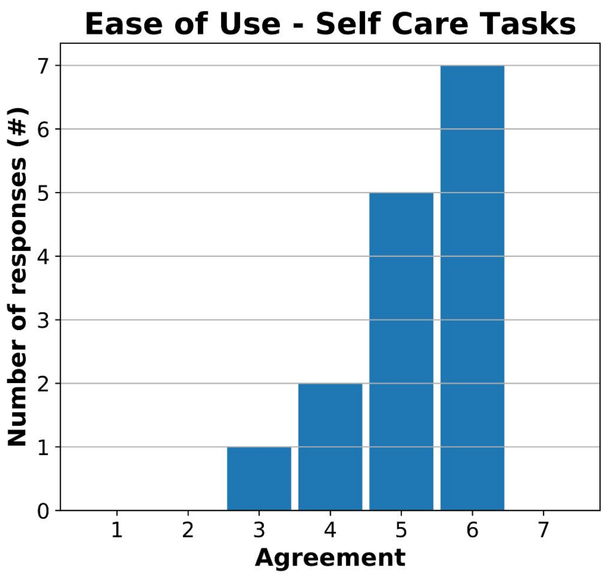
Wilcoxon signed-rank test vs neutral:
W=105, p=.000402

1: Strongly Disagree
2: Disagree
3: Somewhat Disagree
4: Neither Agree nor Disagree
5: Somewhat Agree
6: Agree
7: Strongly Agree

Perceived Ease of Use



Wilcoxon signed-rank test vs neutral:
W=74, p=.00264



Wilcoxon signed-rank test vs neutral:
W=87.5, p=.00142

1: Strongly Disagree
2: Disagree
3: Somewhat Disagree
4: Neither Agree nor Disagree
5: Somewhat Agree
6: Agree
7: Strongly Agree

Limitations

- Slow operation
- Errors
- Depth perception

Limitations

- Slow operation
- Errors
- Depth perception
- **The robot**

The Robot

- Willow Garage shut down in 2014
- PR2 was impractical
  - 227 kg (~500 lb)
  - 67 cm wide (~2.2 ft)
  - $400,000

Photo from Willow Garage

Q&A