Pediatric Robotics – A Journey from the Lab to a Child’s Home

Session #56, February 12, 2019

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InterSystems
Health | Business | Government

Agenda

- Problem Statement
- Overview of Healthcare Robotics
- Motivation for Pediatric Robotics
- Presentation of the Pediatric Robotic System
- Results from Pre-Clinical Studies
- Concluding Remarks
- Q&A

Learning Objectives

- Discuss the role of robotics and related technologies for pediatric therapy
- Illustrate challenges to enable successful interaction between patients, clinicians, and robots
- Describe technologies to address real-life therapy goals for children with special needs
- Evaluate methods for improving the rehabilitation outcomes of children
- Discuss artificial intelligence methods to endow robots with the ability to playfully interact with the child

About Disabilities

Disability … the state of being limited, due to a chronic mental or physical health condition, in the type or amount of normative activities that a person is expected to perform.

In countries with life expectancies > 70 years of age, individuals will spend ~8 years of their life span, living with a disability.

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150 MILLION

CHILDREN WITH DISABILITIES WORLDWIDE

$1.6 BILLION

U.S. PEDIATRIC REHABILITATION INDUSTRY

15%

of the world's population live with a disability

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Robots to Enable Us

1965: GE Hardiman 1

ReWalk - http://rewalk.com, today

Robots to Augment Us

1867: Samuel Decker
https://twentytwowords.com/civil-war-veterans-ingenious-self-designed-mechanical-arms-3-pictures/

DEKA, Rehabilitation Institute of Chicago

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Robots Controlled by Us

University of Pittsburgh, 2012

University of Pittsburgh, 2008

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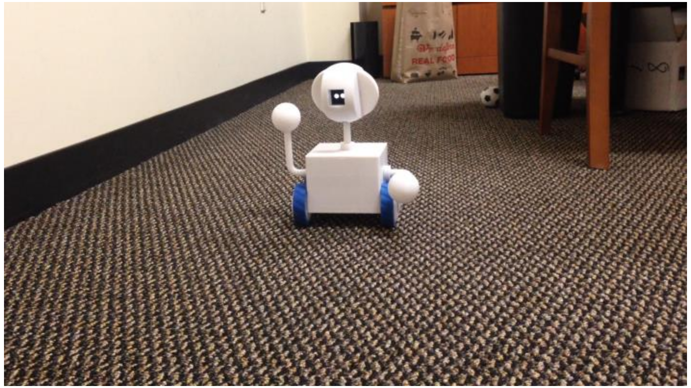
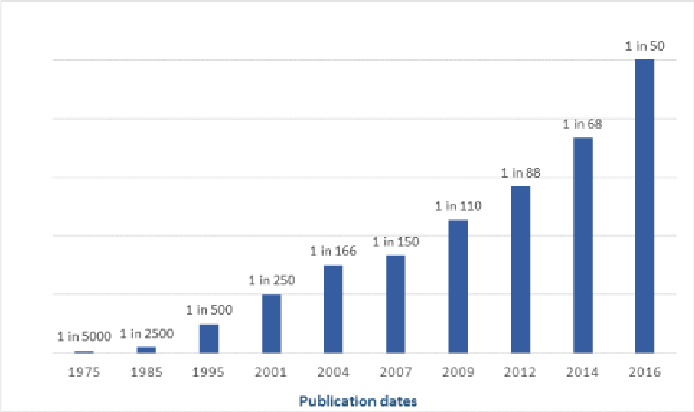
Why Robots for Pediatrics?

- Most children, including children with disabilities, are attracted to robots.
- This natural affinity can be exploited, and the robot used as an interactive motivator through repetitive and predictable interaction.

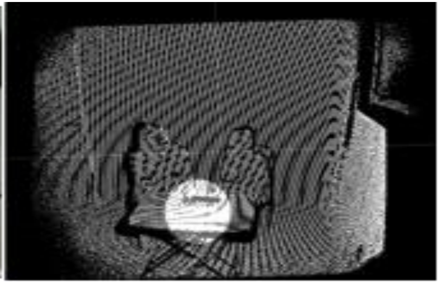


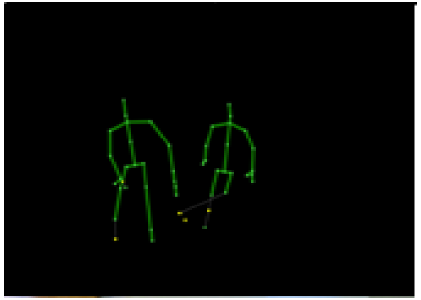
1:323 U.S. CHILDREN WITH CEREBRAL PALSY

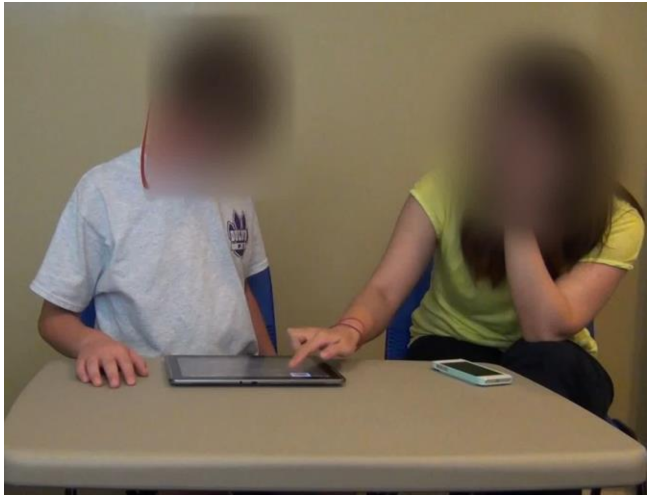


Statistics of changes in Autism Spectrum Disorder (ASD) occurrence over the past three decades (USA)

Physiotherapy Sessions







Ge, Park, Howard, “Identifying Engagement from Joint Kinematics Data for Robot Therapy Prompt Interventions for Children with Autism Spectrum Disorder,” *ICSR*, 2016.

Challenge: Child Movement Behavior

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

GMFCS II

GMFCS IV

Challenge: 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

Fry, Chen, Howard, "Detection of Infant Motor Activity During Spontaneous Kicking Movements for Term and Preterm Infants Using Inertial Sensors," *IEEE EMBC*, July 2018.

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From Child-Clinician to Child-Robot Interaction

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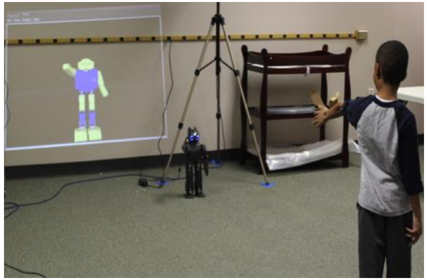
Robot-Assisted Therapy System

Gamified Therapy

Assistive Technology



Robot Therapy Coach

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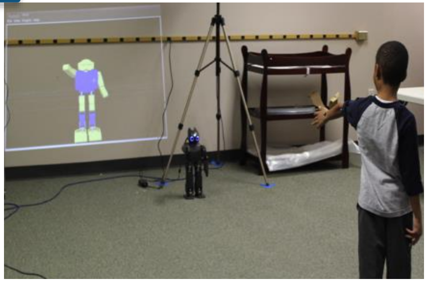
Robot-Assisted Therapy System

Gamified Therapy

Assistive Technology



Robot Therapy Coach

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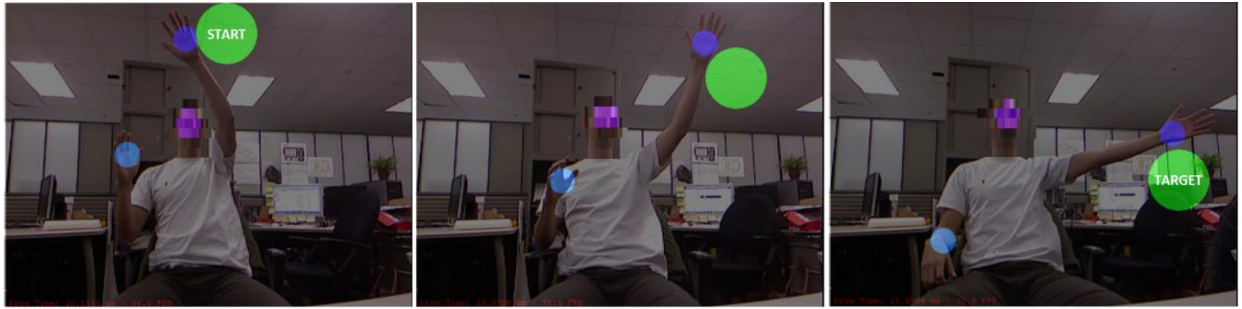
Virtual Reality Therapy Game



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Tablet-Based Therapy Games

zyrobotics.com

- Many clinicians use cause-and-effect mobile apps since this concept is an important step in a child’s developmental process
- Purposeful movement across space will not occur until a child with special needs understands this concept of cause-and-effect

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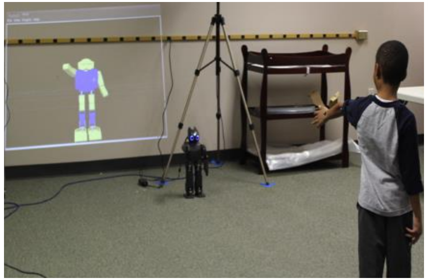
Robot-Assisted Therapy System

Gamified Therapy

Assistive Technology



Robot Therapy Coach

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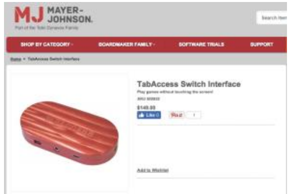
The First Input (AT) Device



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Expanding Market Size (The Pivot)

- Needed device to engage younger children
- Needed a larger customer base to reduce production costs

Physical Therapy Metrics

- To provide feedback to the clinician, need to quantify rehabilitation measures
- Peabody Developmental Motor Scales – used to assess gross and fine motor skills
- Kinematic Parameters:
  - Range of Motion
  - Deviation from Path
  - Path Length
  - Movement Time
  - Movement Smoothness
  - Average Movement Speed

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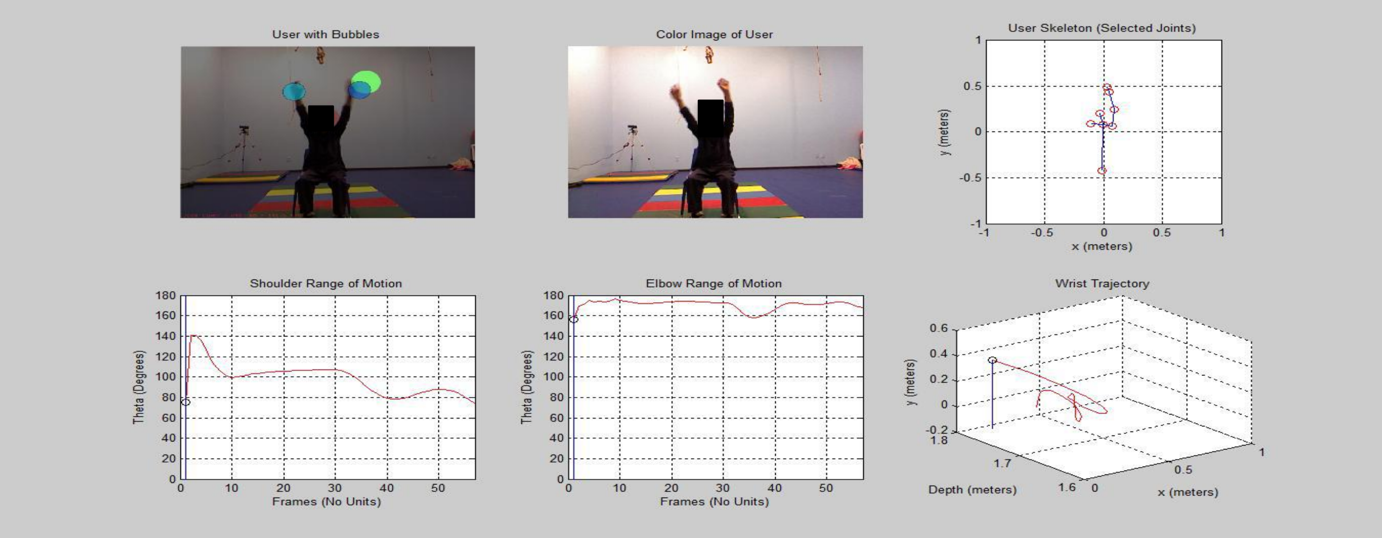
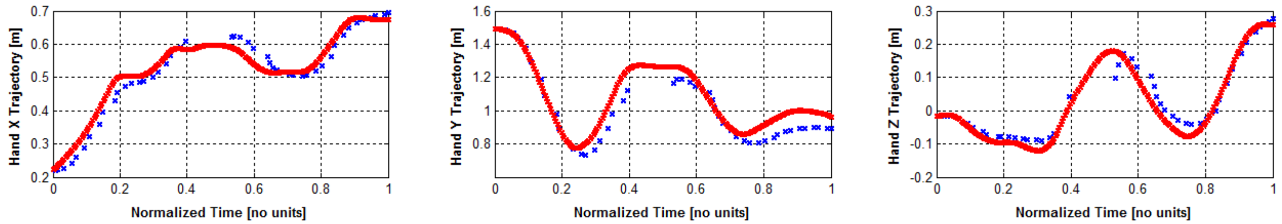
Quantifying Movements





Accuracy wrt ground truth: ROM ∈ [5, 7]% Path Length ∈ [10.5, 12.5]%

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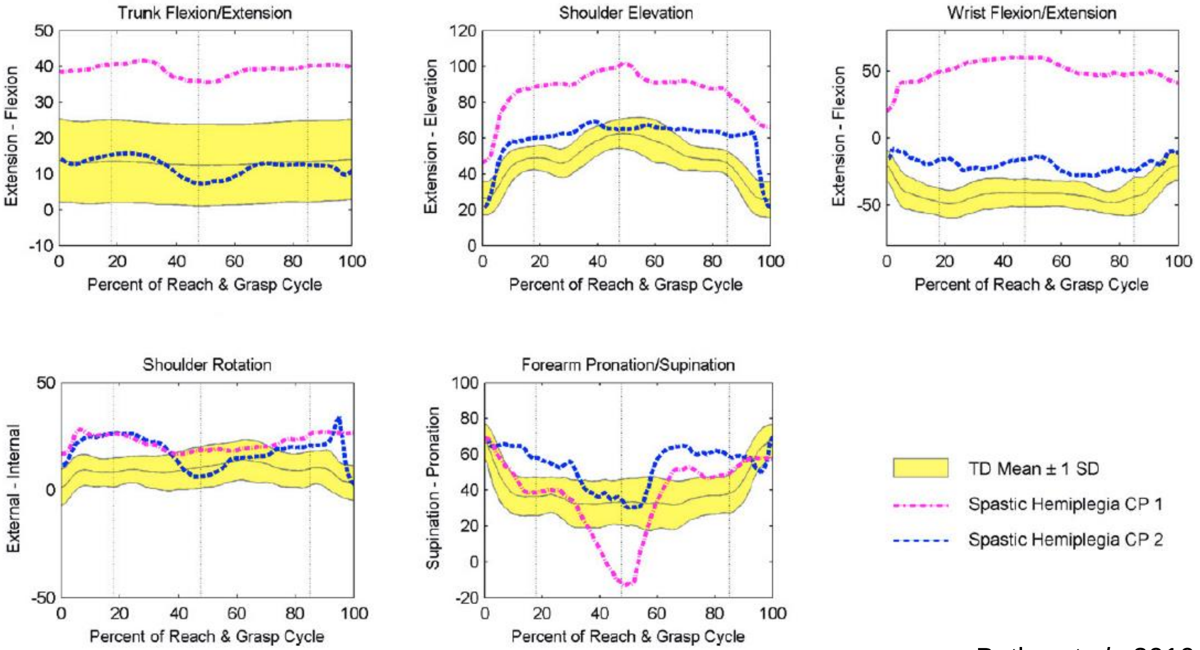
Importance of Baselines

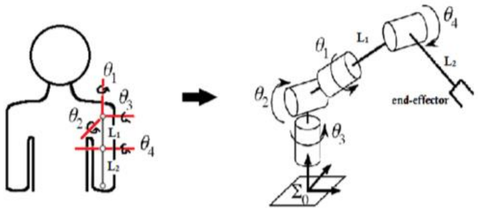


c. o. Butler *et al.* 2010

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

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.

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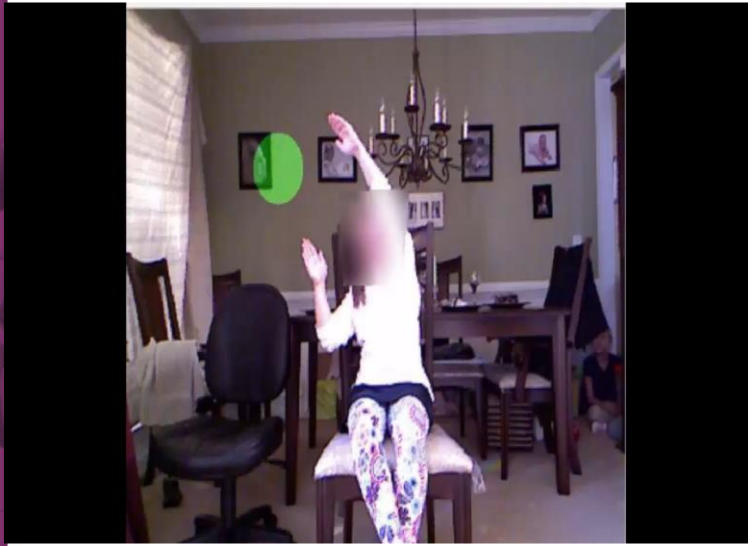
Children with Typical Development

Bent elbow



Popped with “wrong” hand

HumAnS Lab

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

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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 games provide a feasible method for use with children with movement disorders to collect desired reaching kinematics in their natural environment.

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

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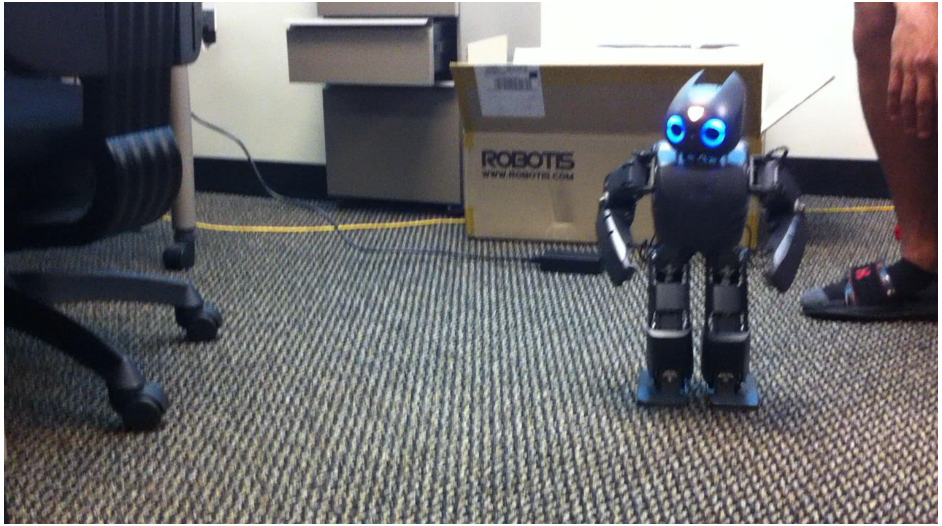
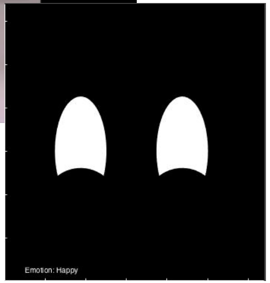
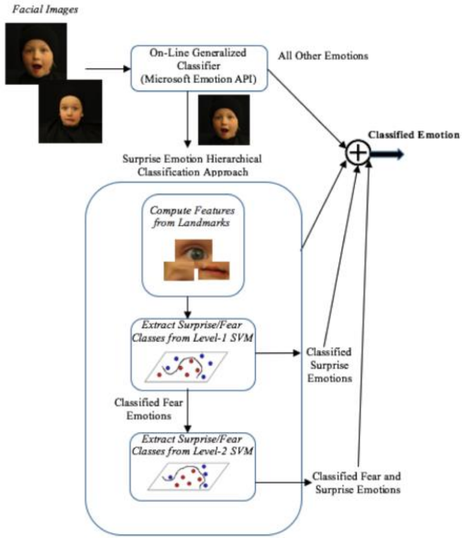
Interactive Robot Play Strategies



Robot Coach: Engagement Strategies





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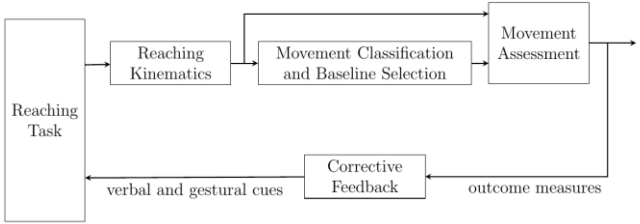
Mimicking Physiotherapy Sessions



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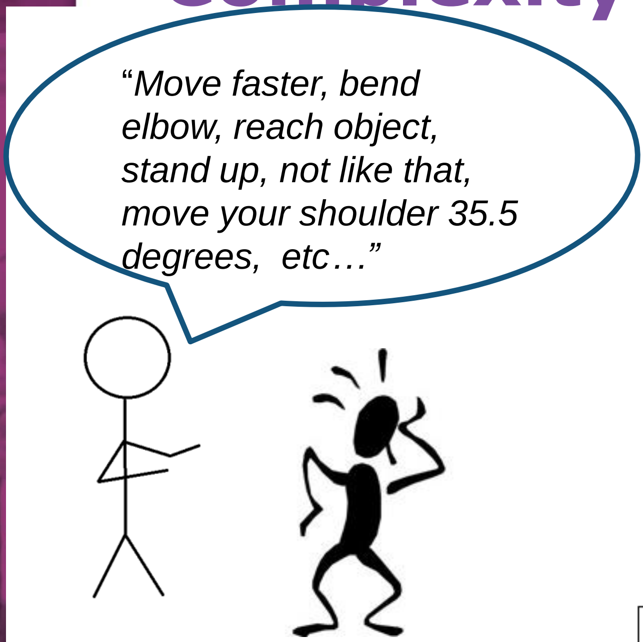
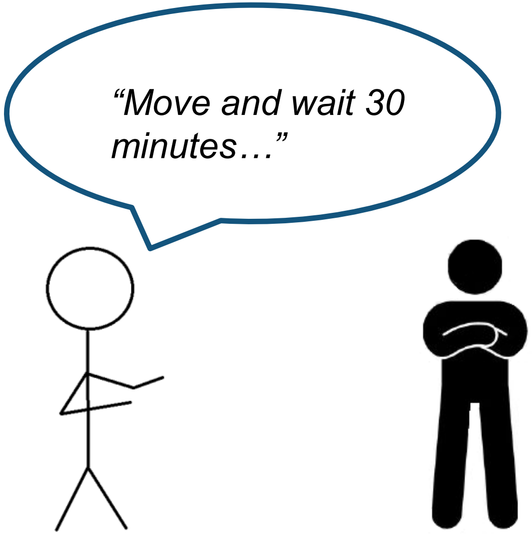
Complexity of Feedback Cues





Movement Time, MT	Verbal	Nonverbal
$MT > target$	"Great job. Move a little faster like this..."	
$MT < target$	"Great job. Move a little slower like this..."	
$MT = target$	"Fantastic."	

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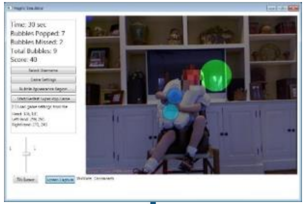
Pilot Study: Guiding Performance through Feedback

Phase 1



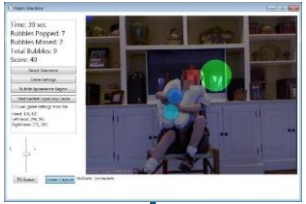
```
>> MTs.P1 =

   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
```

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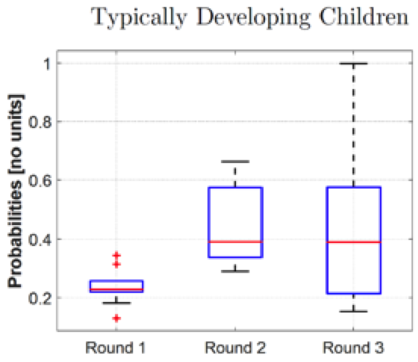
Pilot Study: Guiding Performance through Feedback

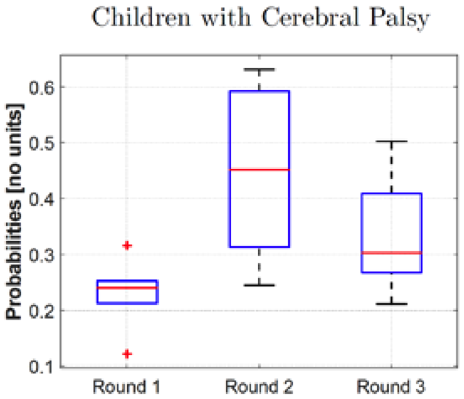
Table 1. Characteristics of children with and without CP that participated in this study.

id	Diagnosis	Age	GMFCS	MACS	More affected or non-dominant side	Gender
C1	R spastic hemiplegia	11	I	II	Right	F
C2	Spastic diplegia	8	III	II	Right	M
C3	Spastic diplegia	9	III	III	Left	M
C4	L spastic hemiplegia	12	I	I	Left	F
C5	R spastic hemiplegia	10	I	III	Right	F
C6	R spastic hemiplegia	9	I	II	Right	F
C7	L spastic hemiplegia	10	I	II	Left	M
T1	Typical	8	N/A	N/A	Left	F
T2	Typical	8	N/A	N/A	Left	F
T3	Typical	11	N/A	N/A	Left	M
T4	Typical	9	N/A	N/A	Left	F
T5	Typical	8	N/A	N/A	Left	M
T6	Typical	10	N/A	N/A	Left	F
T7	Typical	11	N/A	N/A	Left	F
T8	Typical	10	N/A	N/A	Left	F
T9	Typical	10	N/A	N/A	Left	F
T10	Typical	11	N/A	N/A	Left	M

GMFCS: Gross Motor Function Classification System
MACS: Manual Ability Classification System.

$p\text{-value} \leq 0.05$





Chen, García-Vergara, Howard, "Effect of feedback from a socially interactive humanoid robot on reaching kinematics in children with and without cerebral palsy," *Developmental Neurorehabilitation*, 2017.

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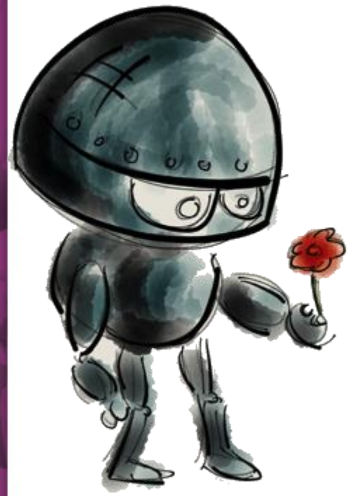
But, there's a Little Problem



Humans are Trusting

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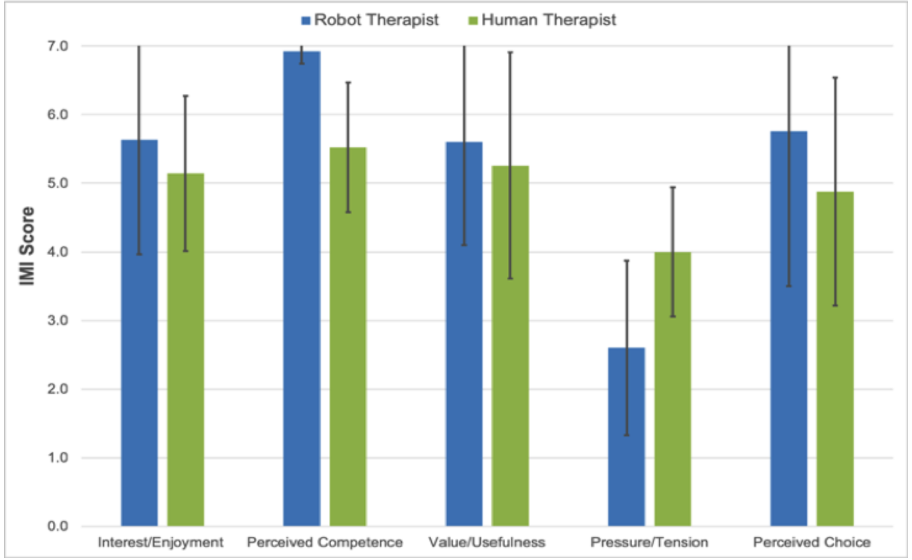
Trust Assessment

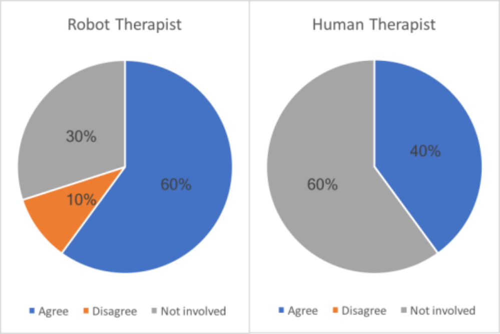
Children
10 {3 females | 7 males}
Mean Age: 5.93



Xu, Bryant, Howard, "Would You Trust a Robot Therapist? Validating the Equivalency of Trust in Human-Robot Healthcare Scenarios," IEEE Int. Symp. on Robot and Human Interactive Communication, Nanjing, China, August 2018.

Trust Assessment

Adults
20 {11 females | 9 males}
17 to 26 yeas old



"I trusted the robot/therapist when I made my choice to follow guidance or not follow guidance from the robot."

	% choose to follow guidance from the therapist		
	Yes	*No*	N/A
Robot	80%	20%	
Human	90%	10%	
	% trusted the therapist when decision was made		
	Agree	*Disagree*	*Not involved*
Robot	60%	10%	30%
Human	40%	0%	60%
	% willing to follow the therapist's guidance next time		
	Agree	*Disagree*	*Not involved*
Robot	70%	10%	20%
Human	80%	10%	10%

Therapist condition has a medium-sized effect (r = 0.35) on trust in participants

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Next Steps …

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

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Robots and Children can Play Together

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?

- Ask questions. Hear experts discuss the major issues impacting computing and the world.
- Available on iTunes and Spotify – search “The Interaction Hour”

Remember to complete online session evaluation