Designing Assistive Robots and Technologies for Pediatric Care

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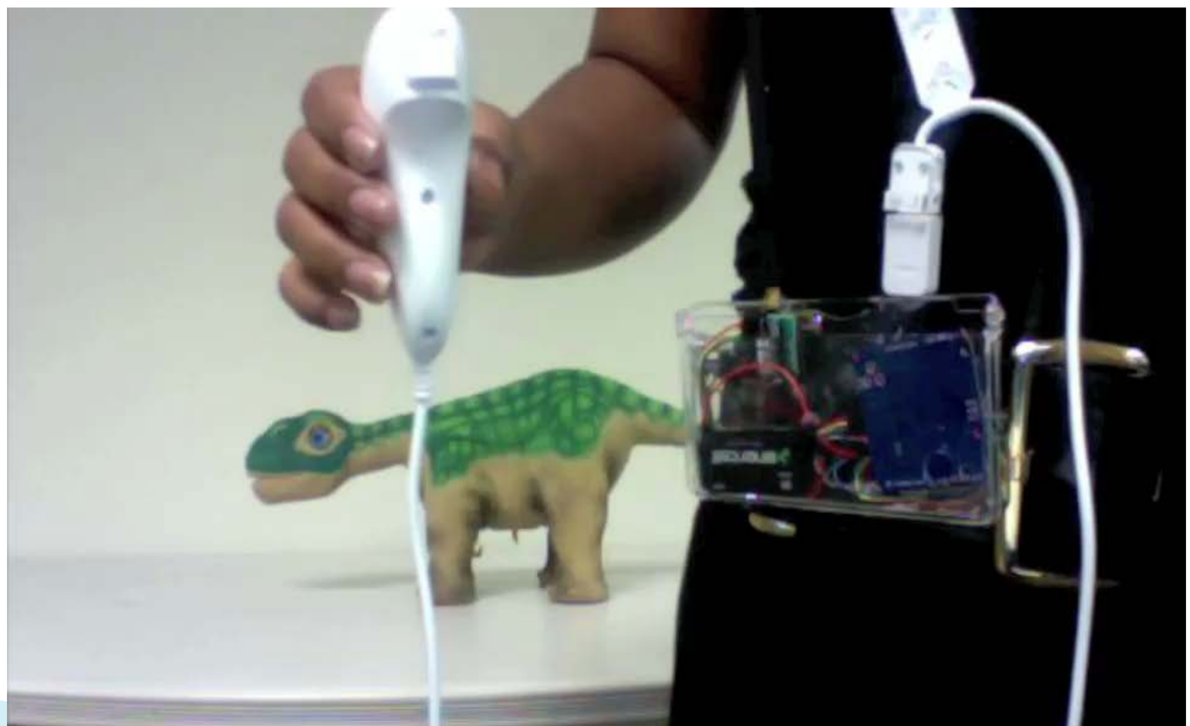
Motivation

- Therapeutic play helps promote cognitive, social, and physical skill development in children.
- Due to a number of factors, there has been interest in finding alternative effective therapeutic devices.
- Intended for use in a range of environments, including hospitals, physical therapy centers, and homes.


Why Robots?

- Most children, including children with special needs, are attracted to robots.
- This natural affinity can be exploited, and the robot used as an interactive toy.
- Robots can provide repetitive and predictable interaction for pediatric care.



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What are the Challenges for Robots?

- How do we establish an evidence-base on efficacy for robot-assisted therapy?
- How do we enable successful interaction between client, clinicians, and robots?
  - How does a clinician communicate therapy objectives to the robot?
  - How does the robot interact with the child to enable adherence to the protocol?
  - How does the robot provide feedback to the clinician on client improvement and compliance?

Statistics – Children with Disabilities

- Over 93 million children with disabilities around the world
- In the United States
  - 1:68 children with Autism
  - 1:323 children with Cerebral Palsy
  - 1:700 children born with Down Syndrome
  - Almost half a million emergency department visits for Traumatic Brain Injuries of children

Case Study: Children with CP

- 1 in 323 children in the U.S. are diagnosed with Cerebral Palsy (CP)
- These children typically participate in physical/occupational therapy interventions on a regular basis
- For such children, therapeutic play is the best form of physical therapy
  - Natural
  - Engaging
  - Long lasting

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Physiotherapy Sessions

c.o. hmsystemsinc.com

c.o. mtskids.com

c.o. tenderones.com

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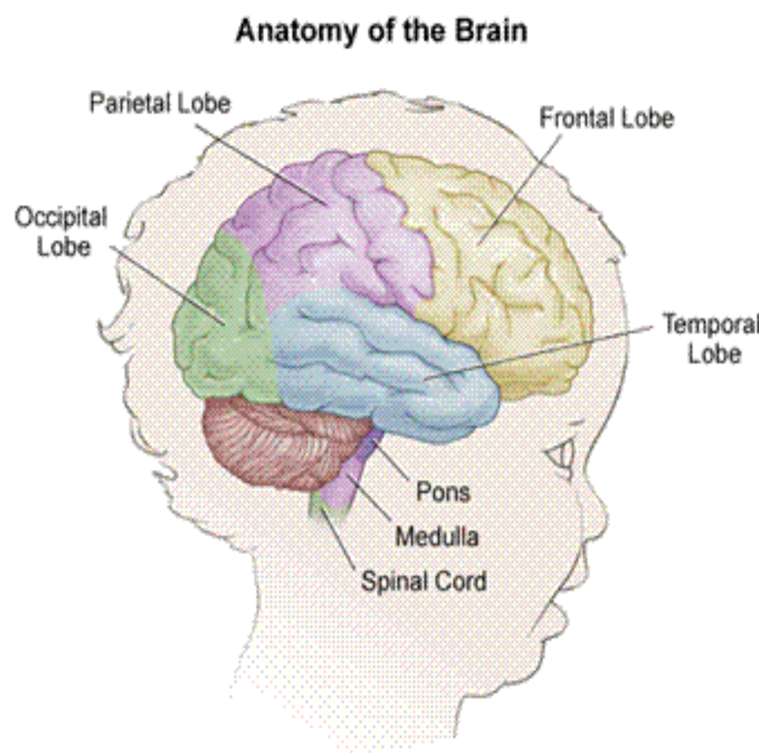
Child Cognitive Behavior

- With repetitive or monotonous conditions over time, performance decreases due to reduced arousal (Cooley and Morris, 1990)
- Generally, sustained attention improves with age



Courtesy of childrensmemorial.org

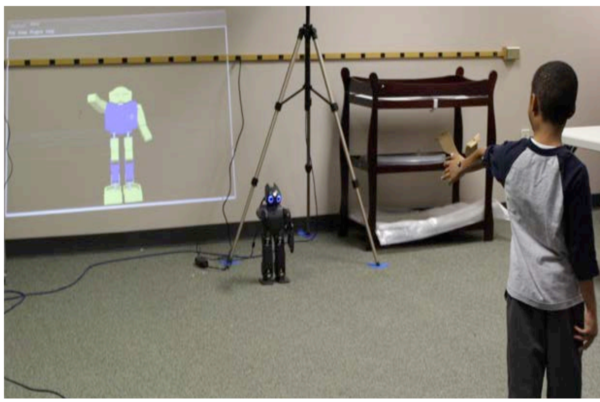
Child Movement Behavior

- Wide variation of movement profiles in children with CP
- Classify gross motor function using the Gross Motor Functional Classification System (GMFCS)

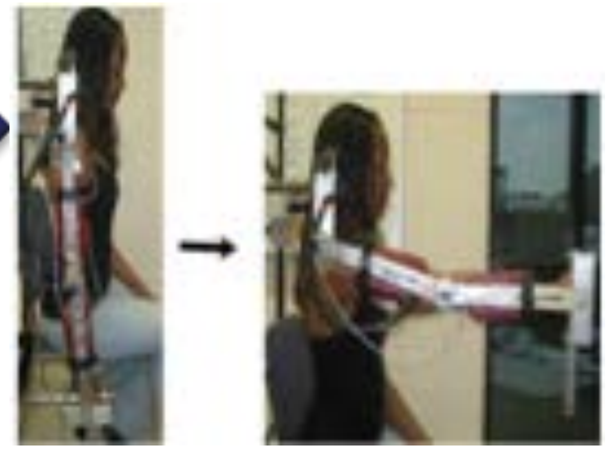
GMFCS II

GMFCS IV

The Objective and Challenge



Interactive and
Child-friendly

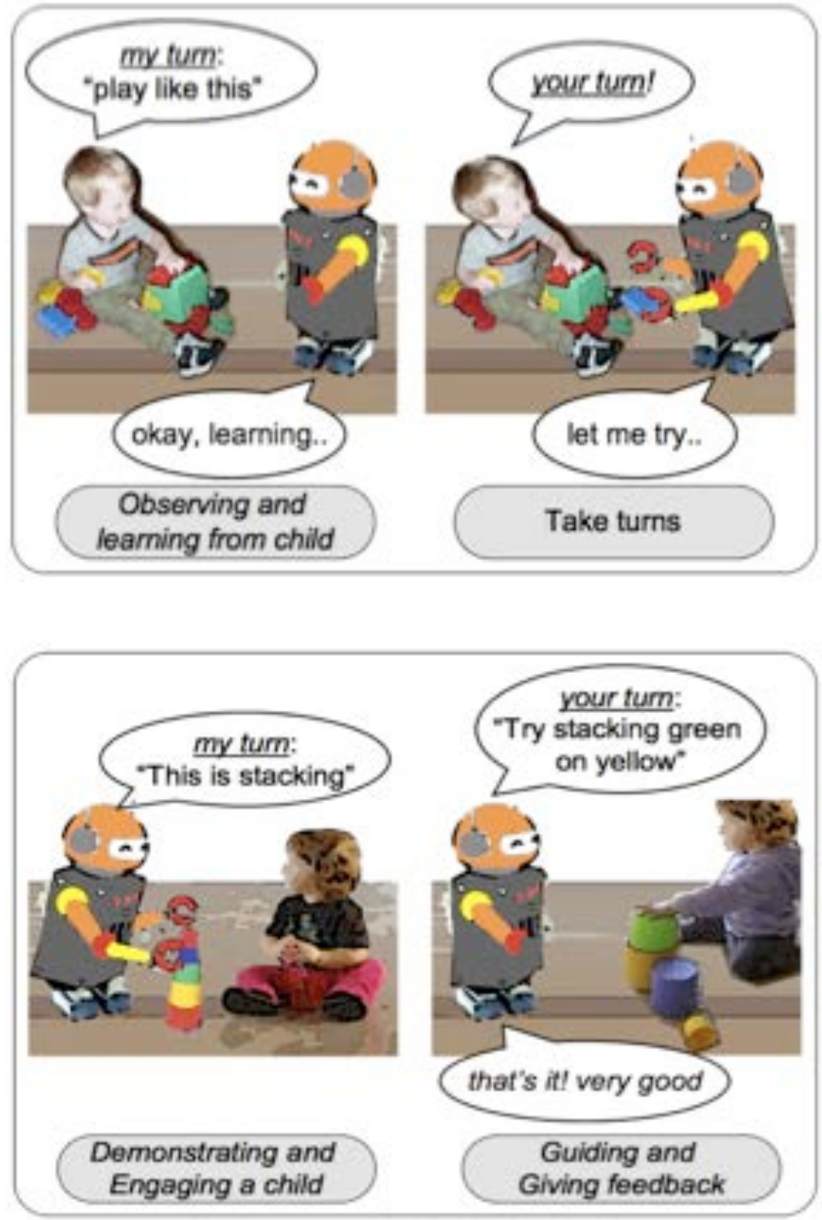


Repeatable and
quantifiable metrics

Addresses both physical and
cognitive needs of children

Exploring Play Therapy

- What has to be explored?
  - Understand, learn, participate in child's play
  - Produce turn-taking play strategies
  - Monitor the child's play and provide feedback
- Stage 1: Child-Led play
- Stage 2: Robot-Led play



The Play Scenario

- Physical and **Virtual**
- Therapy games (**virtual reality**, tablet-based, physical)
- Sensors (**Kinect**/Cameras/Wearable) used to evaluate users in real-time and in the comfort of their own homes
- **Robot designed as physical playmate**

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Virtual Reality Therapy Game

Physical Therapy Metrics

- To provide feedback to the clinician, need to quantify rehabilitation measures
- Kinematic Parameters:
  - Range of Motion
  - Deviation from Path
  - Path Length
  - Movement Time
  - Movement Smoothness
  - Average Movement Speed

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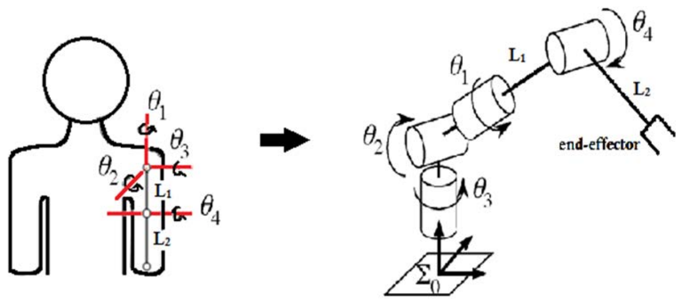
Kinematic Model

- Require a baseline for comparing measures with respect to a norm. We construct a **4 DOF model** that mimics the kinematics of the human arm.
- Generates an **optimal path** between two points in space as a function of:
  - User's arm's link lengths.
  - User's arm's initial pose.
  - Position of the target.



- Resulting trajectory is a curve that matches the **structure of the curve** generated by an individual's movements. [Morasso *et al.* 1981]

Baseline Validation

Typical baseline models created by collecting human data shows an error ranging from 13.8% to 66.7%

	Elbow ROM		Shoulder ROM	
Participants	**User [deg]**	**Error [%]**	**User [deg]**	**User [%]**
1	27.45	10.74	46.27	17.59
2	27.65	12.45	34.16	12.20
3	7.38	4.42	31.58	2.46
4	6.62	2.10	25.84	2.12
5	27.38	17.88	20.09	9.15
6	0.23	4.38	19.31	3.18
7	16.93	3.01	36.28	1.22
8	-	-	-	-
9	2.92	2.63	21.73	0.99
10	3.27	1.63	17.11	2.68
11	5.06	1.71	47.63	2.93
AVG		**6.10**		**5.45**
STD		**5.32**		**5.33**

*Missing values are due to corrupt data in the collection process.

Participant Pool	Typically Developing Children
No. of Participants	11 {6 females | 5 males}
Age Range [years]	8.87 ± 1.87

Baseline Validation

Elbow Range of Motion (EROM), Shoulder Range of Motion (SROM), Deviation from Path (DfL): ***Are the two baselines equivalent?***

	Parameters	Means [Human Model]	Means [Kinematic Model]	99.99% CI Bounds [±]
Right Arm	DfL $[10^{-3} m^2]$	27.86	32.03	9.62
	EROM [deg]	4.25	5.59	2.36
	SROM [deg]	27.57	29.03	4.02
	PL [mm]	346.84	289.83	42.63
Left Arm	DfL $[10^{-3} m^2]$	35.60	48.224	15.62
	EROM [deg]	5.48	6.09	2.90
	SROM [deg]	29.66	31.40	4.90
	PL [mm]	398.18	309.76	59.59

Participant Pool	Able-bodied Adults
No. of Participants	10 {6 females | 4 males}
Age Range [years]	24-31
General Description	Participants completed a 90° trajectory 10 times for each arm.

Effect Sizes ~ 0

CI Bounds:

$< 5°$ for EROM and SROM parameters.

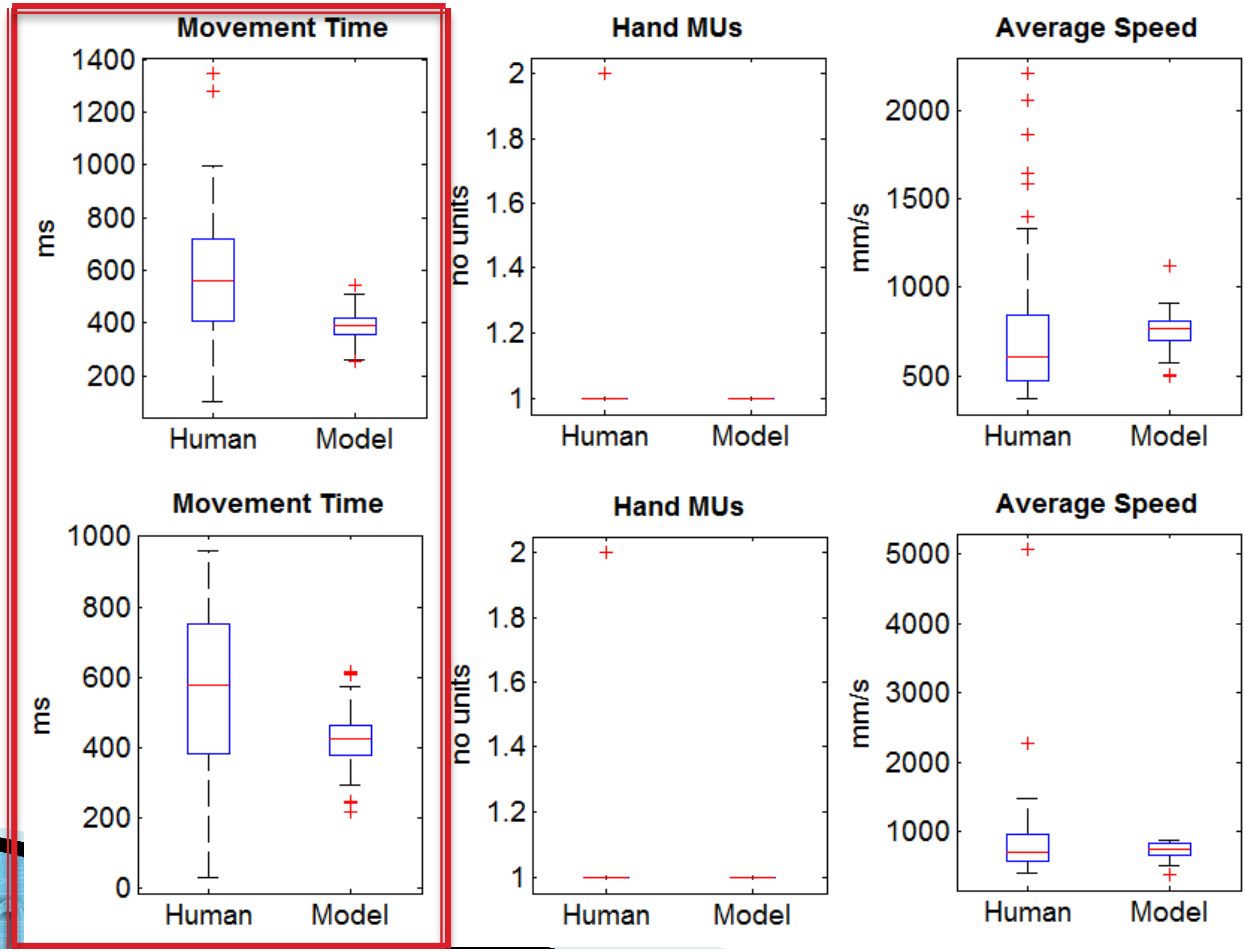
$\in [1, 15]\ 10^{-3}\ m^2$ for DfL parameter.

Baseline Validation

Movement Time, Movement Smoothness, Average Speed: ***Is the variability of the model lower or equivalent to the variability obtained from human data?***

RIGHT

LEFT



Pre–Clinical Trials I: Feasibility

Participant Pool	**Children with Cerebral Palsy**
No. of Participants	3 {3 females | 0 males}
Age Range [years]	9 ± 1.73
General Description	Received a 8-week VR intervention and were asked to maintain their regular physical therapy sessions.

Participant Pool	**Typically Developing Children**
No. of Participants	11 {6 females | 5 males}
Age Range [years]	8.87 ± 1.87
General Description	Played once and their outcome measures served as the 'norm' comparison.

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Pre–Clinical Trials I: Feasibility

Children with CP [AVG]	**PL [m]**	**MT [s]**	**MUs [no units]**	**AvgS [m/s]**	**EROM [deg]**	**SROM [deg]**
Pre-test	0.93	2.34	4.83	0.52	21.37	48.73
Mid-test	0.52	1.17	4.23	0.46	18.23	37.14
Post-test	0.42	0.97	2.52	0.82	17.93	24.31
TD Children [AVG]	0.43	0.80	2.23	0.61	16.25	35.49
TD Children [STD]	0.17	0.26	1.06	0.24	8.88	9.79

PL: Path Length
MT: Movement Time
MUs: Movement Units
AvgS: Average Hand Speed
EROM: Elbow Range of Motion
SROM: Shoulder Range of Motion

	Kinematic Parameters					
	PL	**MT**	**MUs**	**AvgS**	**EROM**	**SROM**
Pre-test	✓	✓	✓	✗	✗	✓
Mid-test	✗	✓	✓	✗	✗	✗
Post-test	✗	✗	✗	✗	✗	✗

✓: there is a statistical difference between the group of children with CP and without
✗: there is no statistically significant difference

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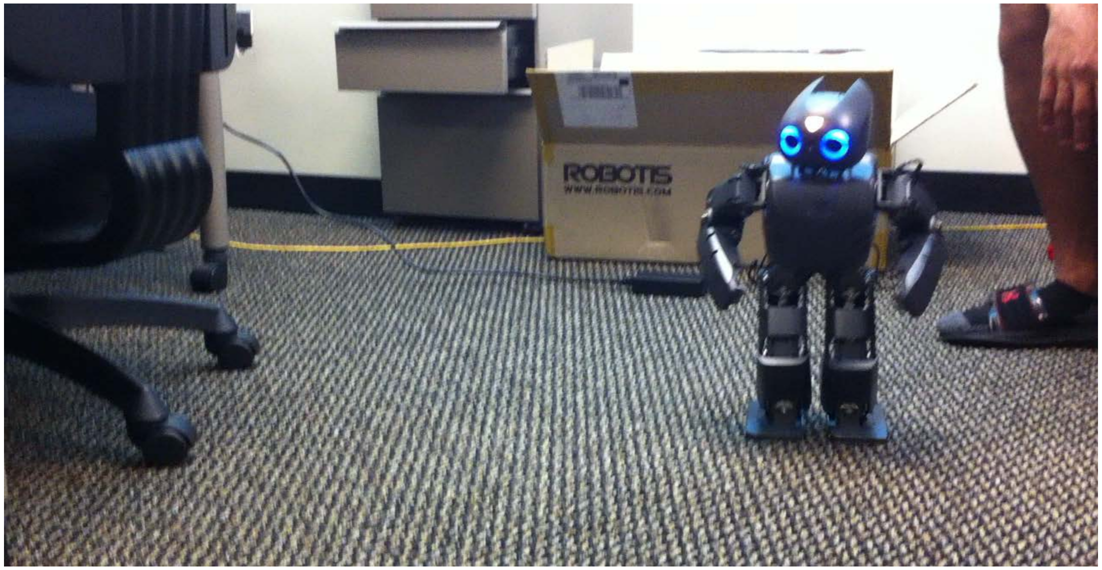
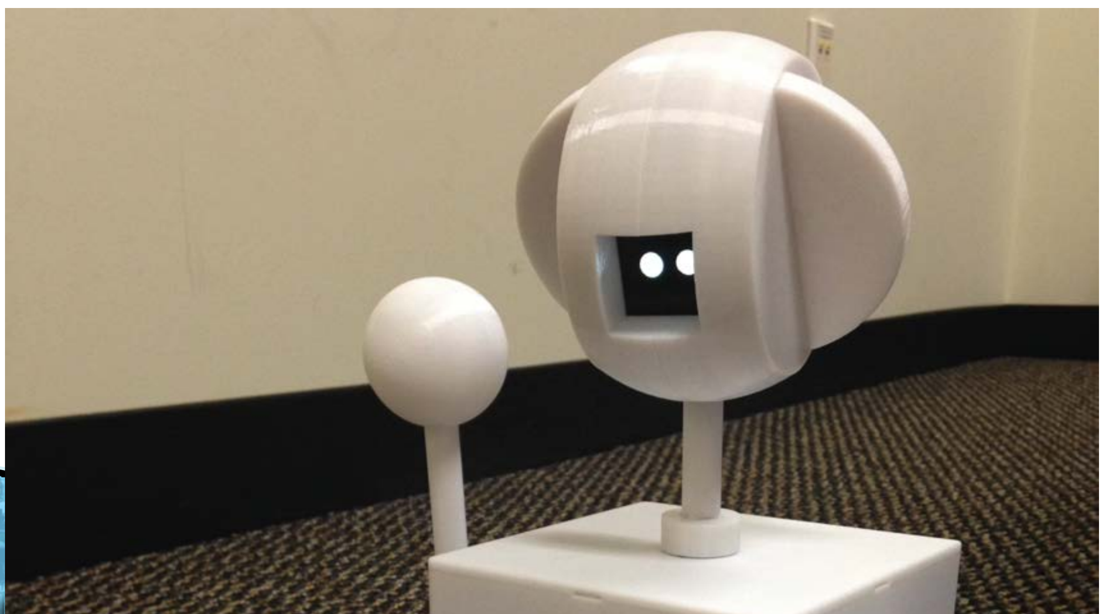
Pre-Clinical Trials I: Feasibility

Our virtual reality therapy game is a feasible technology for use with children with CP to collect desired reaching kinematics in their natural environment.

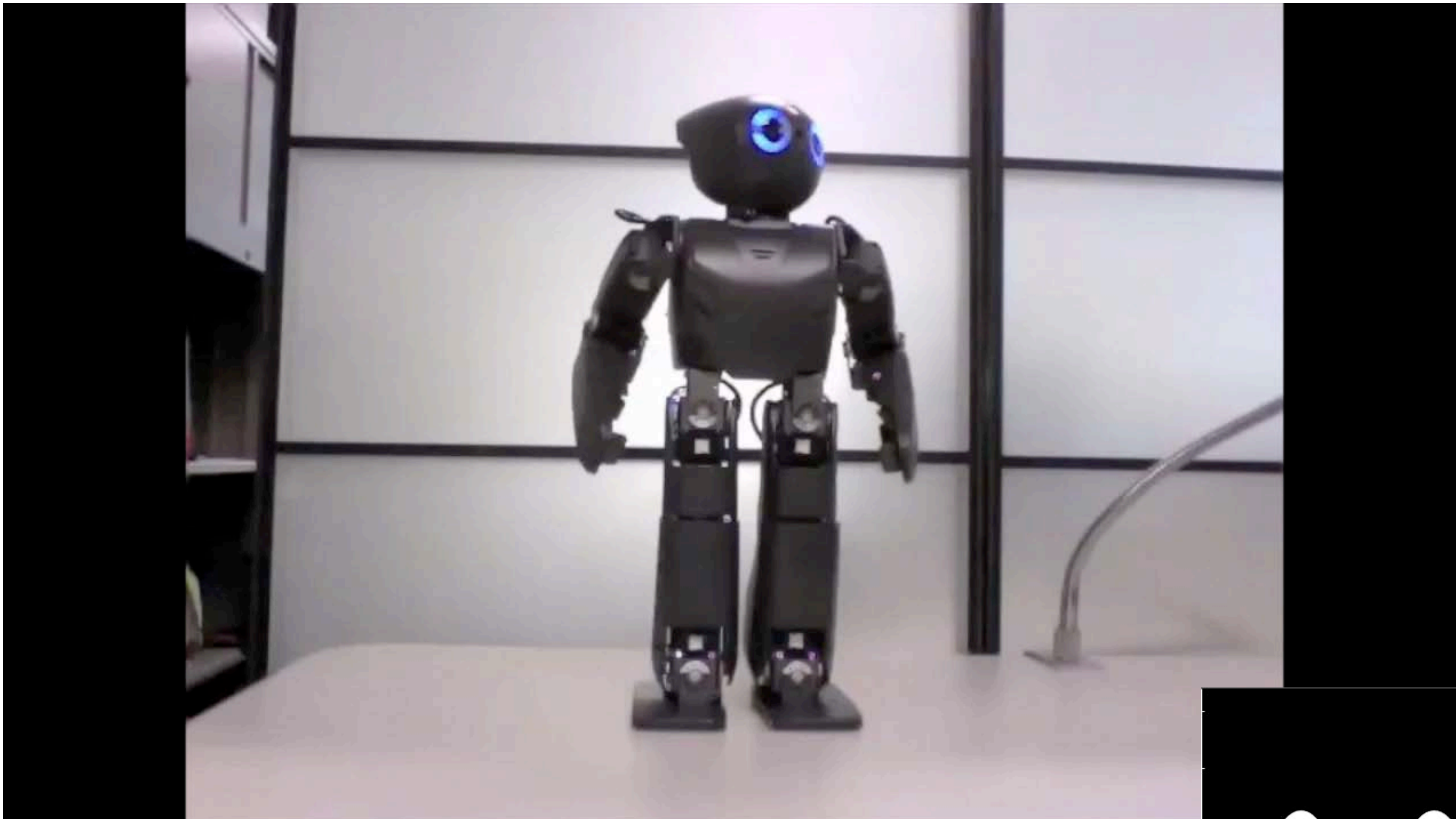
How do we incorporate the robot playmate for enhancing the feedback and motivation?

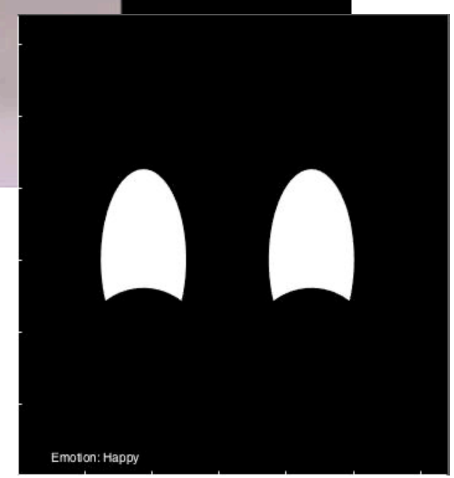
Interactive Robot Play Strategies





Behavioral Play Strategies: Nonverbal





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Interactive Robot Play Strategies

Child-Robot Interactive Play Therapy

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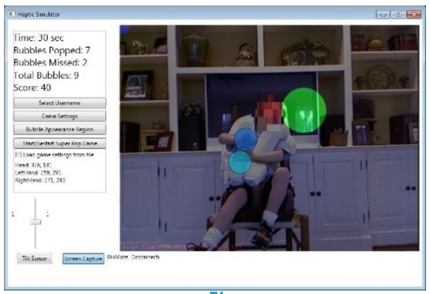
Pilot Study: Guiding Performance through Feedback

Phase 1



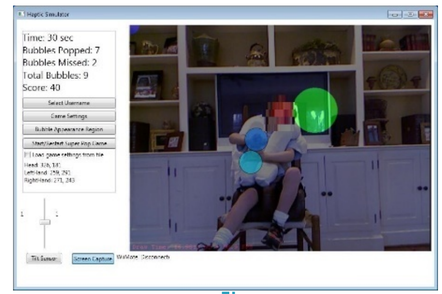
```
>> MTs.P1 =

    3.9830
    2.6968
    4.7250
    4.2565
    2.5051
    2.7809
    2.8523
    2.3855
    5.9580
    5.5834
    ...

>> avg.P1 =

    3.4875
```

Phase 2 (H_1)

```
>> TH = 0.8*avg.P1
      = 2.7900
```

"Move a little faster."

Phase 3 (H_2)



```
>> MTs.P3 =

    3.7872
    2.2598
    2.2895
    3.3632
    2.6043
    2.4635
    2.2424
    2.2807
    2.1325
    2.3900
    ...

>> avg.P3 =

    2.9849
```

Pilot Study: Guiding Performance through Feedback

Movement Time, MT	Verbal	Nonverbal
$MT > target$	*Keep up the good work. Move a little faster*	
$MT <= target$	*Fantastic. Let’s move at th exact same speed*	

Pilot Study: Guiding Performance through Feedback

Participant Pool	**Children with Cerebral Palsy**
No. of Participants	7 {4 females | 3 males}
Age Range [years]	9.86 ± 1.35
General Description	Participants completed a 90° trajectory 10 times for each arm.

Participant Pool	**Typically Developing Children**
No. of Participants	10 {7 females | 3 males}
Age Range [years]	9.60 ± 1.26
General Description	Participants completed a 90° trajectory 10 times for each arm.

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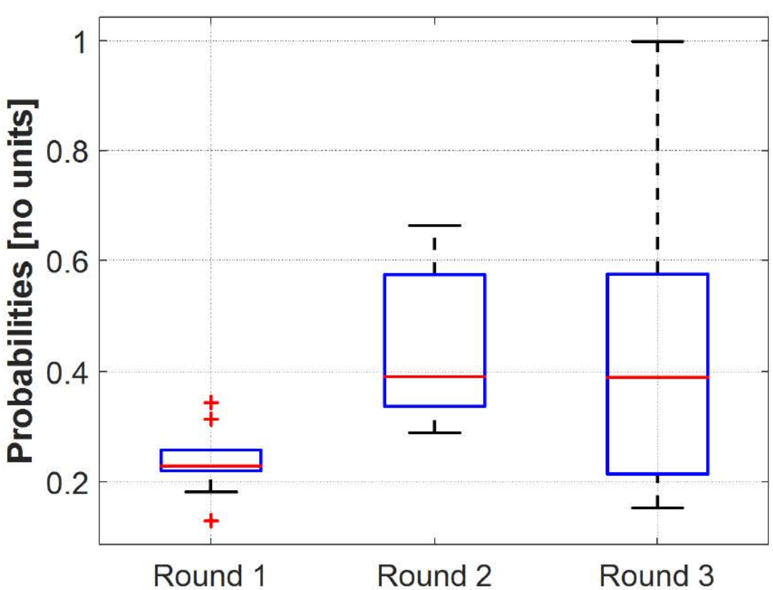
Pilot Study: Guiding Performance through Feedback

Central Limit Theorem: $X \sim N(\mu, \sigma)$

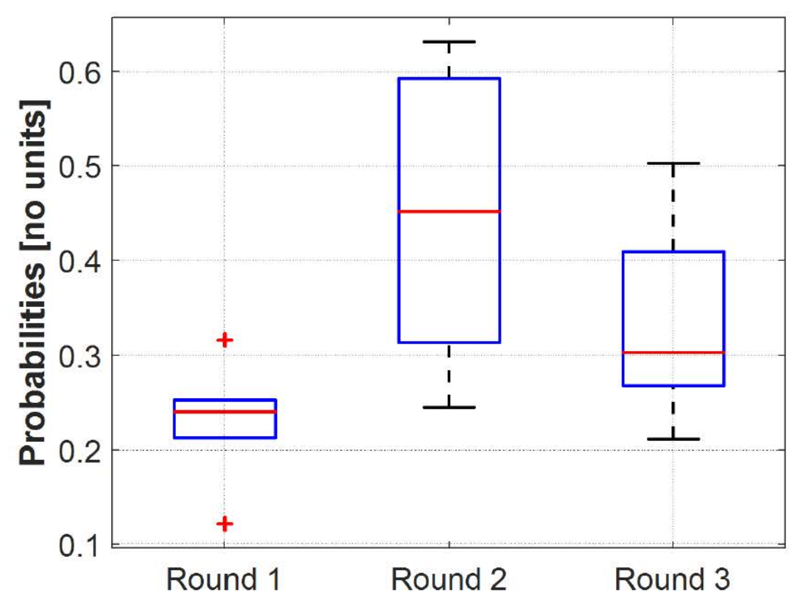
$$F_X(x) = P(X \leq x);\ x = MT_{TH}$$

$$F_X(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-t^2/2}\, dt$$

Typically Developing Children



Children with Cerebral Palsy

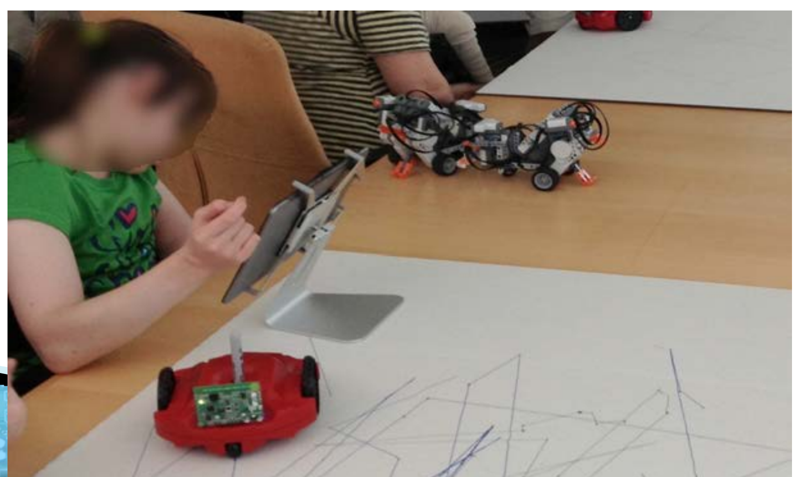


p-value $\leq$ 0.05

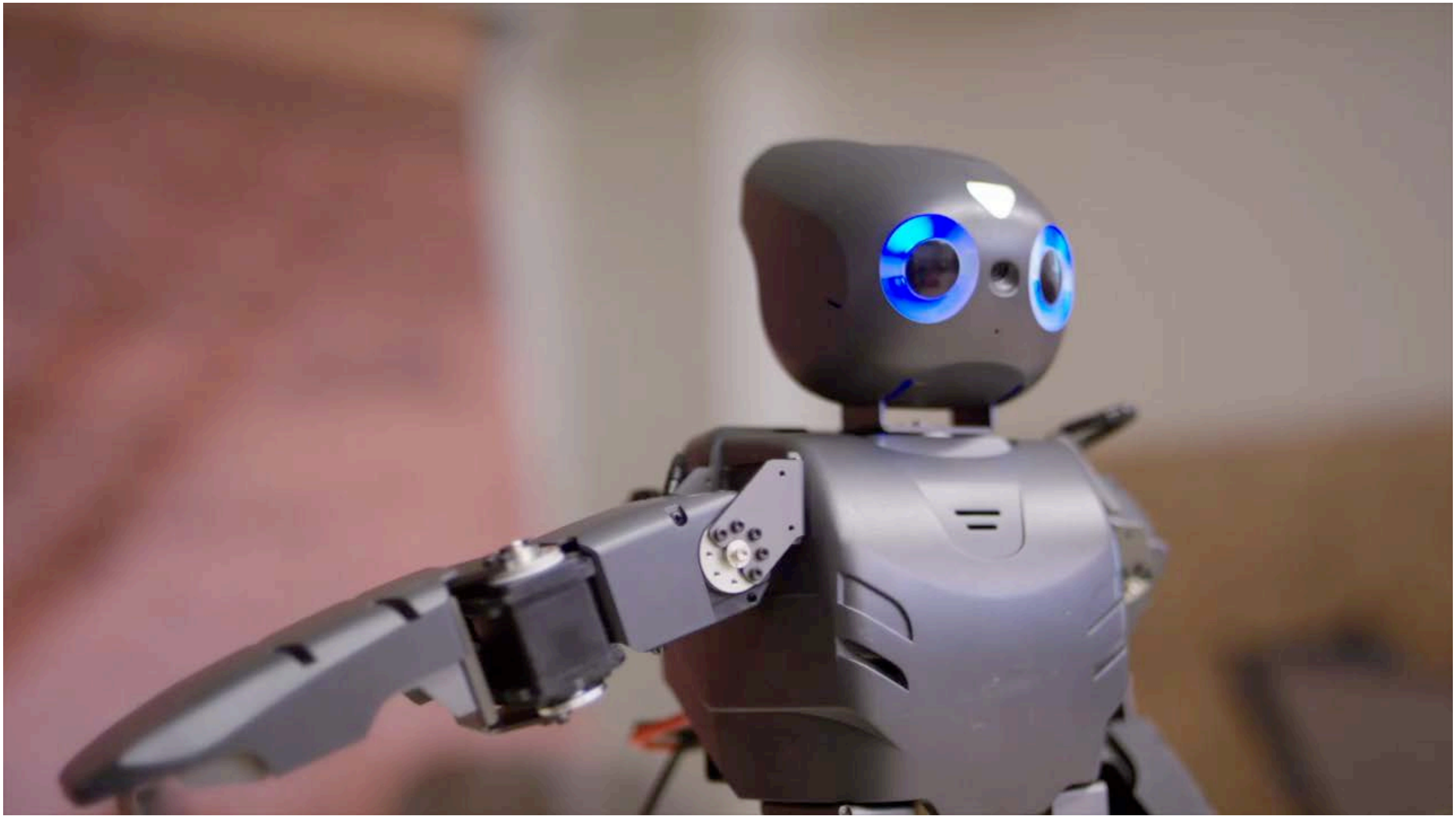
Robots and Children Can Play Together

Robot Camps for Children with Special Needs

- Designed an accessible robot programming interface for children with special needs that is adaptable to individual capability
- 12 camps (and running), > 140 children with differing abilities
- Disclosure: Technology licensed to Zyrobotics, GT-startup



From Research to Commercialization



Concluding Thoughts …

- As pediatric robotics becomes more advanced, how far can we push it? How far *should* we push it?

Since 1950, inventions have revolutionised the way we live. Radio, Telephones, Television, Computers, Washing Machines - we've come a long way. Whats the next big thing? Robots. Of course.

Thanks to My Grad Students and Collaborators

- Dr. Yi-Ping Chen, GSU (Physical Therapist Co-I)
- Dr. Hae Won Park, MIT (former student)
- Dr. LaVonda Brown, Emory University (former student)
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- Dr. Barbara Weissman & Dr. Jamika Hallman-Cooper, Children's Healthcare of Atlanta/Emory
- Lekotek of Georgia & Atlanta-Based Play Clinics

Atlanta Clinical & Translational Science Institute

NSF

GRAMMY FOUNDATION®

Atlantic Pediatric Device Consortium
Devices That Grow As Children Grow

Georgia Tech IPaT

Children's Healthcare of Atlanta

Thank you!

Human Automation Systems Lab

Georgia Institute of Technology

humanslab.ece.gatech.edu

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