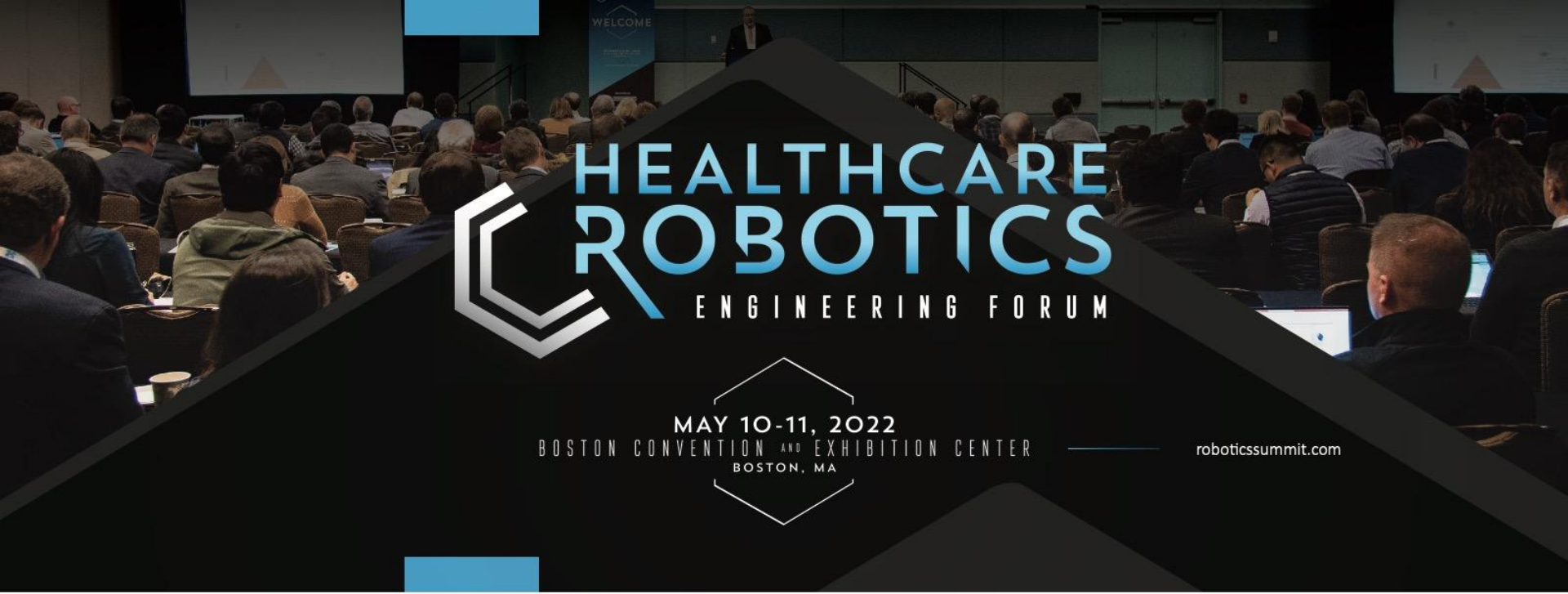

Mobile Manipulation for Healthcare

Charlie Kemp
Georgia Tech / Hello Robot

Associate Professor, Department of Biomedical Engineering

Georgia Tech

Wallace H. Coulter Department of Biomedical Engineering

EMORY UNIVERSITY

Co-founder & CTO, Hello Robot Inc.

hello robot™

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.

Georgia Tech

hello robot™

A Story in Three Parts

- Research on Personal Assistance
- A Novel Commercialized Robot
- A Growing Community

Part 1: *Research on Personal Assistance*

1980 - Star Wars: The Empire Strikes Back

2014 - Big Hero 6 (Baymax)

Mobile Manipulators Can Provide Meaningful Assistance






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

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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.
[image] found on the internet and used without permission

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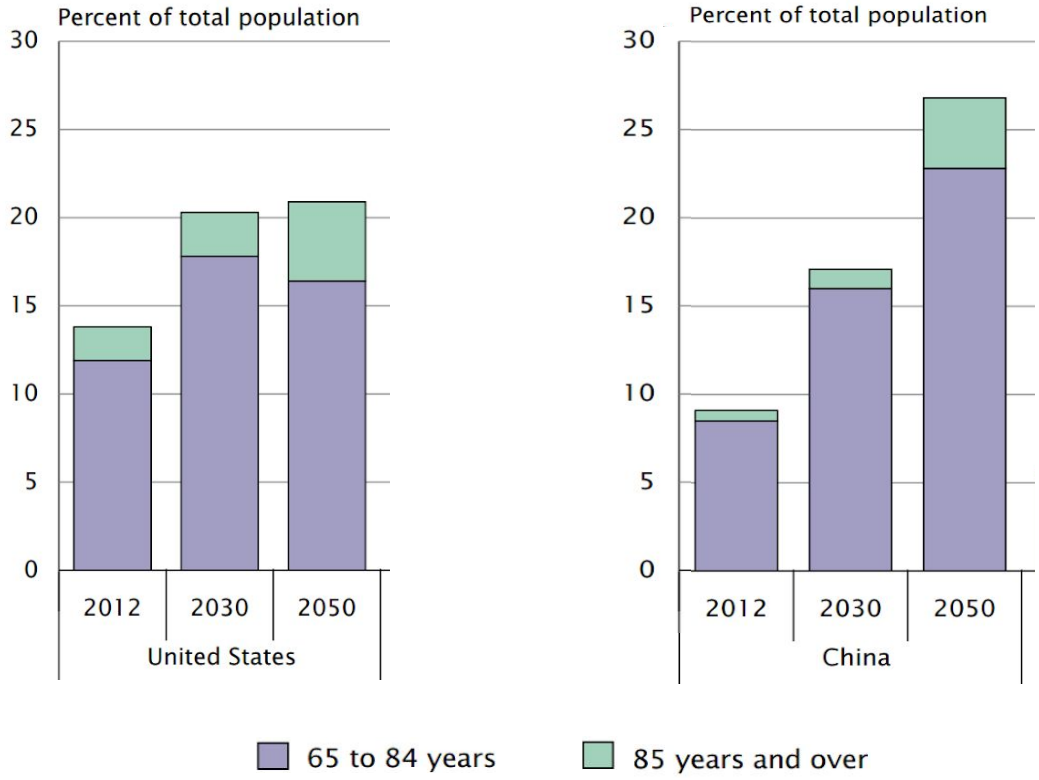
Short-term Disabilities

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

"*The 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.

Aging Societies will Increase Demand



Ortman, Jennifer M., Victoria A. Velkoff, and Howard Hogan. “An aging nation: the older population in the United States”. Washington, DC: United States Census Bureau, Economics and Statistics Administration, US Department of Commerce, 2014.

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, …

[images] found on the internet and used without permission

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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

[images] found on the internet and used without permission

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

JACO by Kinova

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

DynamicArm by Ottobock

My Spoon by SECOM

Myomo by Myomo Inc.

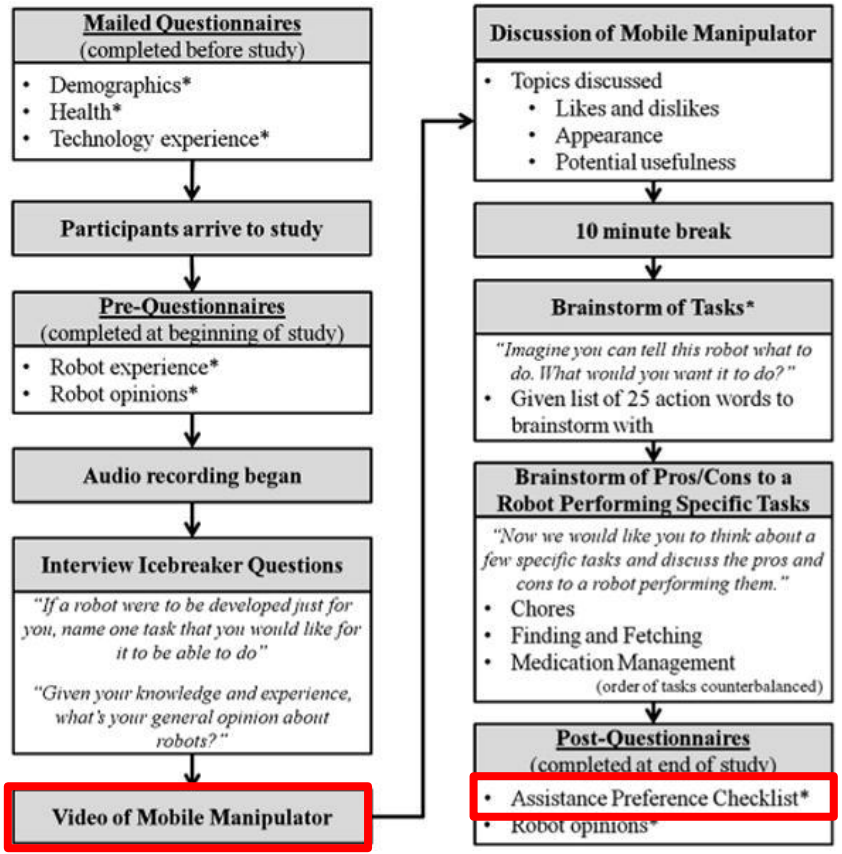
Advantages of Mobile Manipulators

- Operate independently from the user
- No don/doff
- Assist diverse users
- Potential for mass market product

People are Open to Assistance from Mobile Manipulators

- Since 2007, hundreds of participants
  - Older adults
  - Nurses
  - People with disabilities

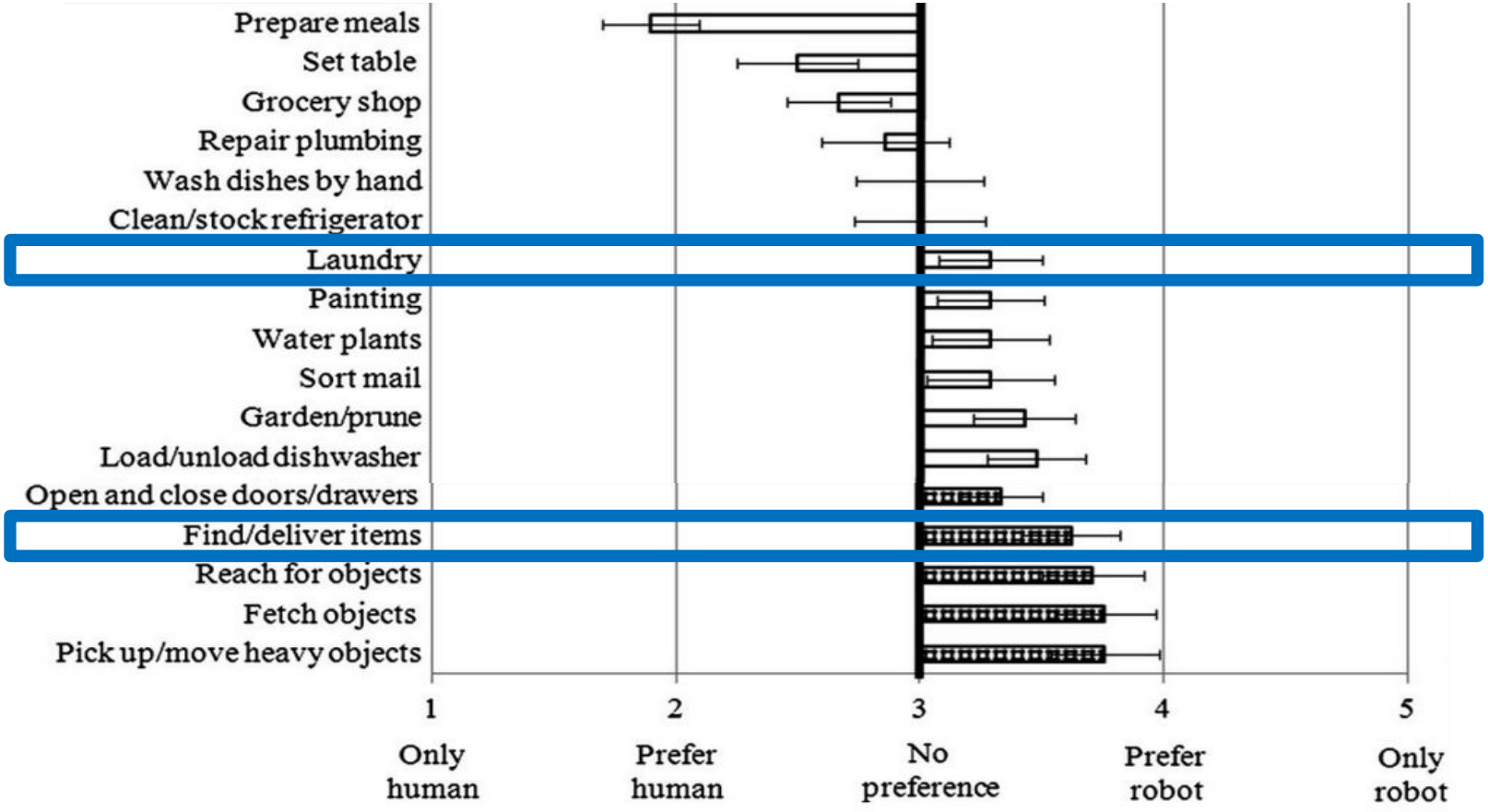
Structured Group Interview and Questionnaires with Older Adults (N=21)



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.

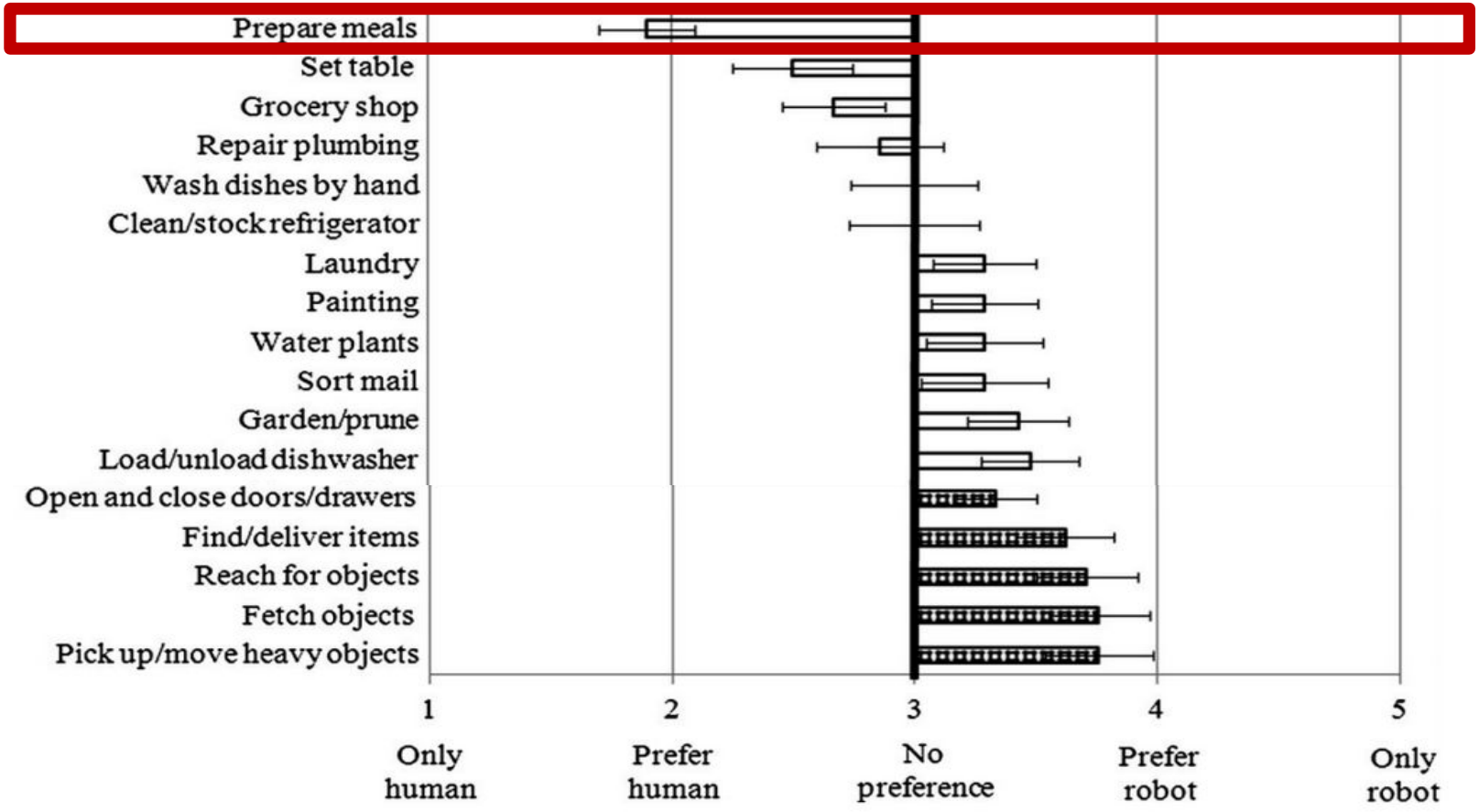
Preferred Robots for Some Tasks

(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)

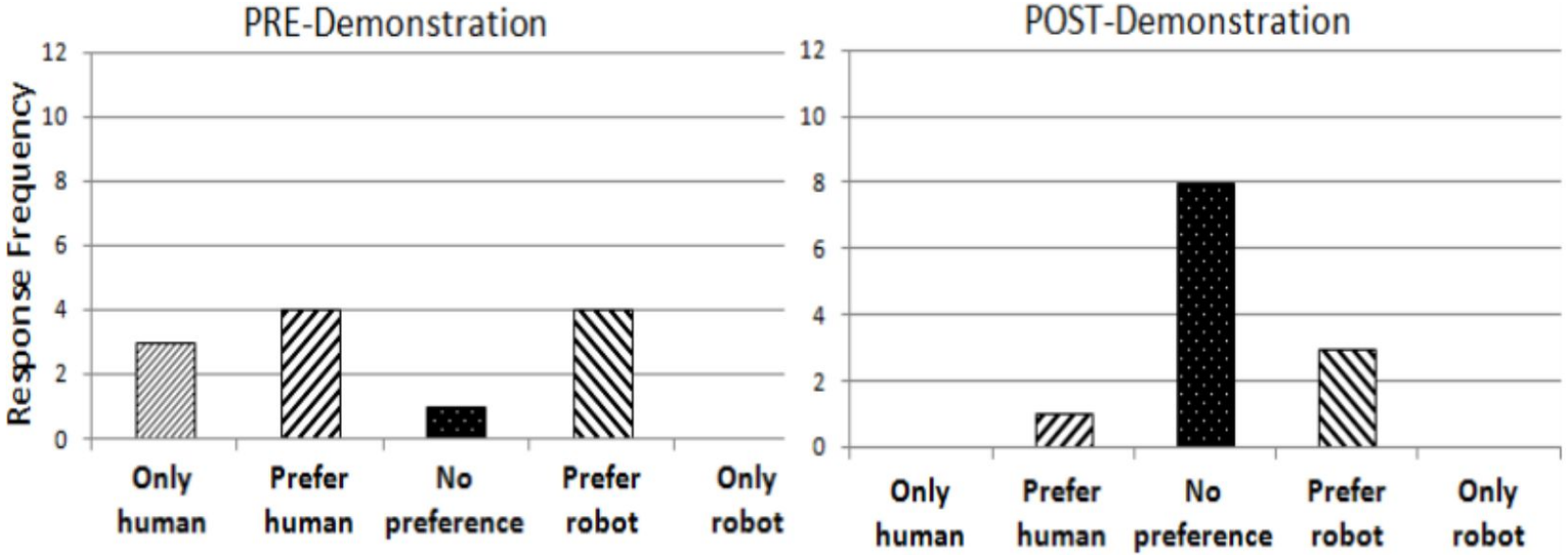

Fig. 4. Human versus robot assistance with delivering medication.

But Not for Everything

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

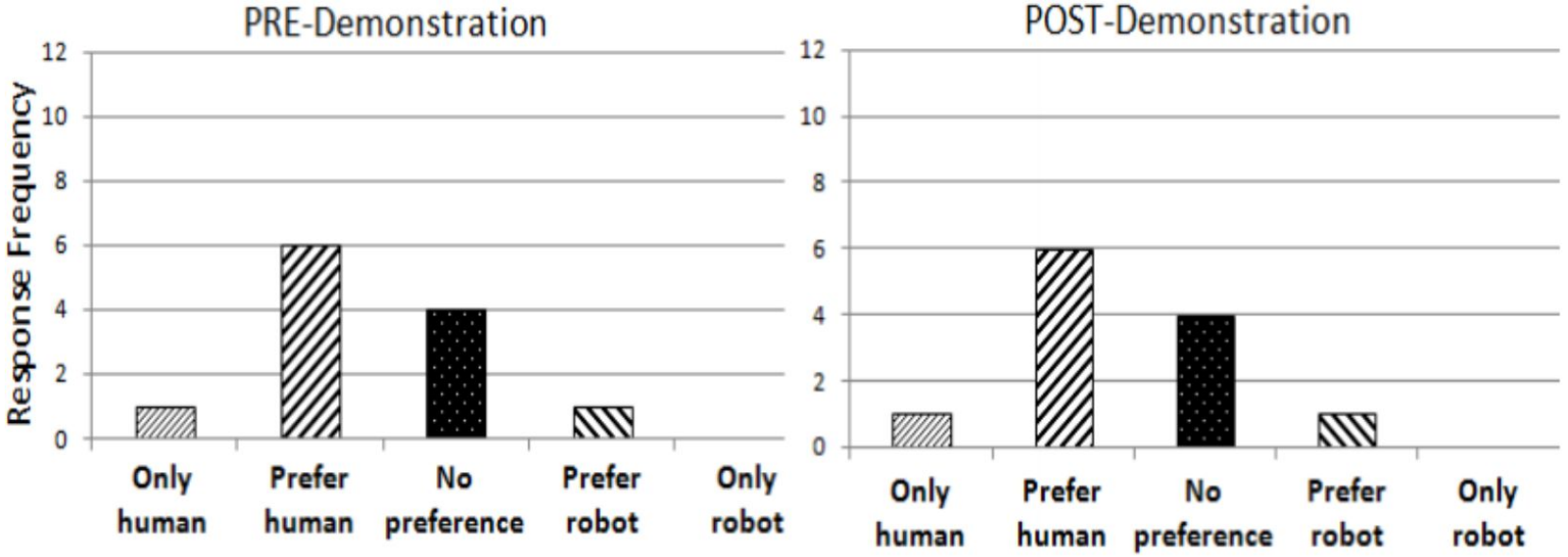

Fig. 5. Human versus robot assistance with taking medication.

Mobile Manipulators Can Provide Meaningful Assistance






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

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Mobile Manipulators Can Provide Meaningful Assistance

The Robots for Humanity Project

Robots for humanity: using assistive robotics to empower people with disabilities, Tiffany L. Chen, Matei Ciocarlie, Steve Cousins, Phillip Grice, Kelsey Hawkins, Kaijen Hsiao, **Charles C. Kemp**, Chih-Hung King, Daniel A. Lazewatsky, Adam Leeper, Hai Nguyen, Andreas Paepcke, Caroline Pantofaru, William D. Smart, and Leila Takayama, IEEE Robotics & Automation Magazine, 2013

Photo taken on June 16, 2011 at Willow Garage. Image from https://www.flickr.com/photos/willowgarage/5941309642 .

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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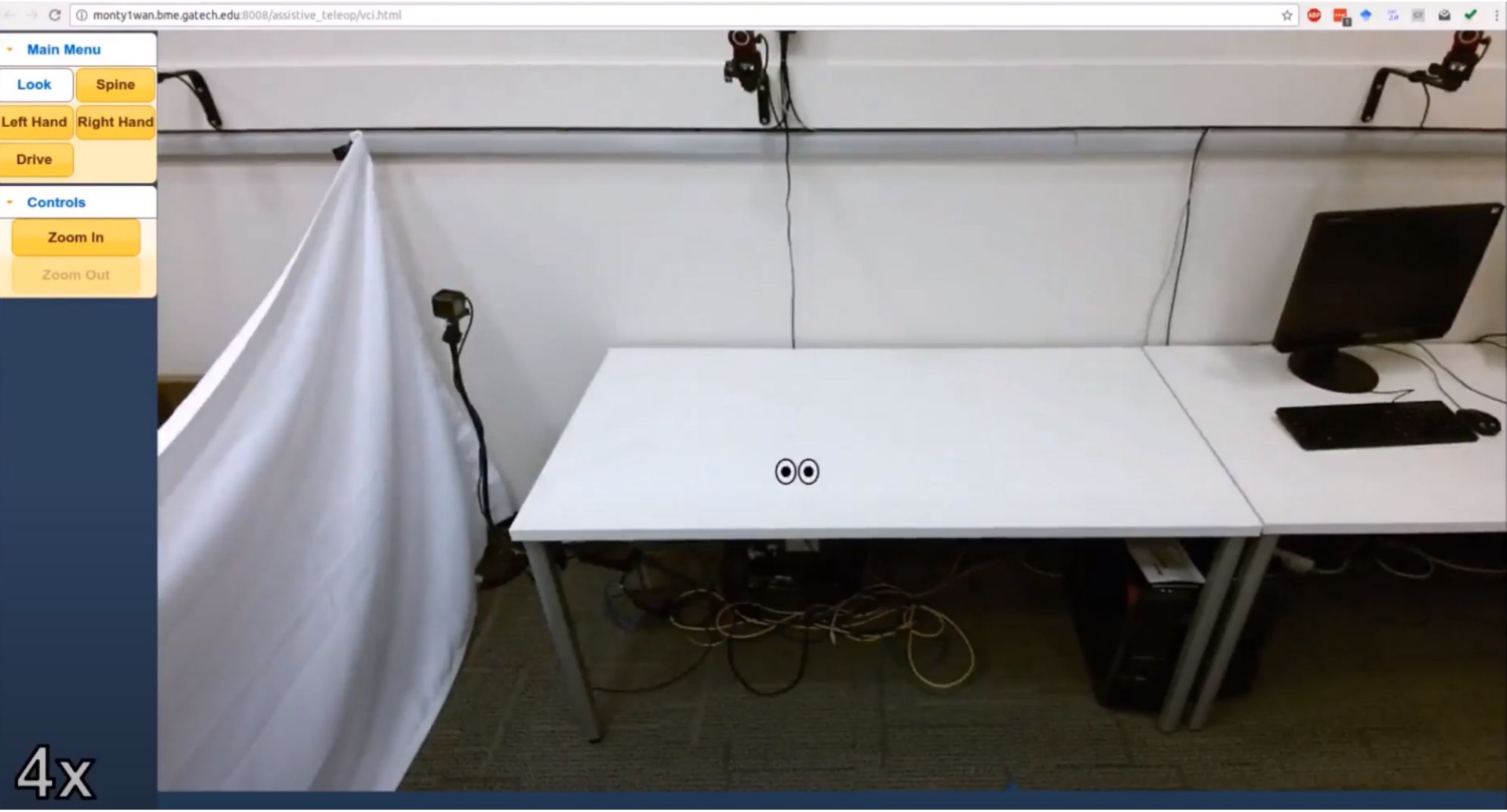
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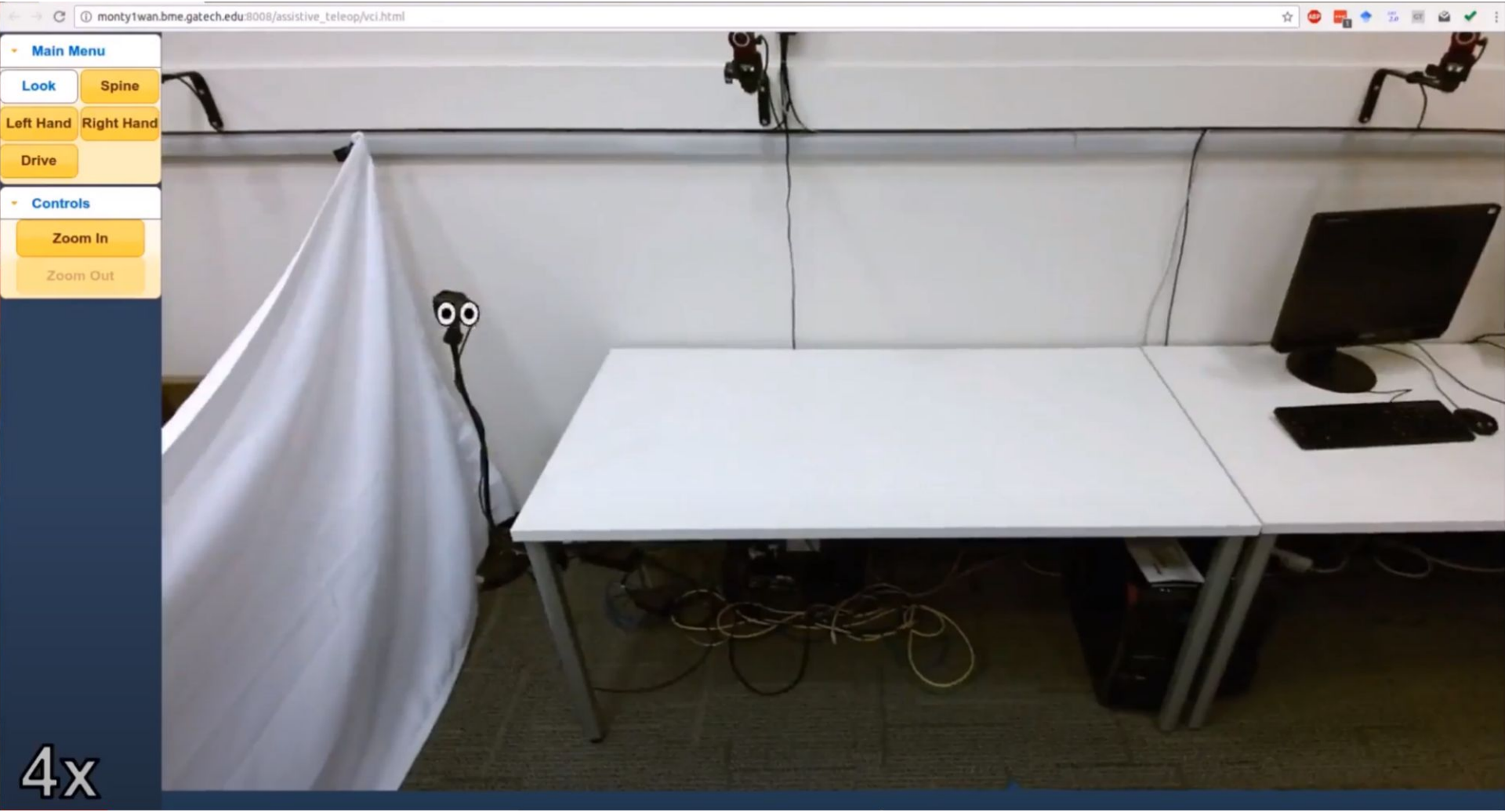
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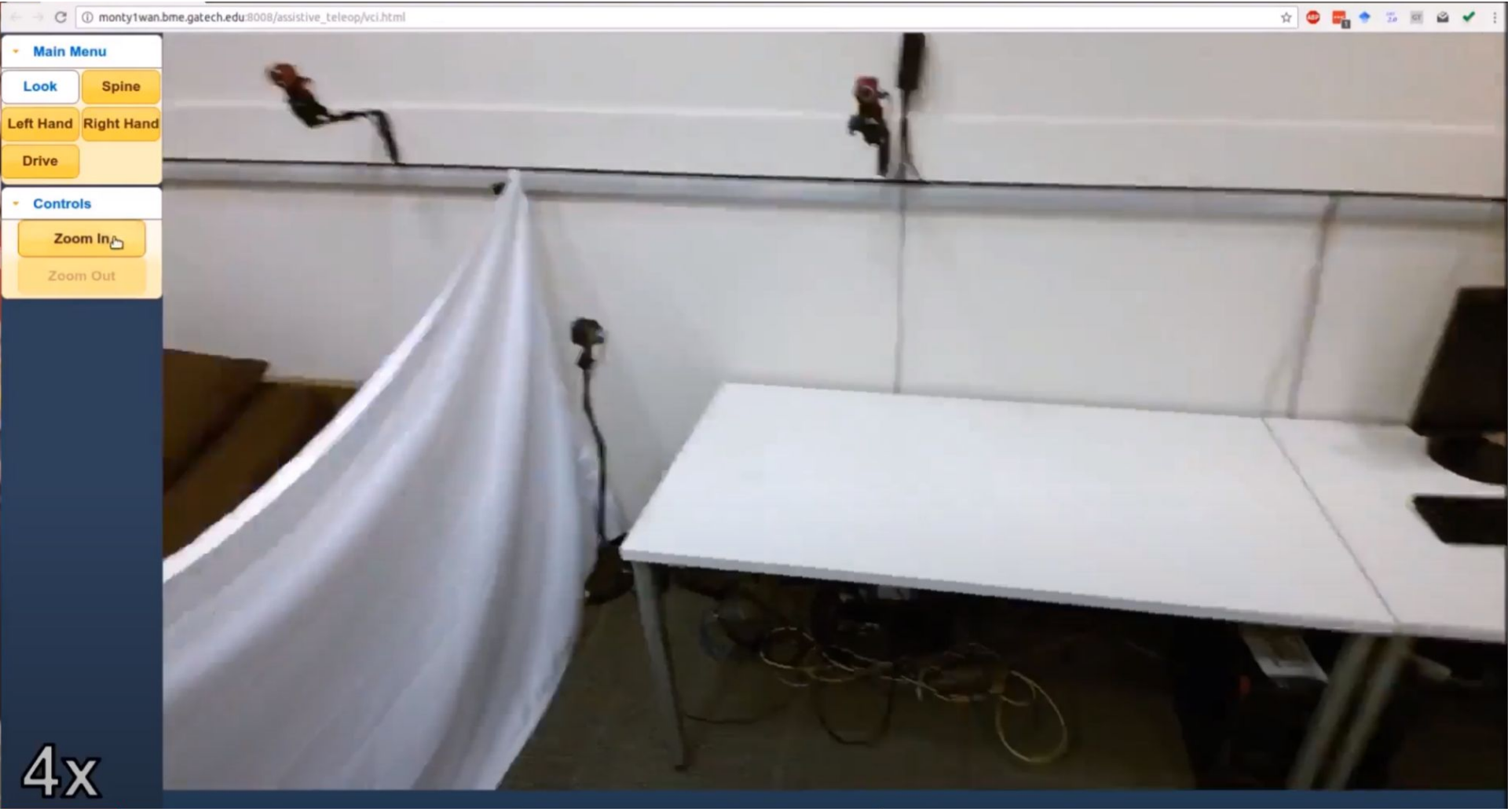
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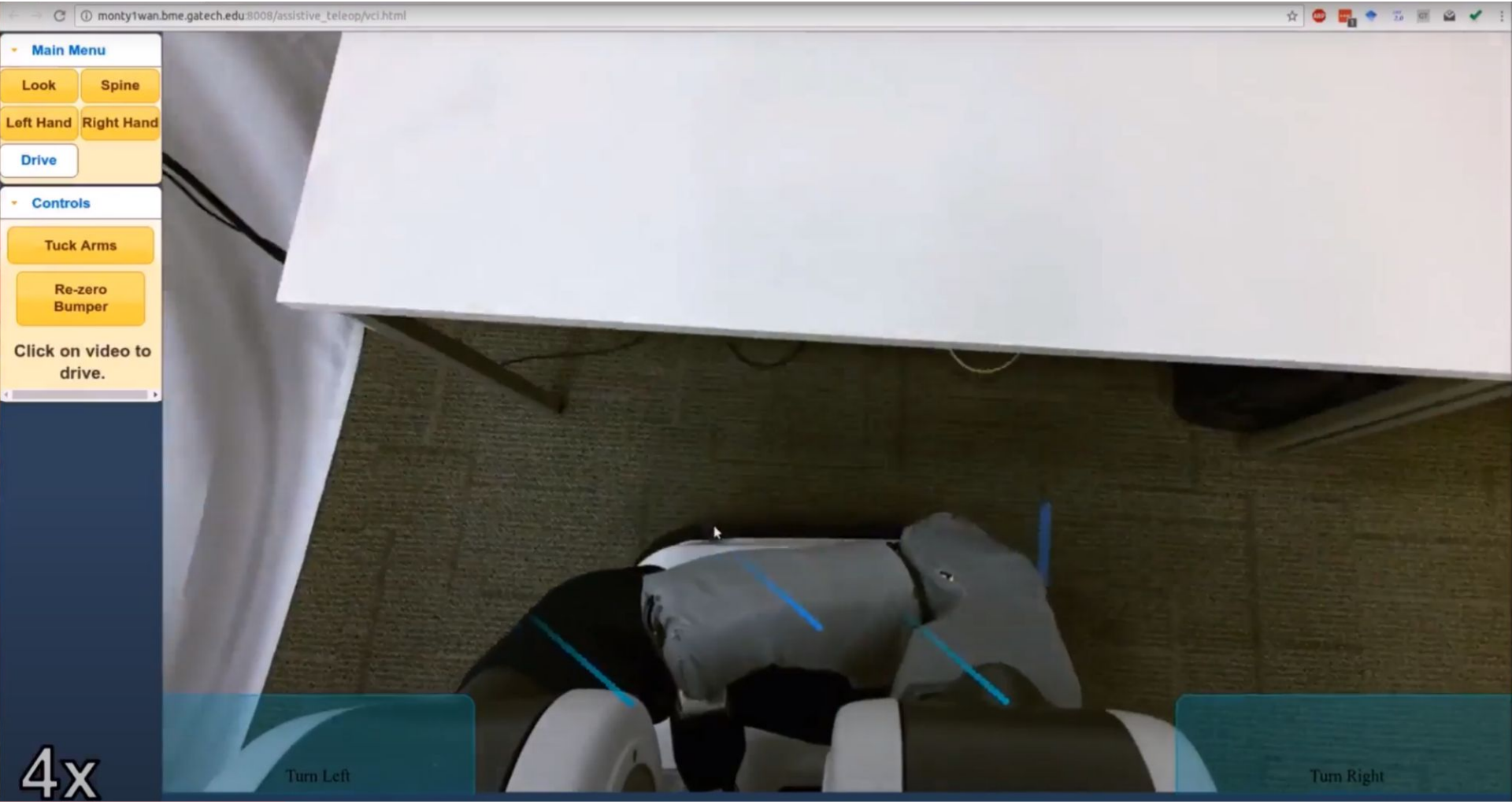
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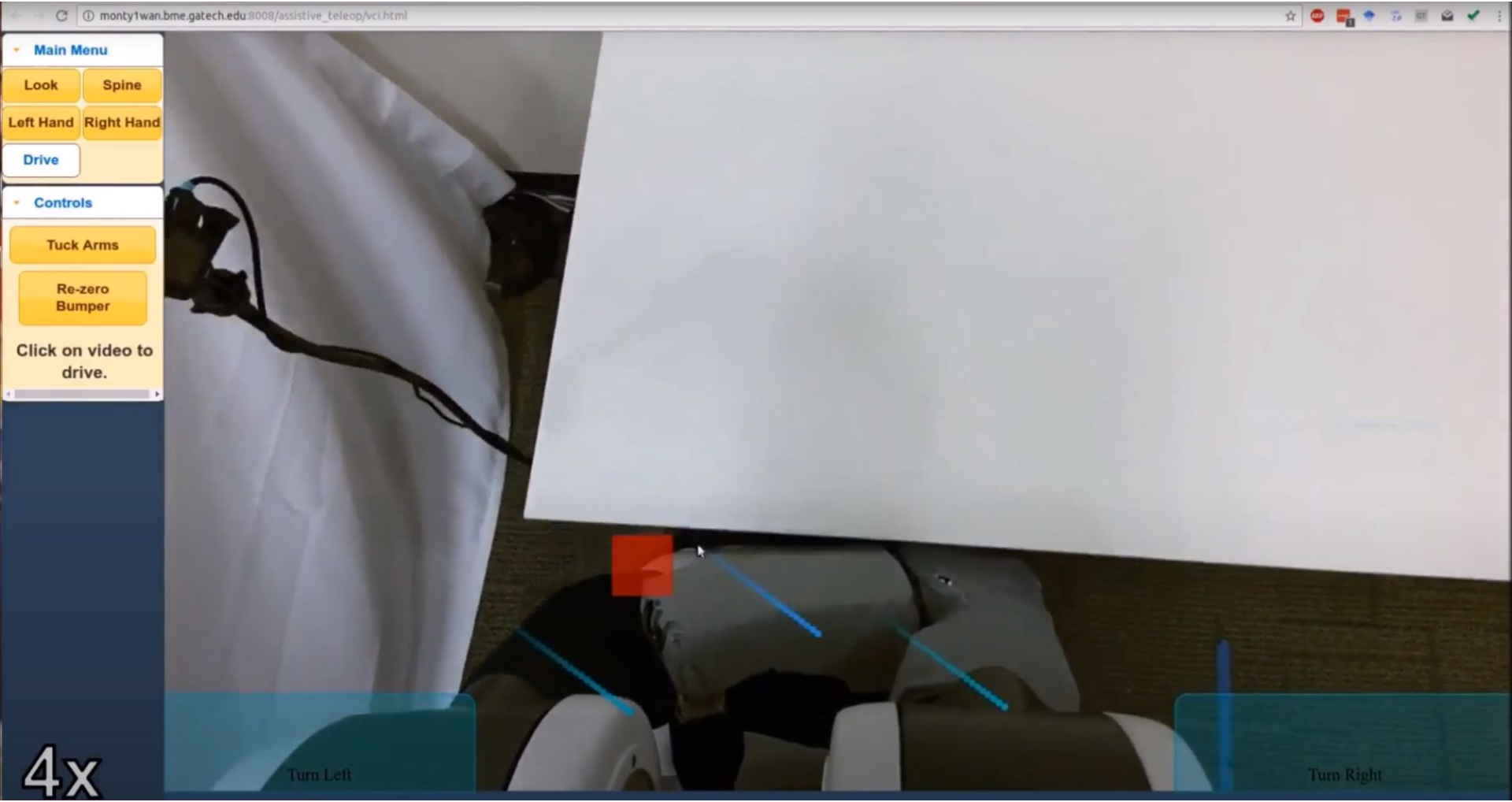
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Move Aside
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Re-zero Skin
Gripper
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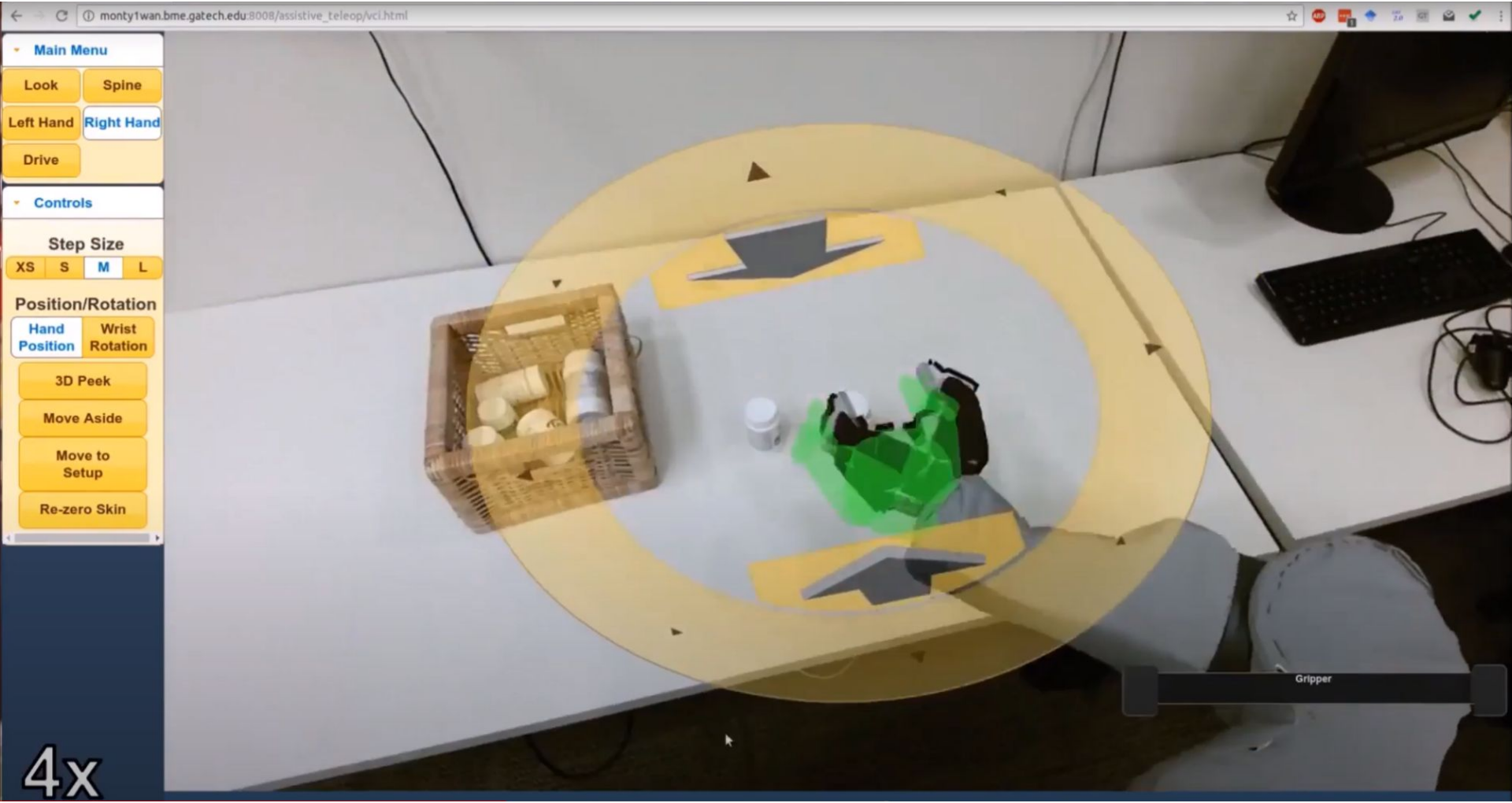
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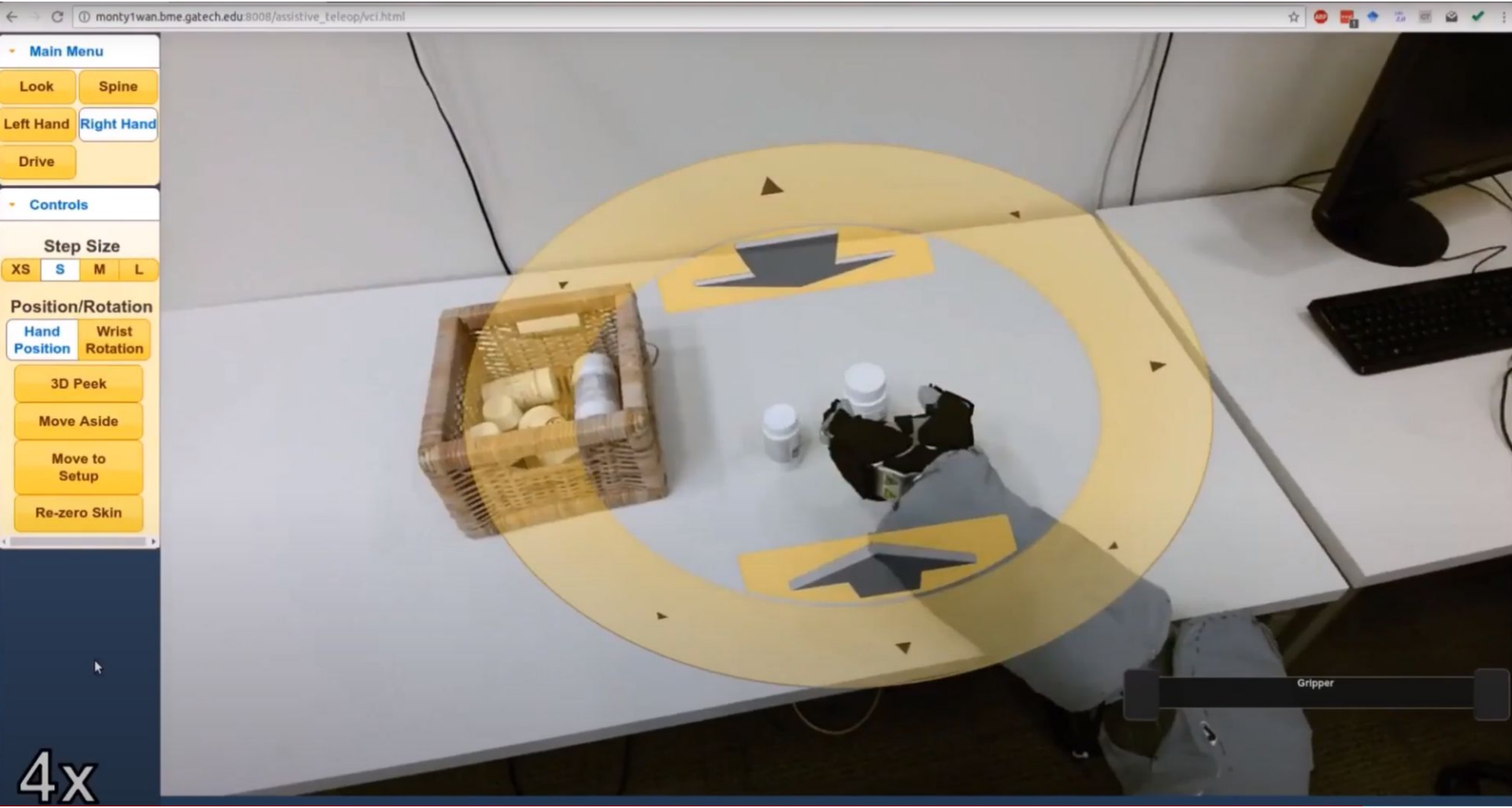
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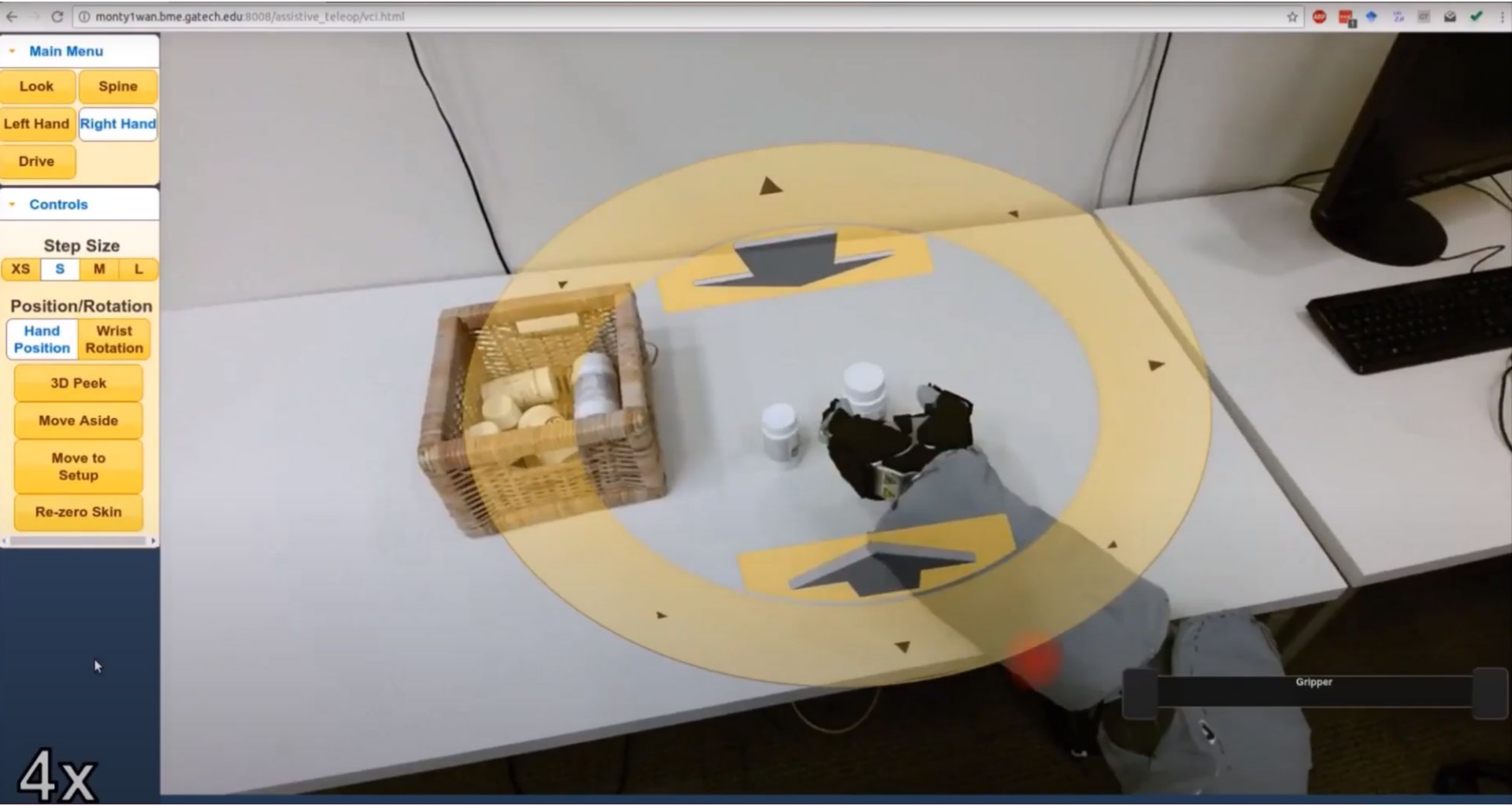
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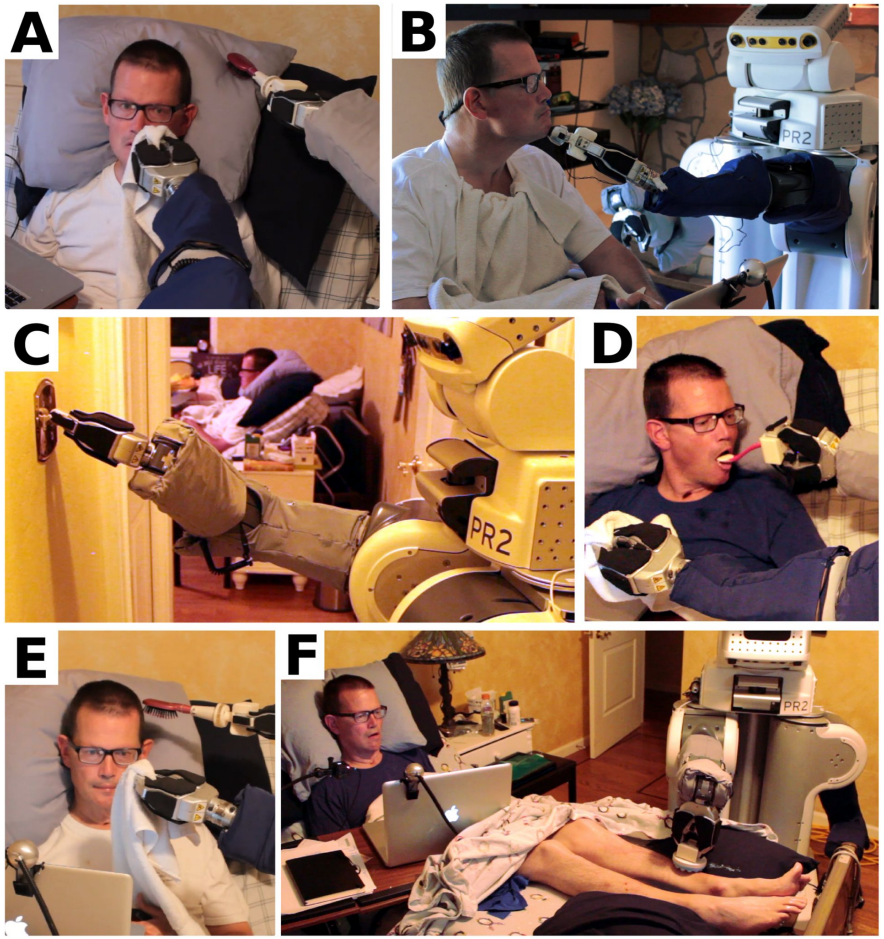

In-home and remote use of robotic body surrogates by people with profound motor deficits, Phillip M. Grice and Charles C. Kemp, PLoS ONE 14(3), 2019.

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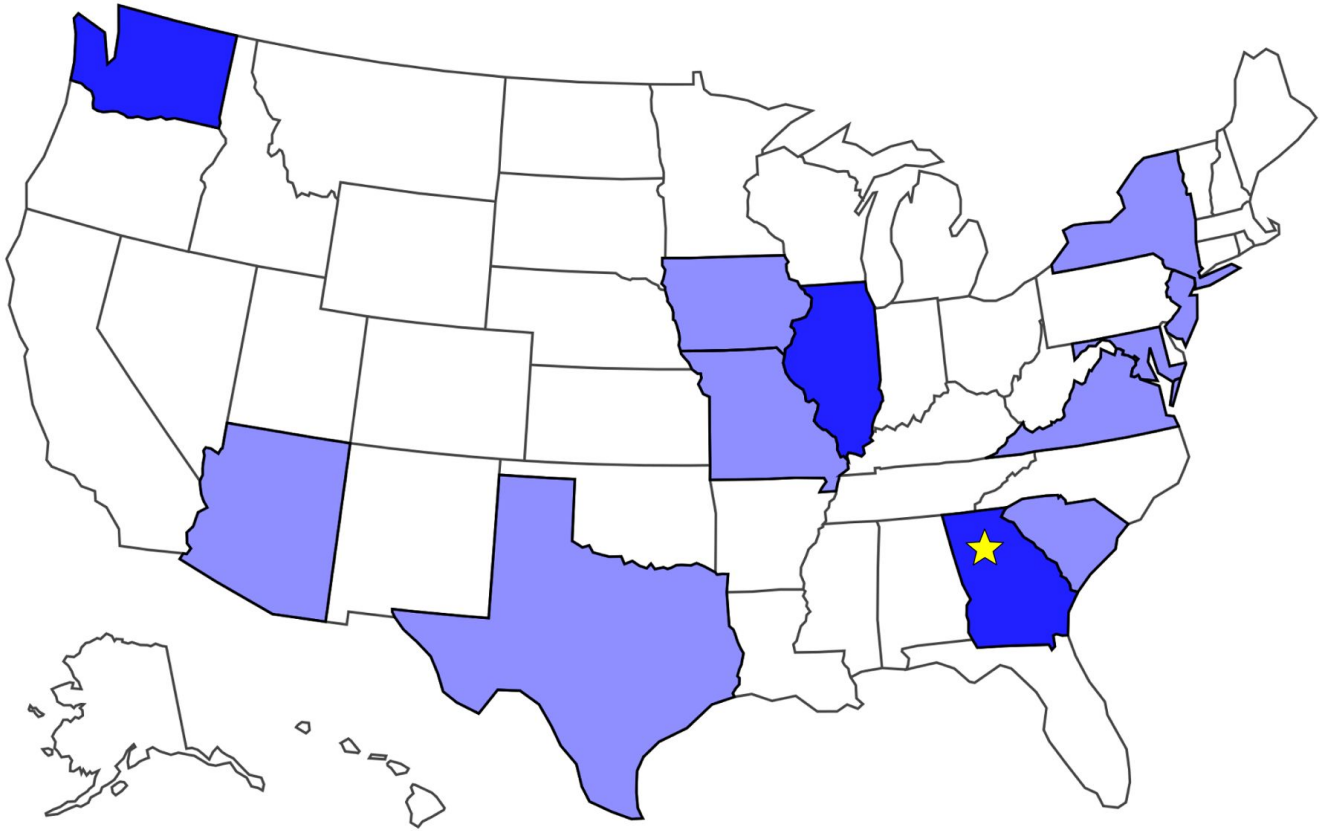
15 Participants



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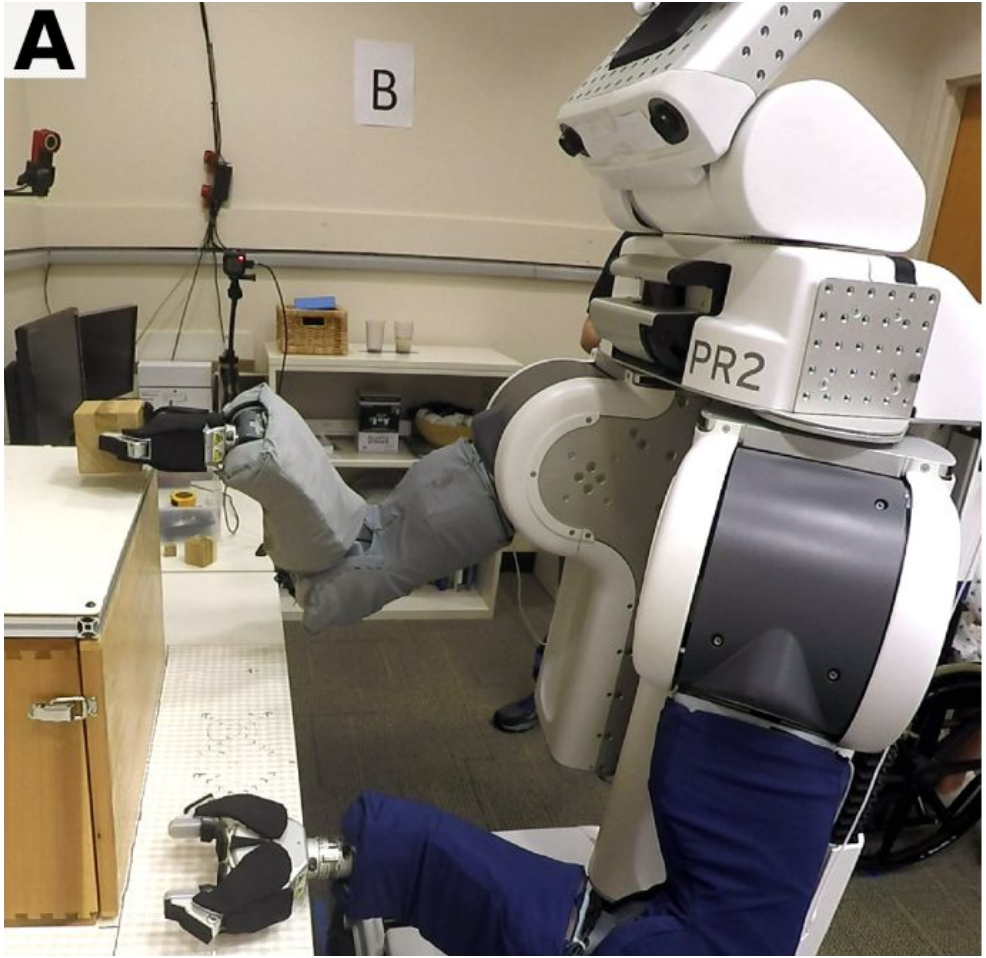

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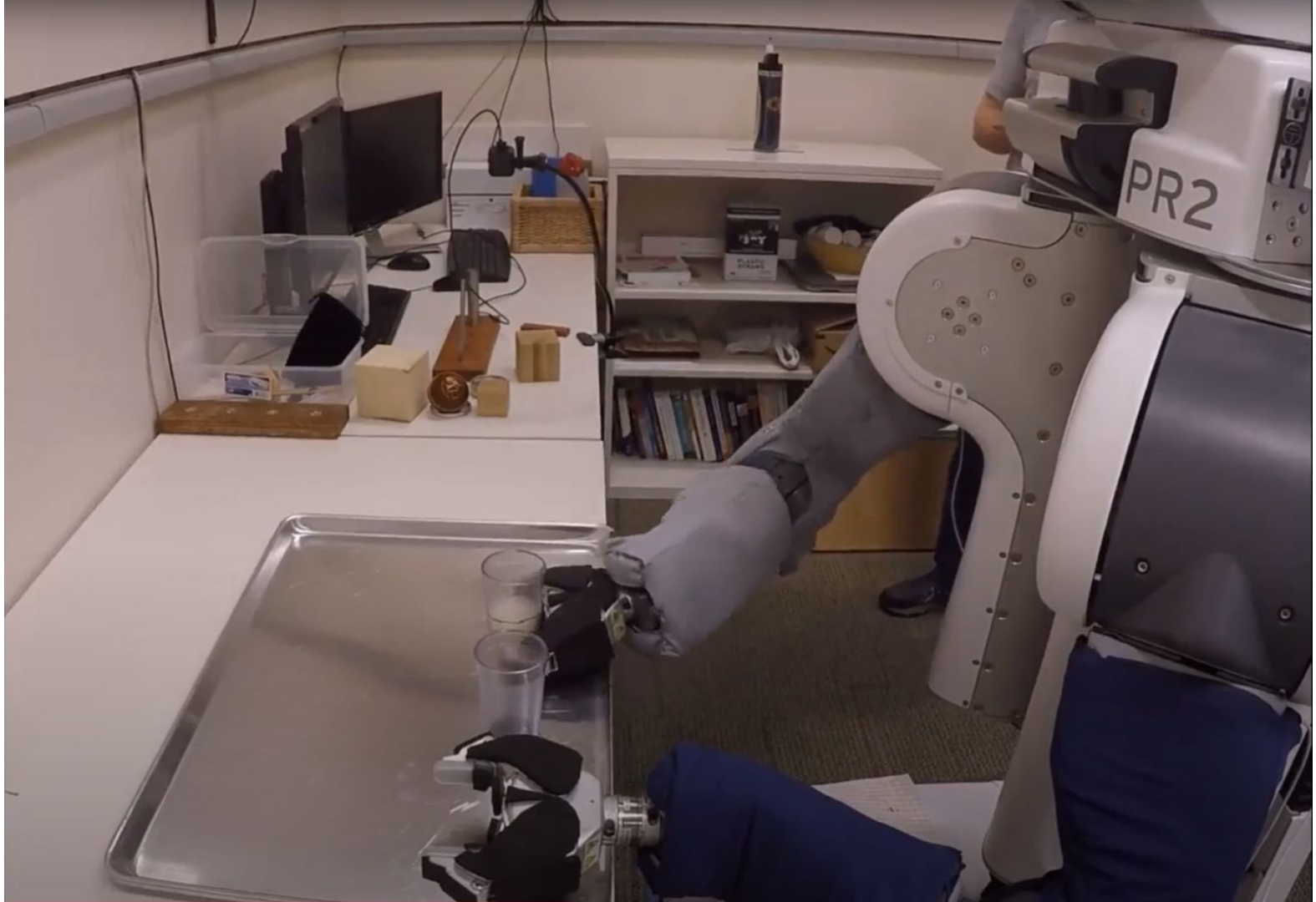
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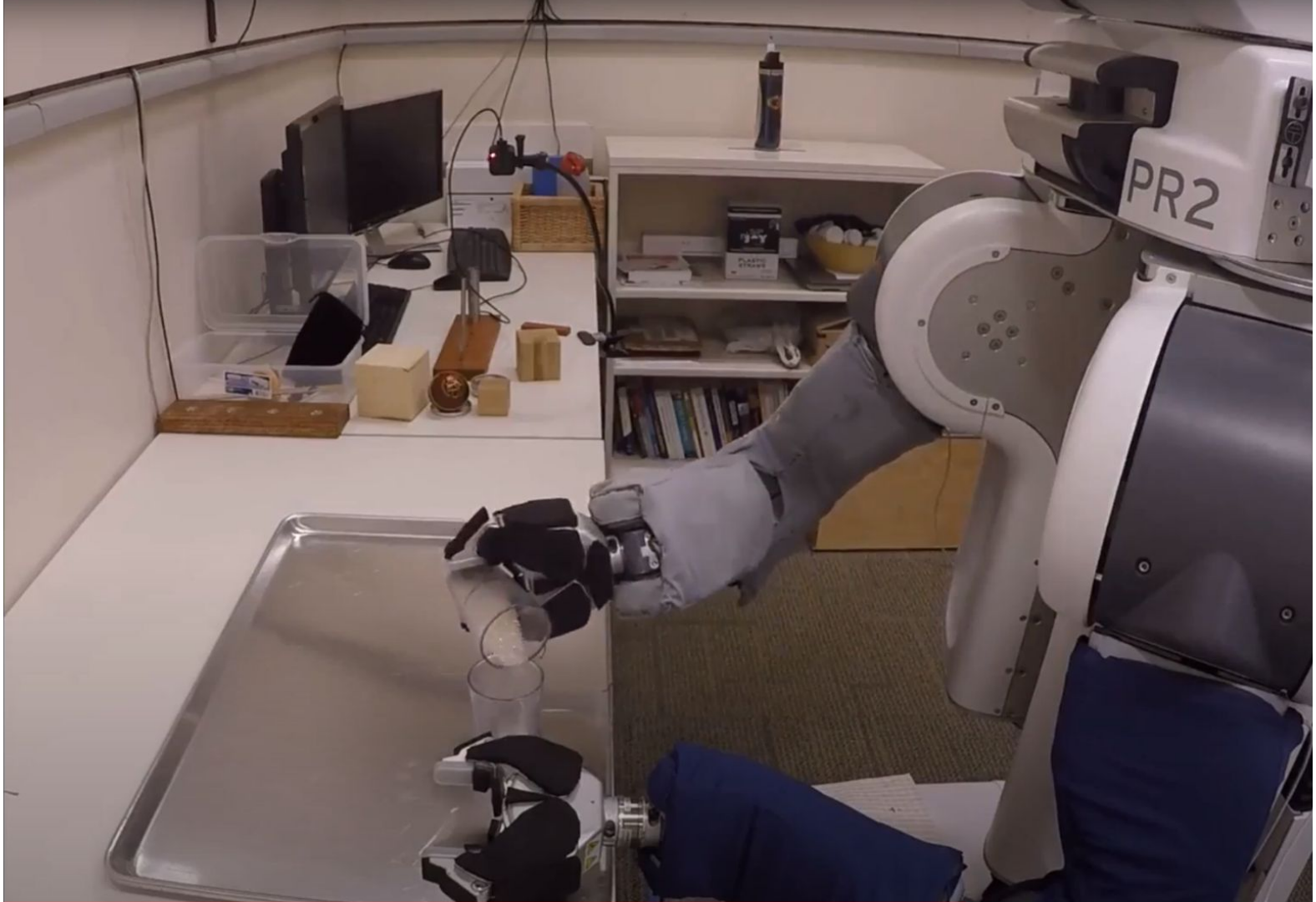
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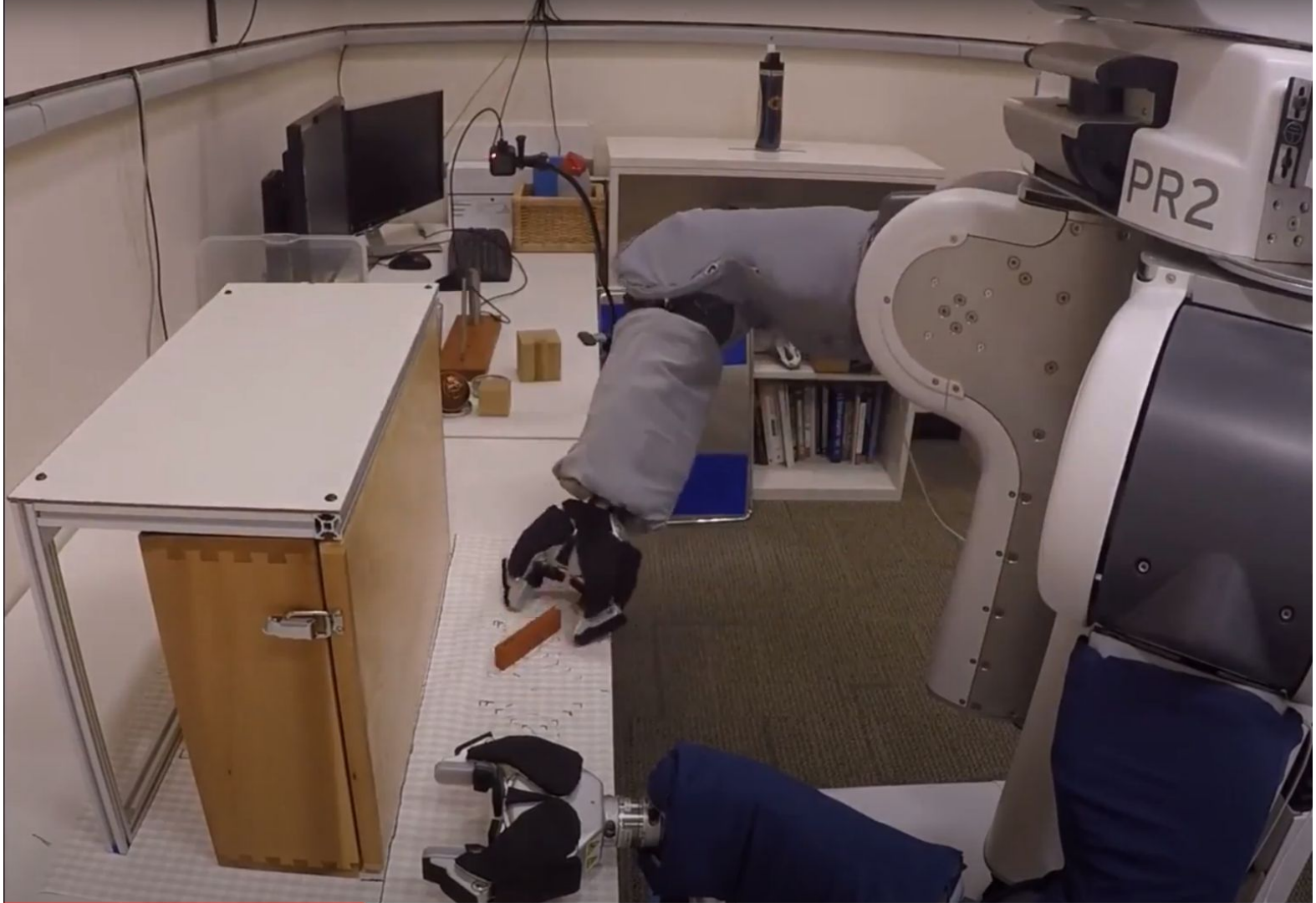
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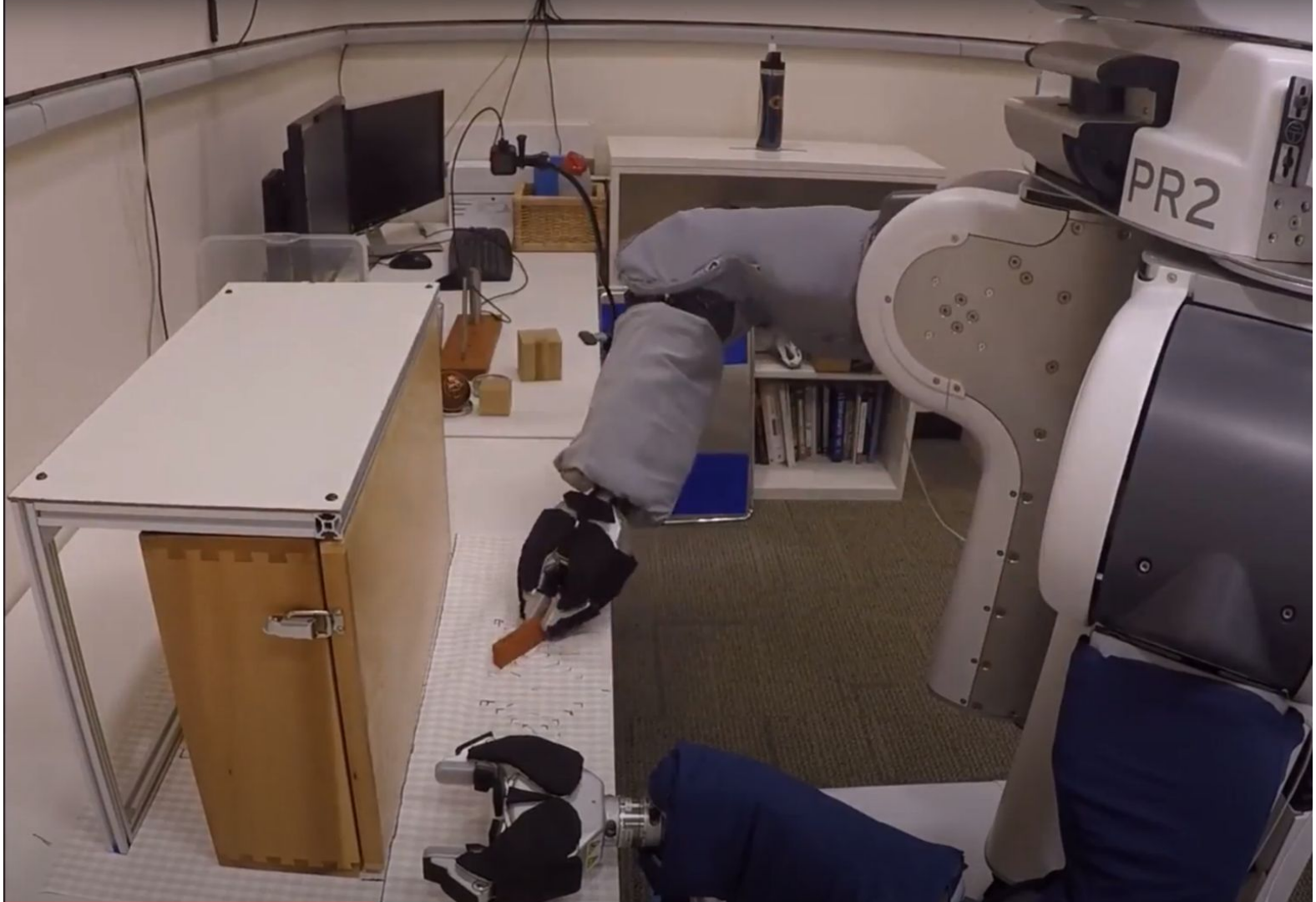
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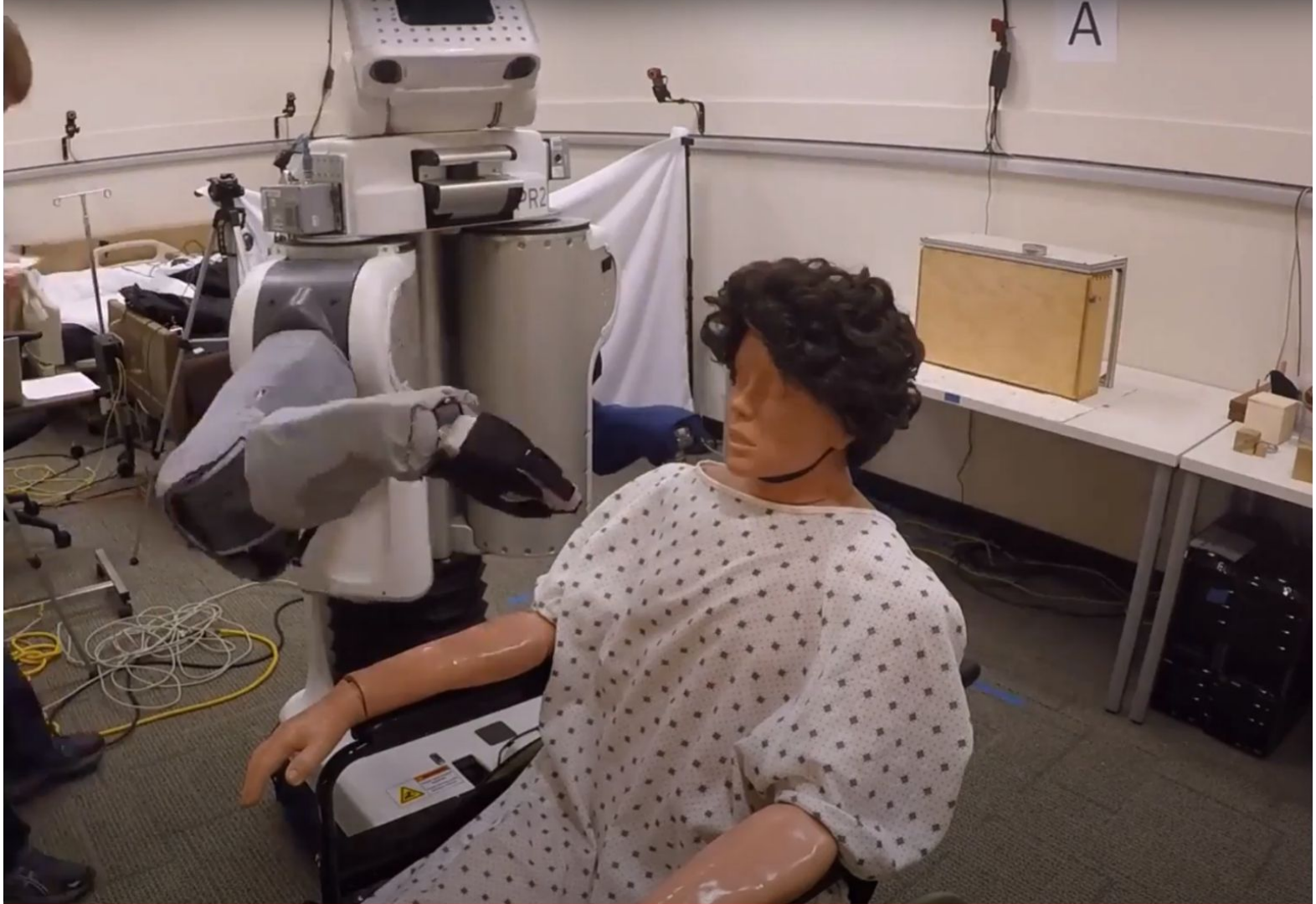
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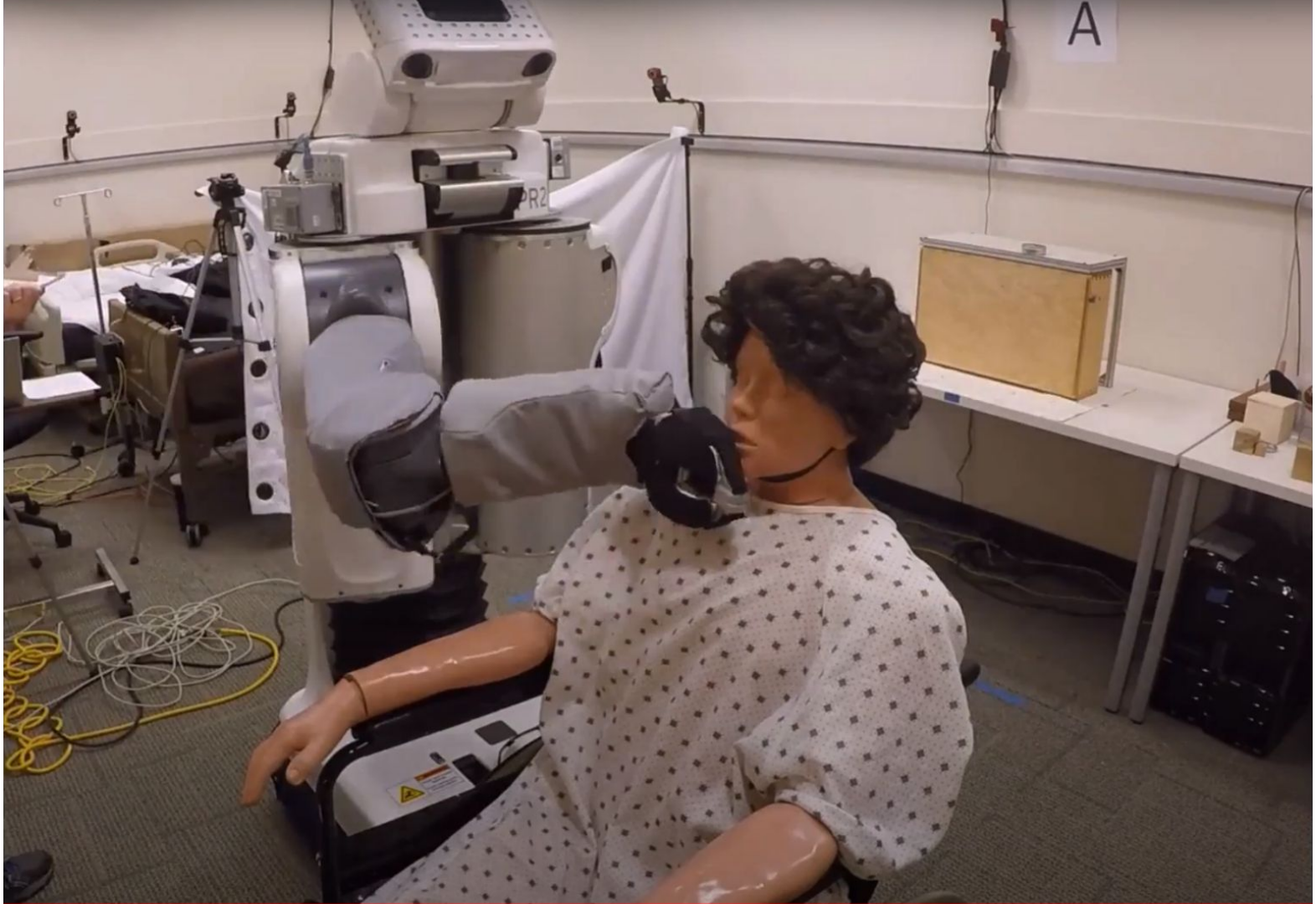
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Causes of Motor Impairment

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)

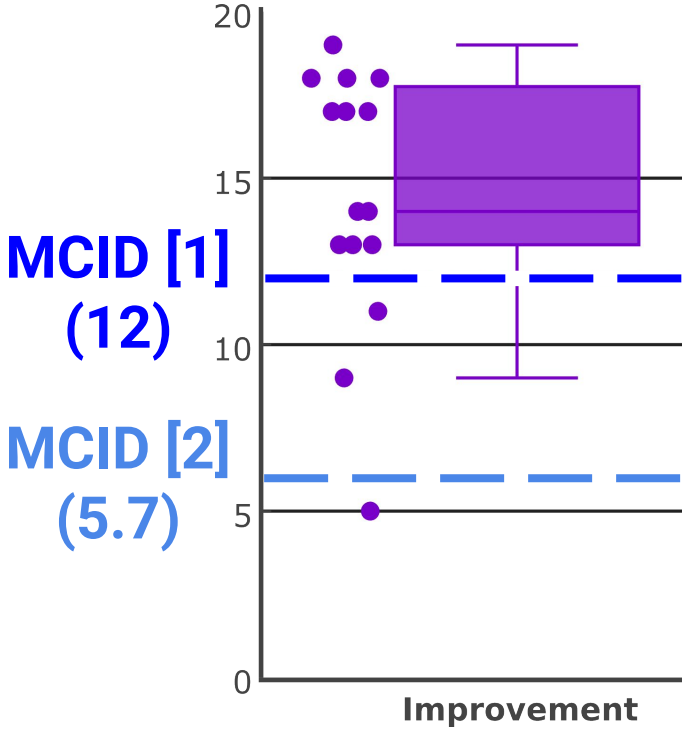
2 – Standard mouse

1 – Eye-gaze (Tobii)

1 – Touchpad w/Stylus held in mouth

1 – Speech (Dragon MouseGrid)

Improvement Exceeded Conservative Minimal Clinically Important Difference (MCID)

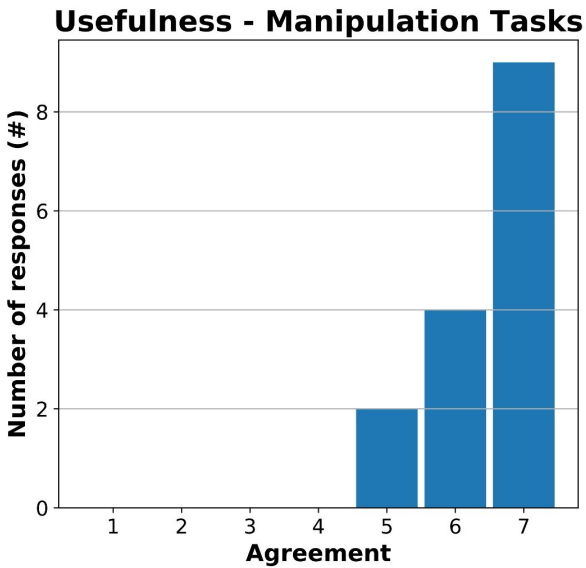


[1] C. E. Lang, D. F. Edwards, R. L. Birkenmeier, and A. W. Dromerick, **"Estimating minimal clinically important differences of upper-extremity measures early after stroke,"** Archives of physical medicine and rehabilitation, vol. 89, no. 9, pp. 1693– 1700, 2008.

[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

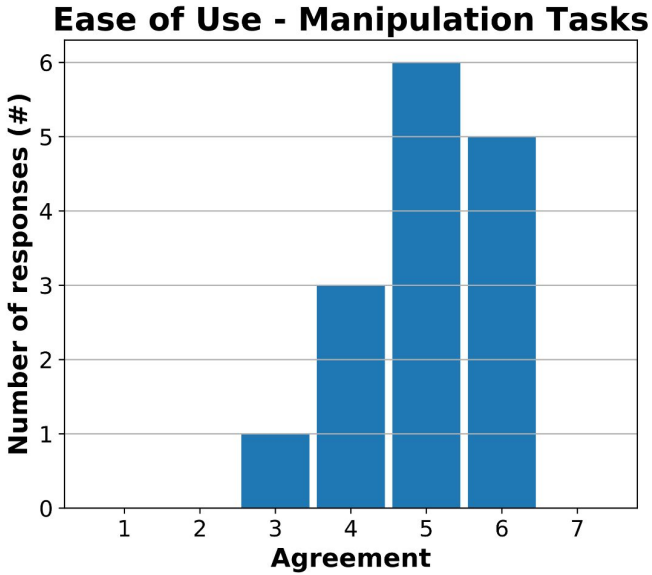


Wilcoxon signed-rank test vs neutral:
W=120, p=.000258

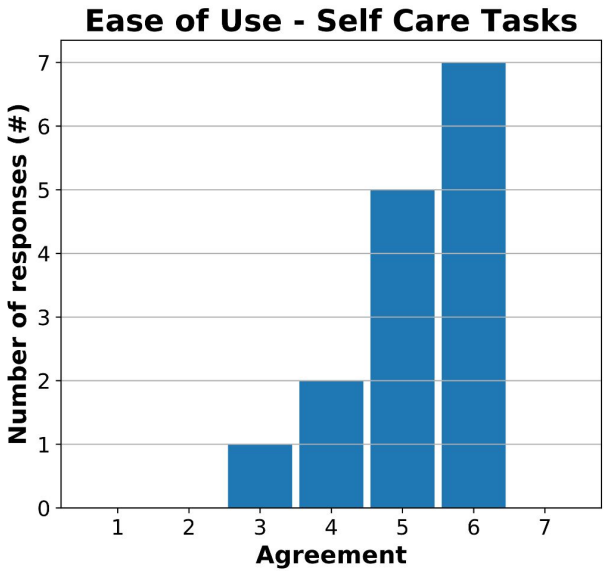
Wilcoxon signed-rank test vs neutral:
W=105, p=.000402

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

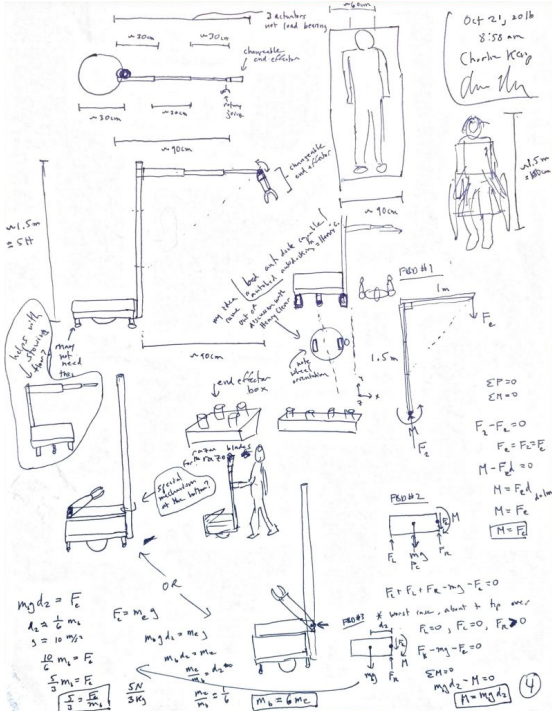
Photo from Willow Garage

Part 2: *A Novel Commercialized Robot*

Frustration Leads to Invention

Goals

- **affordable**
- compact
- lightweight
- humancentric
- capable



My Initial Georgia Tech Notes
October 2016

[The Design of Stretch: A Compact, Lightweight Mobile Manipulator for Indoor Human Environments](), Charles C. Kemp, Aaron Edsinger, Henry M. Clever and Blaine Matulevich, IEEE International Conference on Robotics and Automation (ICRA), 2022. [[4-min video presentation]()]

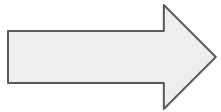
Georgia Tech

The Core Design Problem

Smaller

Lighter Weight

Lower Cost



Smaller Workspace

Lower Applied Forces

Fewer Degrees of Freedom

Photo from Willow Garage

Georgia Tech's 1st Prototype
March 2017

Hello Robot's Product - A Robot for Research
July 2020

2016	2017		2018	2019	2020

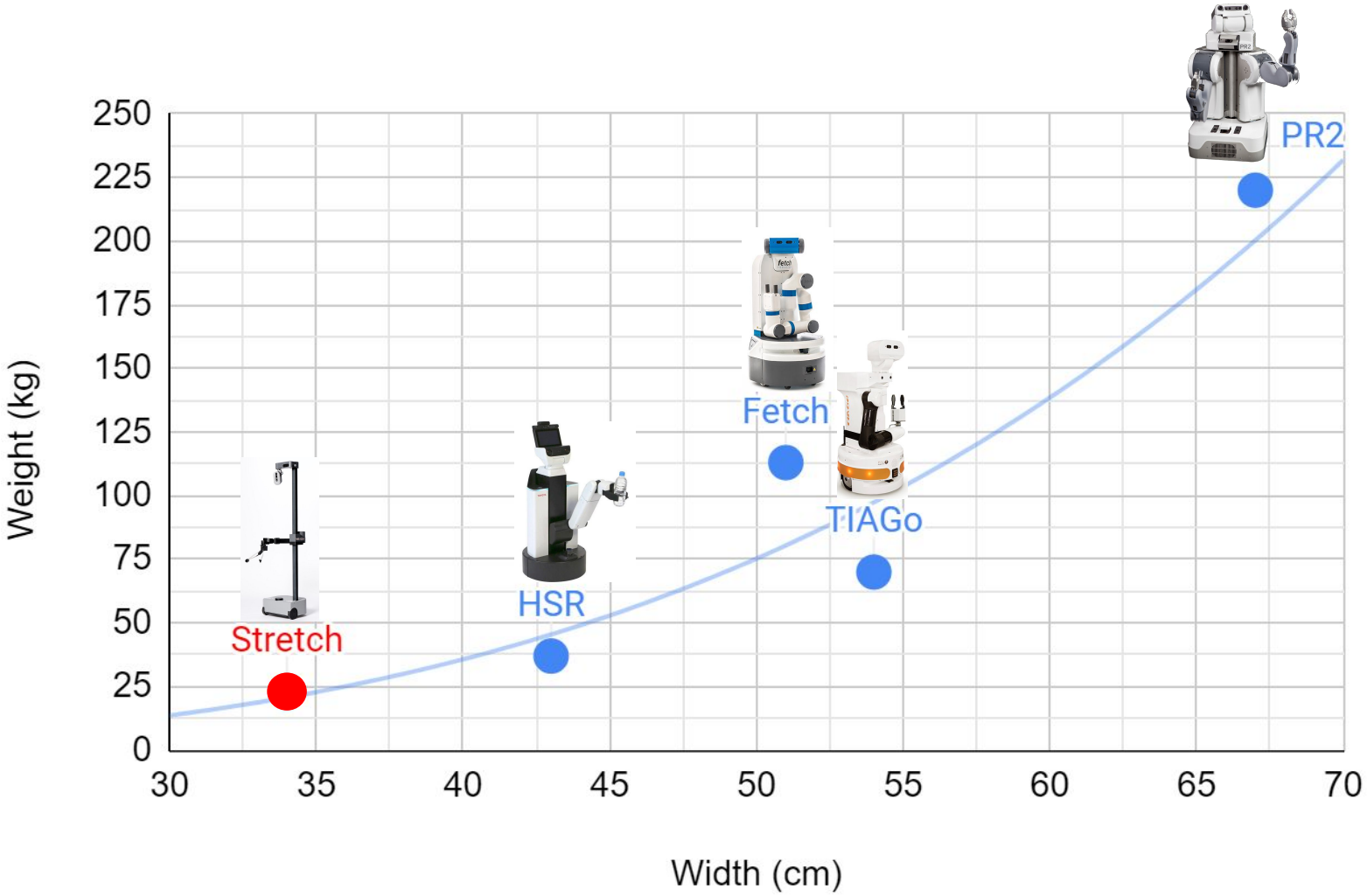
Georgia Tech

hello robot™

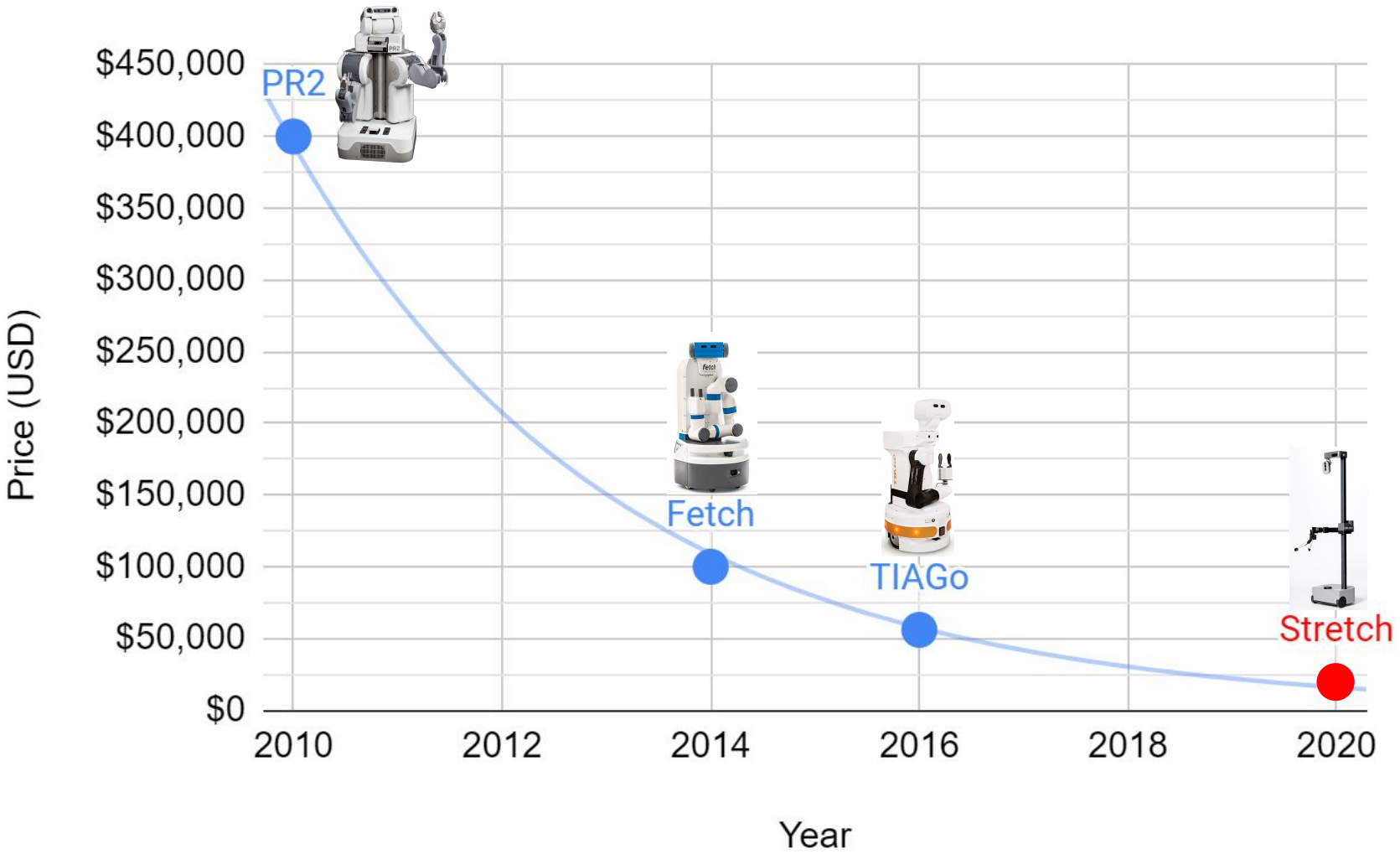
Smaller, Lighter, More Affordable

- 34 cm wide (~1.1 ft)
- 23 kg (~51 lb)
- $20,000

Photos from Willow Garage, https://fetchrobotics.com/fetch-mobile-manipulator/, https://pal-robotics.com/robots/tiago/, https://global.toyota/en/download/8725328

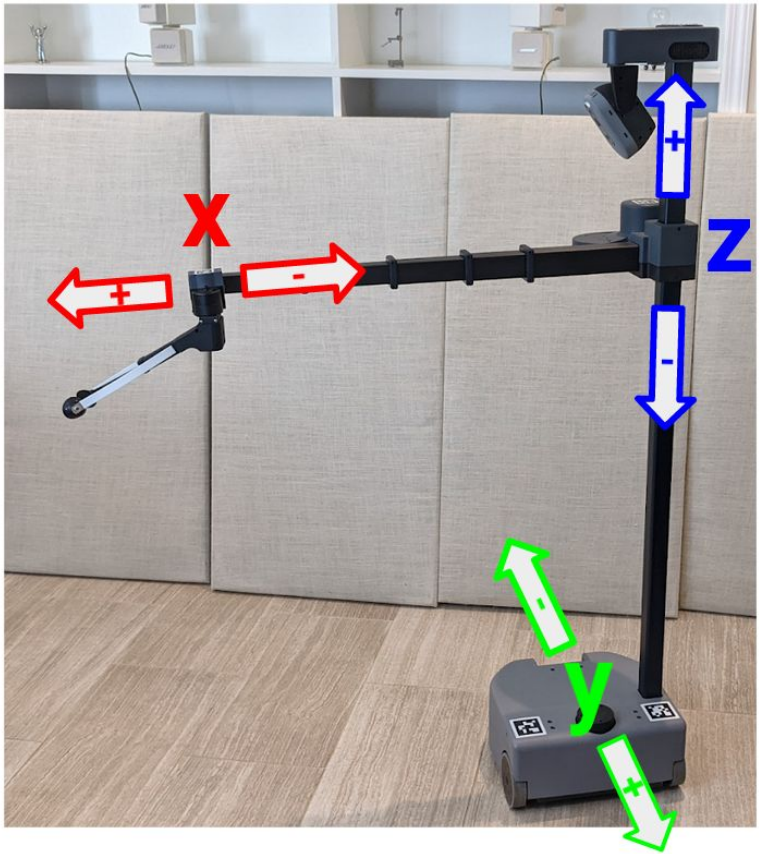


Photos from Willow Garage, https://fetchrobotics.com/fetch-mobile-manipulator/, https://pal-robotics.com/robots/tiago/



Cartesian Manipulator

Cartesian Manipulator



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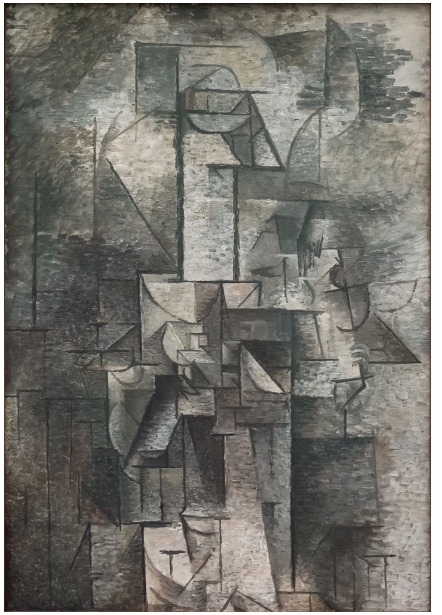
Arm & Tool Stow in the Footprint

Robotic Cubism

- Dimensions matched to human environments
- The human form deconstructed and reassembled

La Femme au Violon - Pablo Picasso, 1911



“In Cubist artwork, objects are analyzed, broken up and reassembled in an abstracted form”
- https://en.wikipedia.org/wiki/Cubism

< 50th Percentile Hip Width

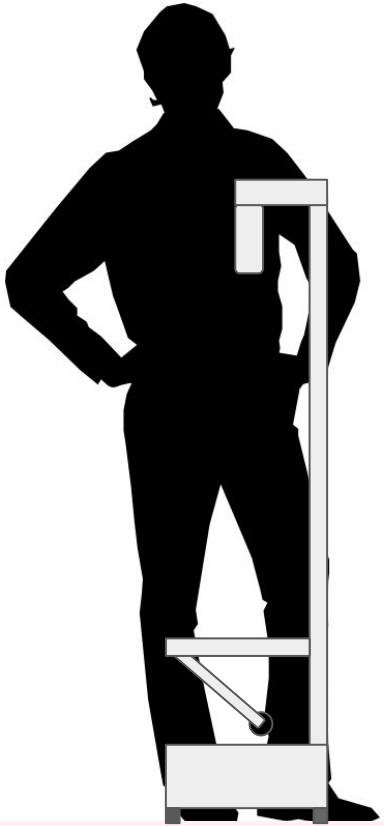


Image: https://openclipart.org/detail/260142/arms-akimbo-male

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50th Percentile Arm Length

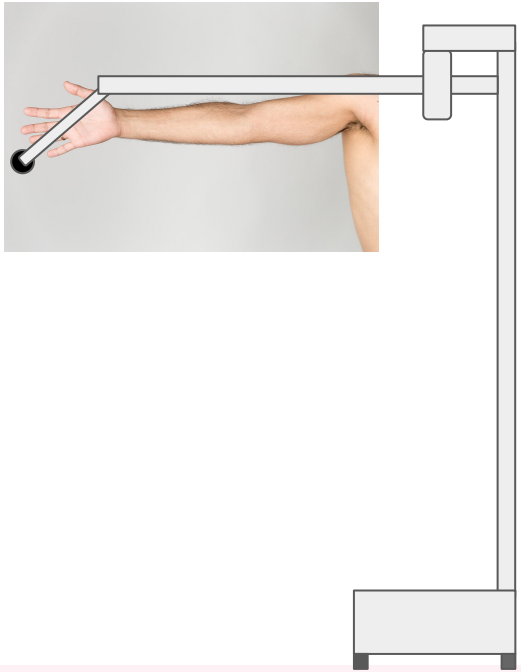

Image: https://en.wikipedia.org/wiki/Arm#/media/File:Extended_arm.jpg

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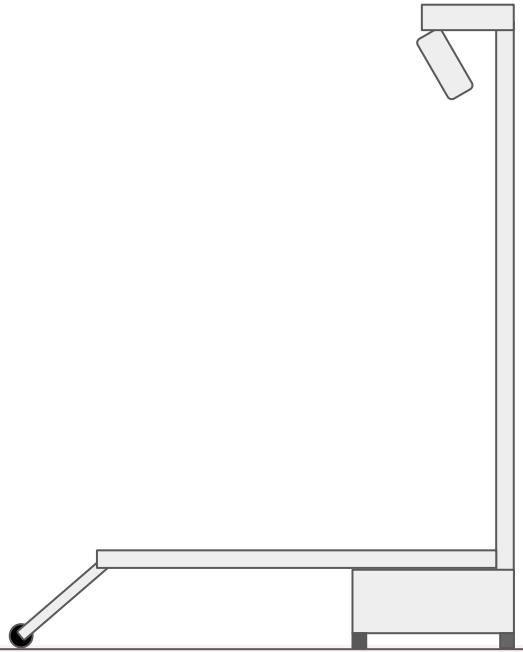
Reaches the Floor



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Reaches 36” Countertops

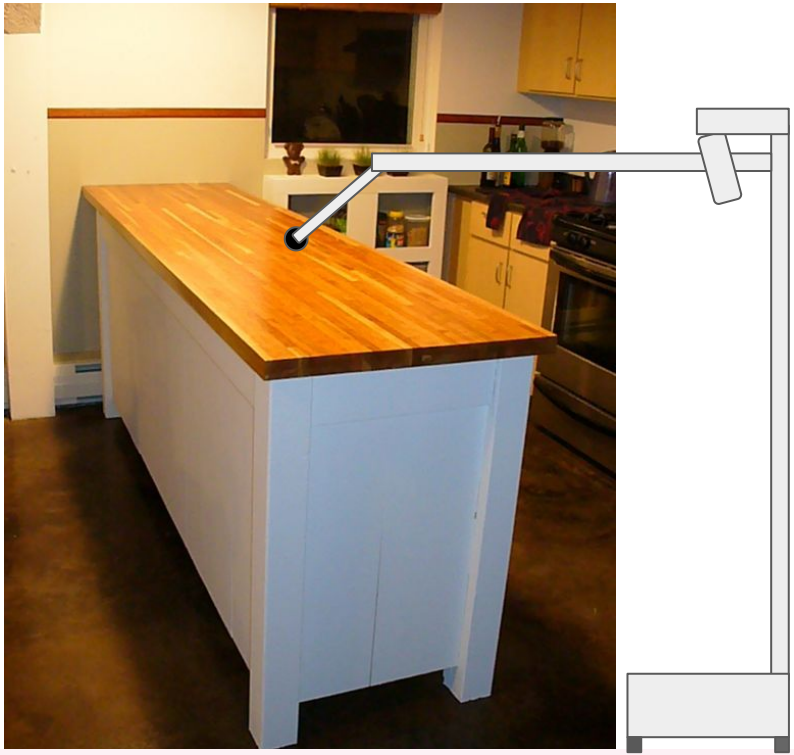

Image: https://commons.wikimedia.org/wiki/File:Butcher_block_counter_top.jpg

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23 kg (51 lb)

Image: https://www.seekpng.com/ipng/u2q8y3i1o0r5a9o0_beautiful-silhouettes-of-children-boy-silhouette-transparent-background/

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Image from https://sites.gatech.edu/robotic-caregivers/ .

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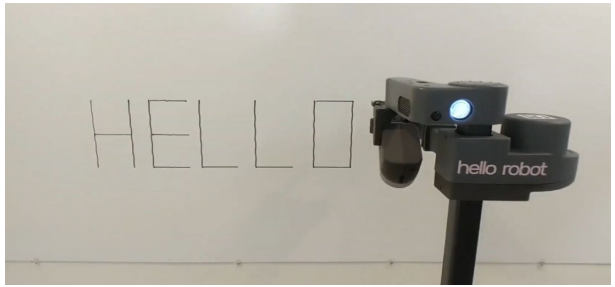
Teleoperated Home Examples

https://www.youtube.com/c/HelloRobot/videos
https://github.com/hello-robot

Autonomous Home Examples

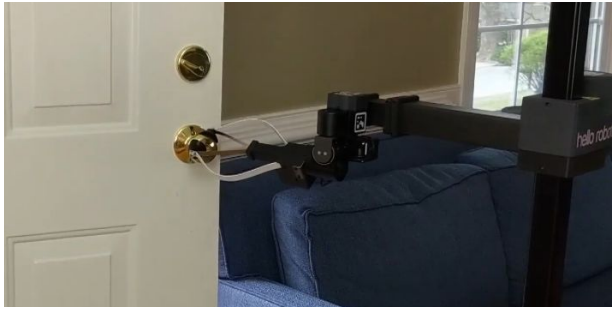


https://forum.hello-robot.com/t/autonomy-video-details

Teleoperated Examples with the Dexterous Wrist








https://www.youtube.com/c/HelloRobot/videos
https://github.com/hello-robot

The Stretch RE1

“Beautifully Simple, Clever Robot Design”

- IEEE Spectrum

Hardware & Software Platform

- Compact, lightweight, contact sensitive, calibrated
- $19,950 for a **complete robot**
  - gripper
  - sensors
  - onboard computer
- Open source software
  - From firmware up
  - Python & ROS

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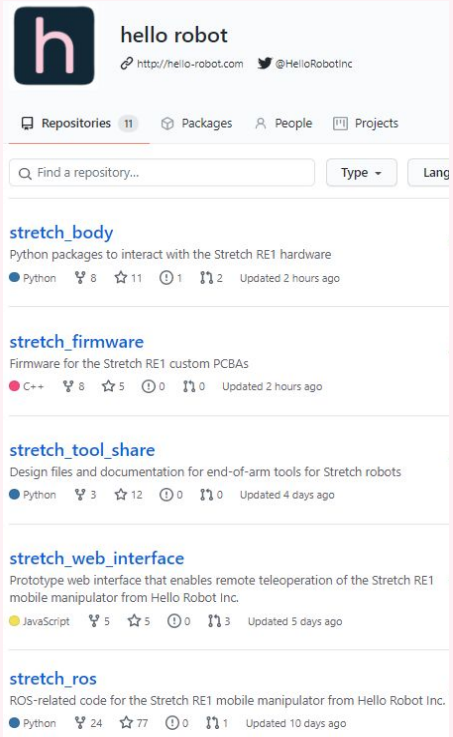
Transparency & Openness

Simple Pricing
hello-robot.com

Open Source & Open Development
github.com/hello-robot

Open Hardware Accessories
github.com/hello-robot/stretch_tool_share

Open Forum
forum.hello-robot.com



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Successful Launch in July 2020

IEEE SPECTRUM Topics Reports Blogs Multimedia

Automaton | Robotics | Home Robots

14 Jul 2020 | 4:01 GMT

Ex-Googler's Startup Comes Out of Stealth With Beautifully Simple, Clever Robot Design

Hello Robot's Stretch wants to reinvent how mobile manipulators perform tasks in home environments

By **Evan Ackerman and Erico Guizzo**

Photo: Hello Robot

Hello Robot, founded by former Google robotics director Aaron Edsinger and Georgia Tech professor Charlie Kemp, is introducing Stretch, a mobile manipulator that weighs only 23 kg and costs less than $20,000.

SVR Silicon Valley Robotics

supporting the innovation and commerc

Hello Robot wins Innovation Award in SVR 'Good Robot' Industry Awards

Posted on December 14, 2020 by Andra Keay

RBR 50 INNOVATION AWARDS

BBC Sign in Home News Sport Reel Wo

NEWS

Home | Prince Philip | Coronavirus | Video | World | US & Canada | UK | Busines

Tech

Research robot helps with housework and other news

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Part 3: *A Growing Community*


UMassAmherst
AUBURN UNIVERSITY
avanade
Carnegie Mellon University
THE UNIVERSITY OF CHICAGO
UNIVERSITY OF Cincinnati
Cornell University
UCDAVIS
UEC TOKYO
Georgia Tech
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN
JOHNS HOPKINS UNIVERSITY
UCLA
UMASS LOWELL
Meta
Microsoft
Massachusetts Institute of Technology
Nara Institute of Science and Technology NAIST
NC STATE
Northeastern University
NYU
OSAKA UNIVERSITY
Pacific University Oregon
PICKNIK
R4H
Rensselaer
RICE
robust AI
Sandia National Laboratories
UC San Diego
UNIVERSITY OF CALIFORNIA SANTA CRUZ
THE UNIVERSITY OF TOKYO
umbrella research
VIAM
UNIVERSITY of WASHINGTON
WISCONSIN UNIVERSITY OF WISCONSIN-MADISON
Yale

Human Fusions at ANA Avatar XPRIZE Semifinals

Prof. Veronica Santos from UCLA

Case Western Reserve University · UCLA · Cleveland State University 1964 · Carnegie Mellon University · UW · Tuskegee University 1881

http://humanfusions.org/ana-avatar-xprize.html

UCLA

Visual Imitation Learning

Prof. Lerrel Pinto

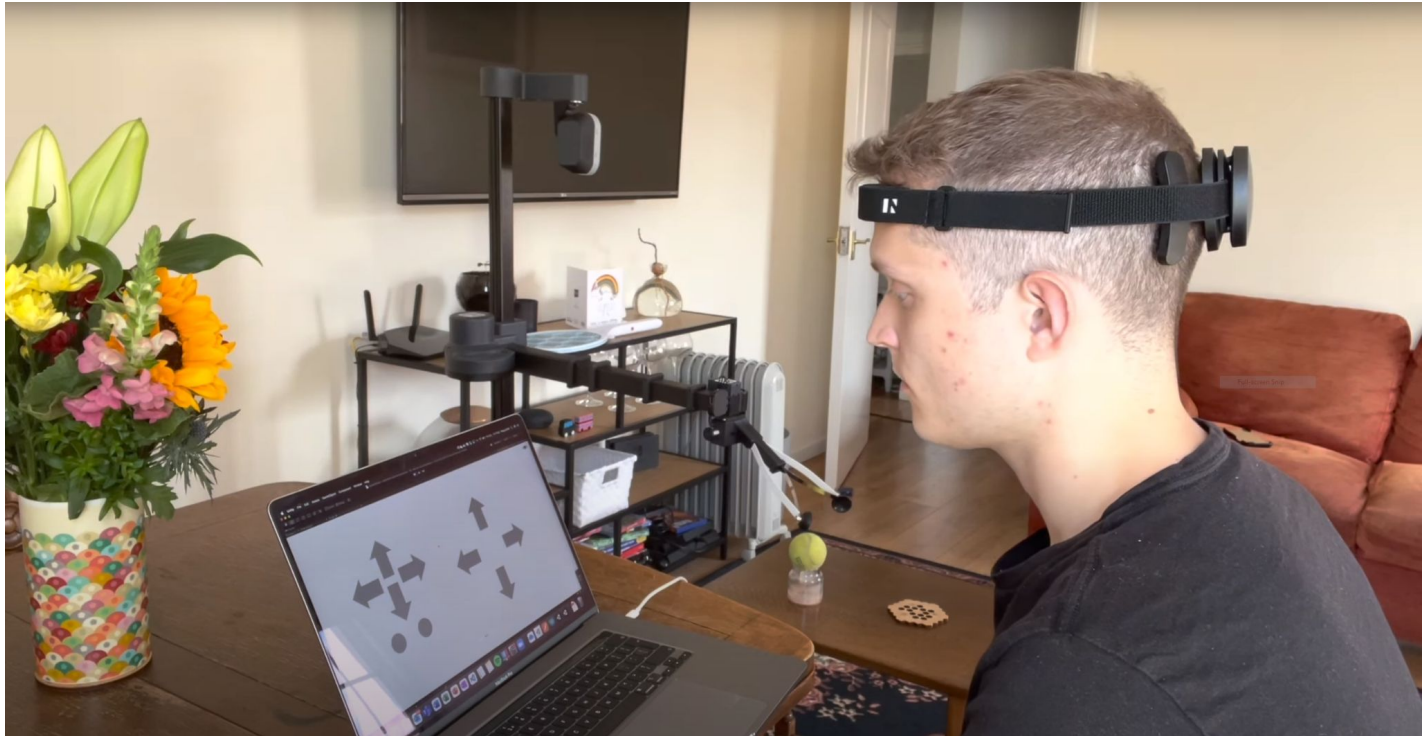
The Surprising Effectiveness of Representation Learning for Visual Imitation. Jyothish Pari, Nur Muhammad Shafiullah, Sridhar Pandian Arunachalam and Lerrel Pinto. ArXiv, 2021.

https://jyopari.github.io/VINN/

NYU

Brain Computer Interface Control & More

Fergus Kidd



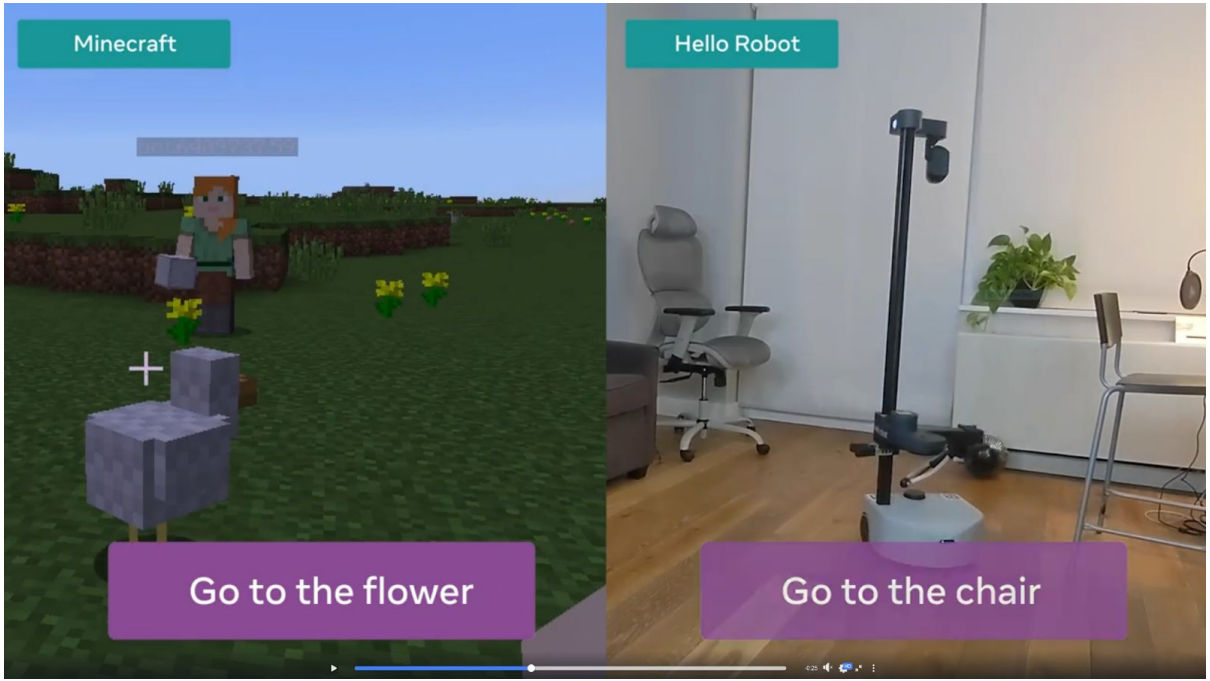
https://ferguskidd.azurewebsites.net/mind-controlled-robot/

https://github.com/Avanade/emtech-stretch-labs

avanade

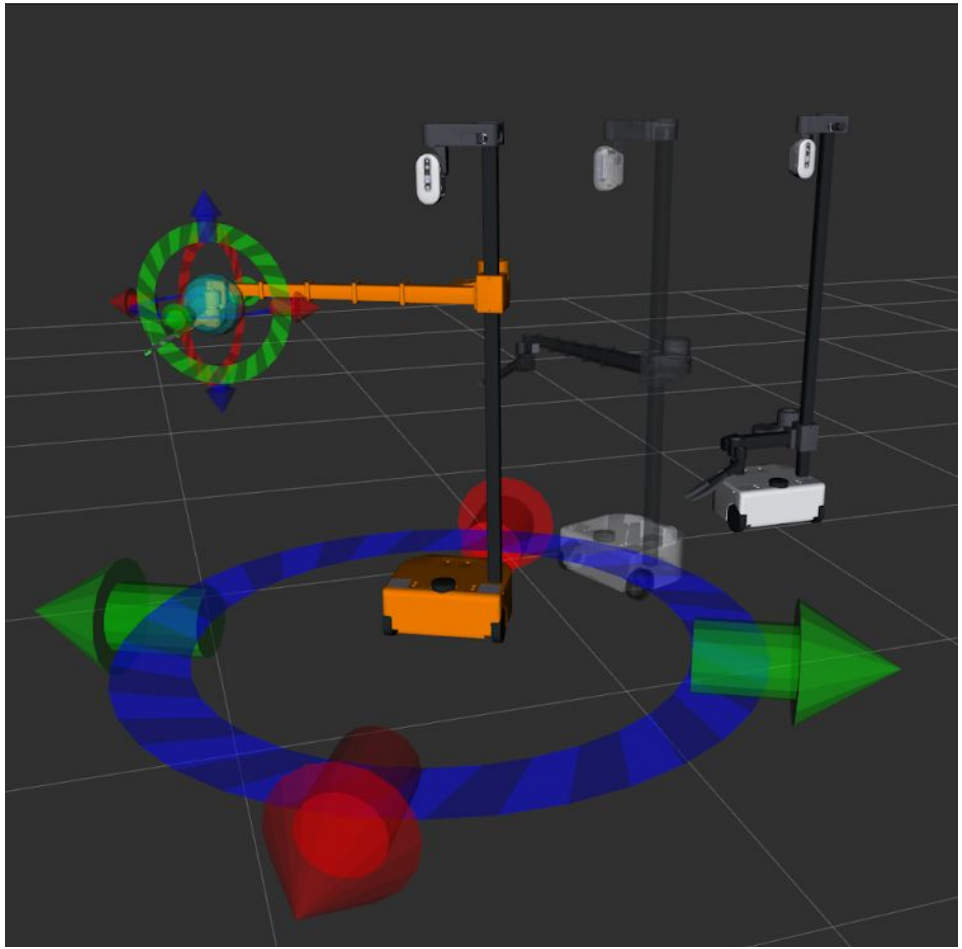
Fairo Robotics Platform

“Fairo (pronounced *"pharaoh"*) is a unified robotics platform developed by researchers at Meta AI.”



https://github.com/facebookresearch/fairo

Meta



MoveIt2

https://moveit.ros.org//events/rosworld-2021-workshop/

https://github.com/hello-robot/stretch_ros2/tree/ros_world2021

PICKNIK

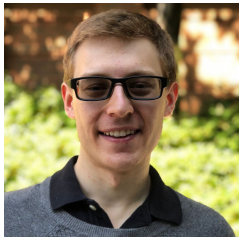
Reaching Body Locations

Robotic Control
(unpublished)
Matt Lamsey
Naveen Balaji

Henry M. Clever, Patrick Grady, Greg Turk, Charles C. Kemp, BodyPressure – Inferring Body Pose and Contact Pressure from a Depth Image, IEEE Transactions on Pattern Analysis and Machine Intelligence, 2022.

https://github.com/Healthcare-Robotics/BodyPressure

Learning from Physics Simulations



Prof. Zackory Erickson

Kavya Puthuveetil

Bodies Uncovered: Learning to Manipulate Real Blankets Around People via Physics Simulations. Kavya Puthuveetil, Charles C. Kemp, and Zackory Erickson. IEEE Robotics and Automation Letters (RA-L), 2022.

https://github.com/RCHI-Lab/bodies-uncovered

Carnegie Mellon University

Project-based Class with Open Materials from Fall 2021

Teaching Award
Student Recognition of Excellence in Teaching:
Class of 1934 CIOS Honor Roll

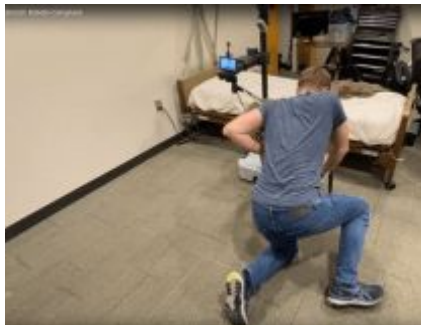
Now a research project in my lab!

Rehabilitation Game

*Madeline Beatty, **Matthew Lamsey**, Zexuan Liu, Arjun Majumdar, and Kendra Washington*

Hydration Assistance via Water Delivery

Zach Shaefer, Miles Macero, Hannah Paterson, Kendra Dawson, & Naveen Balaji N



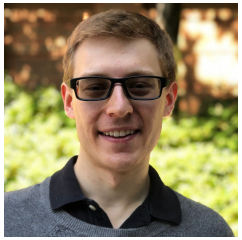
Fall Assistance using Remote Teleoperation

Aparna Subramaniam, Mark Putman, Jeremy Collins, Stuart Song, Prathic Sundararajan

https://sites.gatech.edu/robotic-caregivers/

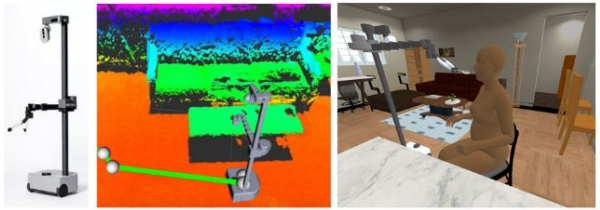
Georgia Tech

New Project-based Class this Term



Prof. Zackory Erickson
https://zackory.com/rc2022/

16-887: Robotic Caregivers and Intelligent Physical Collaboration (Spring 2022)



Course Info

Syllabus

Course Schedule

Course Project Statement

Time: Monday & Wednesday 1:25 - 2:45 PM
Location: NSH 3002
Instructor: Zackory Erickson
Office Hours: Wednesday 2:45 - 3:45 PM
Course Questions and Discussion: Slack – Registered students will be added

Course Description

Robotics researchers and futurists have long dreamed of robots that can serve as caregivers. In this project-based course, you'll learn about intelligent physical human-robot collaboration and opportunities for robots that contribute to caregiving. You'll gain hands-on experience with teleoperation, autonomy, perception, navigation, manipulation, human-robot interaction, and machine learning. You'll also learn about robot design, collaborative research, and healthcare robotics.

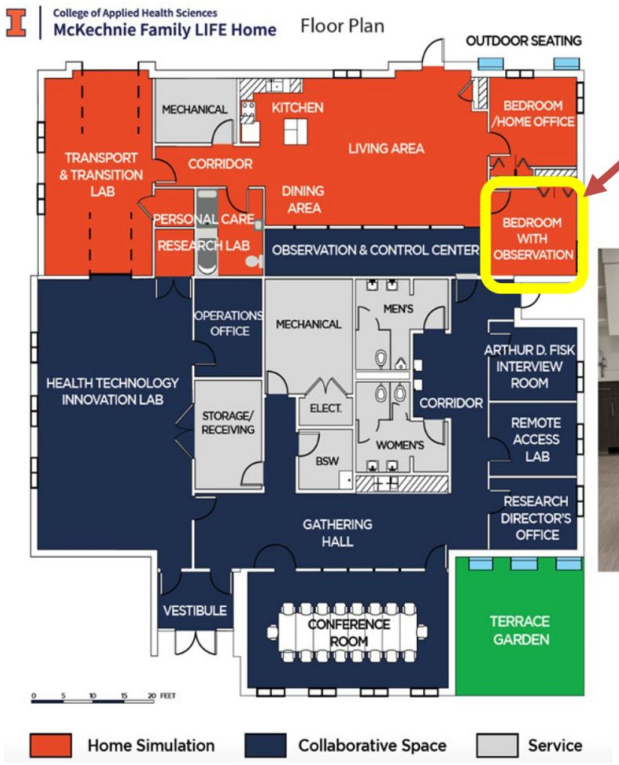
This is a graduate-level project-based course for students interested in physical human-robot collaboration and robotic caregiving. There are no exams nor textbook assignments. You will be working with a group of your peers to develop solutions to real-world problems in which robots physically interact with and assist people. There are two projects where you will work with a ***real mobile manipulator*** and build on state-of-the-art methods from scientific literature, all leading to a live robot demonstration, presentation, and short paper to disseminate your results.

Carnegie Mellon University

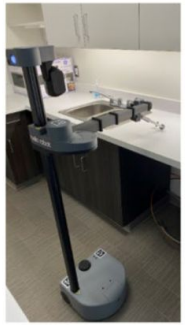
Studies with Older Adults in the McKechnie Family LIFE Home

Wendy Rogers
wendyr@Illinois.edu

Harshal Mahajan
mahajan6@Illinois.edu



Stretch's Bedroom



SBIR Phase I grant funded by the National Institute on Aging of the National Institutes of Health 1R43AG072982

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Pitch Competition

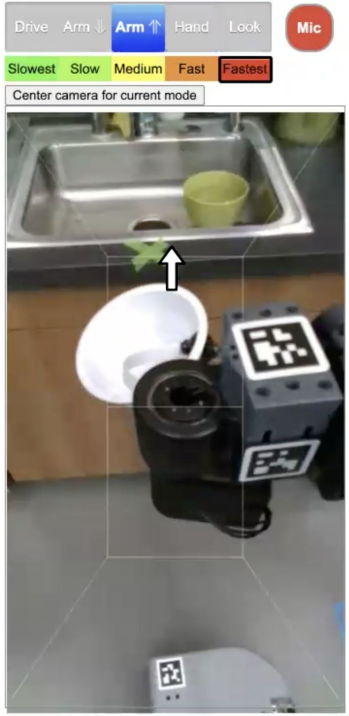
Congratulations to our winners of the 2021 Stretch Robot Pitch Competition! 🎉This competition at @UofIllinois sought innovative & creative solutions to support individuals aging with #disabilities with the Stretch™ robot by @hellorobotinc

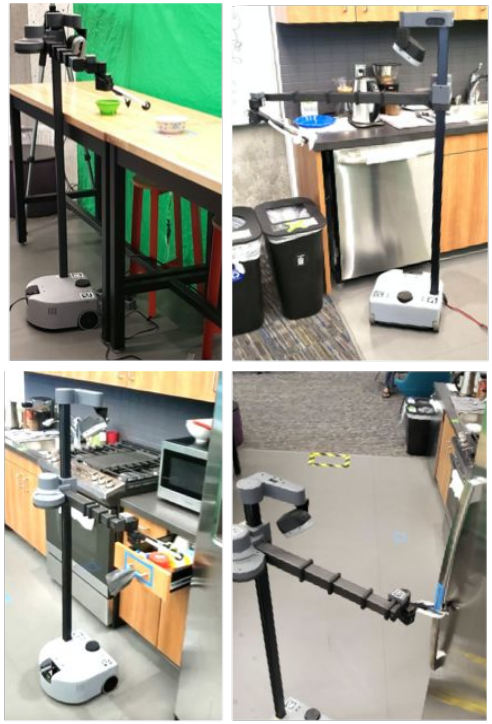
https://ahs.illinois.edu/TechSAge_competition

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Assistive Robotics

21 people, **including 3 people with disabilities**, remotely operated Stretch





Cabrera, Maria E., Tapomayukh Bhattacharjee, Kavi Dey, and Maya Cakmak. "An Exploration of Accessible Remote Tele-operation for Assistive Mobile Manipulators in the Home." In *2021 30th IEEE International Conference on Robot & Human Interactive Communication (RO-MAN)*, pp. 1202-1209. IEEE, 2021.

Maru Cabrera
Assistant Professor
UMass Lowell

Tapo Bhattacharjee
Assistant Professor
Cornell University

Kavi Dey
Research Intern
Seattle Academy

Maya Cakmak
Associate Professor
University of Washington

https://github.com/hcrlab/stretch_web_interface

UNIVERSITY of WASHINGTON

Assistive Robotics

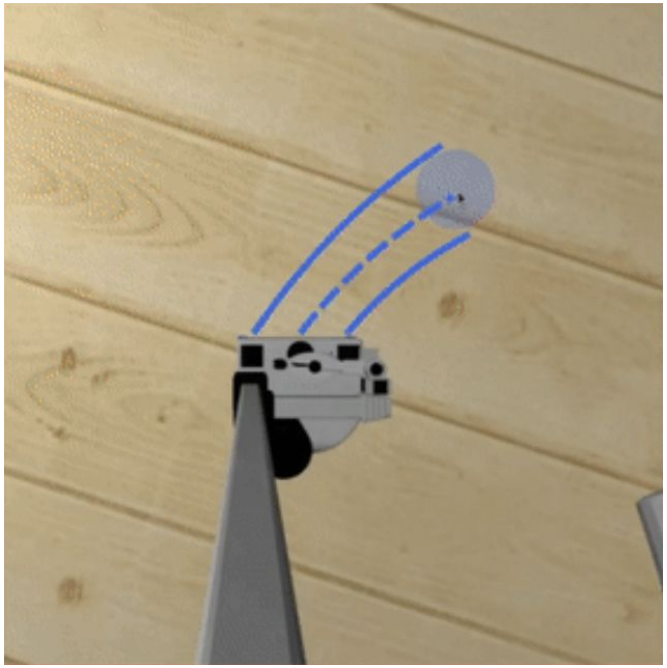
Vinitha Ranganeni

Nick Walker

Kavi Dey

Maya Cakmak

Associate Professor



https://github.com/hcrlab/stretch_web_interface
https://github.com/hcrlab/hcrl_gazebo
https://github.com/hcrlab/stretch_ros

UNIVERSITY of WASHINGTON

Occupational Therapy Doctoral Project

Pacific University Oregon

Vy Nguyen

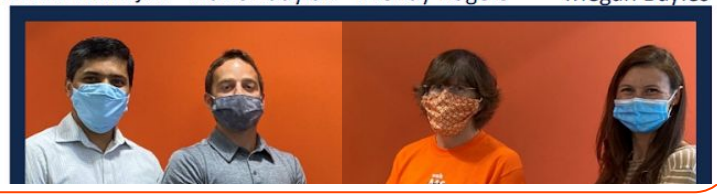
Henry & Jane Evans

Maya Cakmak

Kavi Dey

Tapo Bhattacharjee

Harshal Mahajan Travis Kadylak Wendy Rogers Megan Bayles



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Elliston Franks

Charlie Kemp

Blaine Matulevich

Binit Shah

Stretch Provides Meaningful Assistance

https://forum.hello-robot.com/t/summer-research-on-in-home-use-by-henry-evans
https://www.washingtonpost.com/photography/2021/11/23/my-day-with-henry/

Stretch Provides Meaningful Assistance

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https://www.washingtonpost.com/photography/2021/11/23/my-day-with-henry/

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https://www.washingtonpost.com/photography/2021/11/23/my-day-with-henry/

A Story in Three Parts

- Research on Personal Assistance
- A Novel Commercialized Robot
- A Growing Community

Part 4: *The Future*

Image from: https://upload.wikimedia.org/wikipedia/commons/8/8e/Barley_crop_-blue_sky-4May2008.jpg

Image from: https://upload.wikimedia.org/wikipedia/commons/8/8e/Barley_crop_-blue_sky-4May2008.jpg

Live Demo of Stretch!

Binit Shah
Lead Software Engineer

https://hello-robot.com/

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