Rehabilitation Technology to Improve Motor Function in Children with Cerebral Palsy

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Outline

- **Part I – Robot-Assisted Gait Training in Children with Cerebral Palsy**

  Several research groups have explored the use of robotics to facilitate gait training in children with CP. However, the variability in intervention outcomes demands that we improve our understanding of the processes by which children with CP learn how to walk.

- **Part II – Assessing Intervention Outcomes Using Mobile Health Technology**

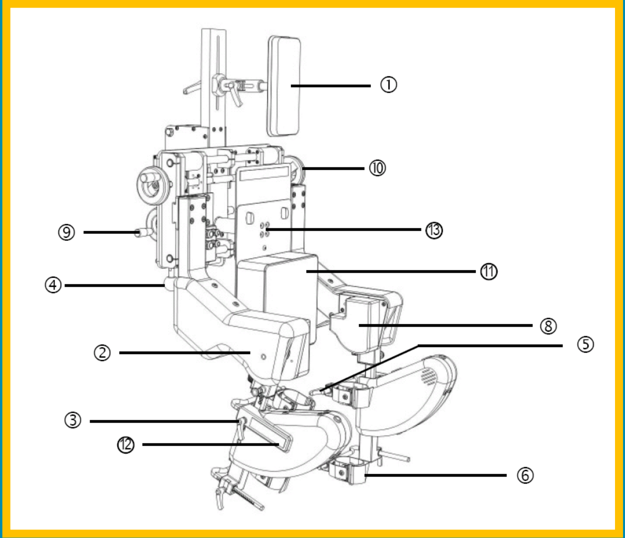
  Advances in miniature sensor technology and communications have led to the development of systems that allow one to monitor intervention outcomes in the home and community settings.

Part I: Robot-Assisted Gait Training in Children with Cerebral Palsy

Gait Training in Children with Cerebral Palsy

Treadmill training with bodyweight support and a driven gait orthosis:

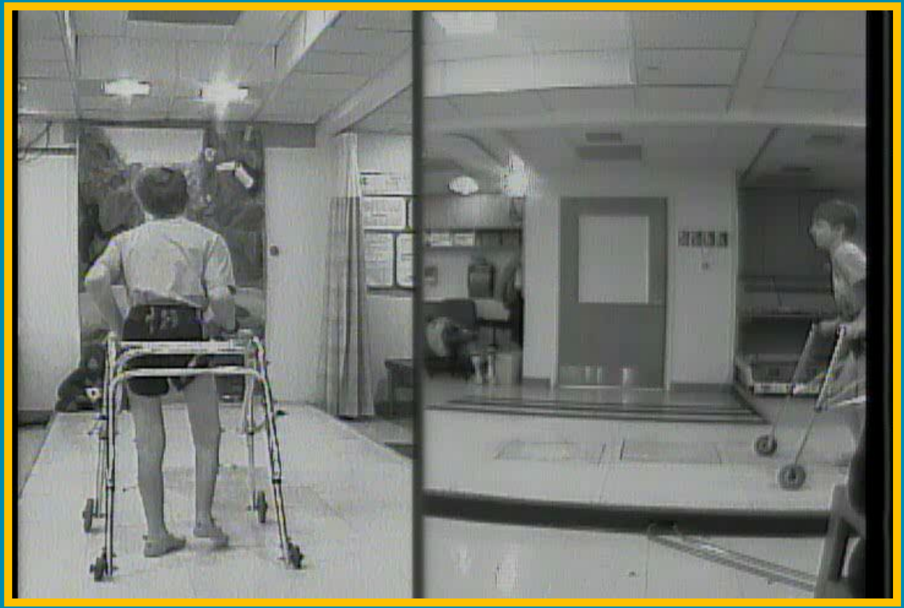
- Meyer-Heim et al. (2007)
- Meyer-Heim et al. (2009)

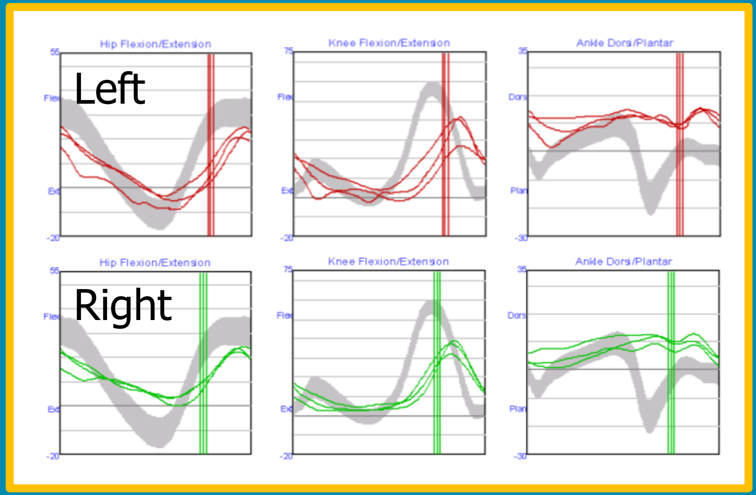


Pediatric Lokomat, Hocoma AG

Meyer-Heim et al. (2007)

The Need for Gait Training in Children with CP…





The need for addressing motor impairments and functional limitations in the pediatric population is obvious.

A number of conditions (e.g. cerebral palsy) are associated with a decreased ability to perform motor activities such as walking, stair climbing, arm reaching, and objects manipulation.

What Can We Infer from Animal Experiments?

Courtesy of James Fawcett, Cambridge University, Centre for Brain Repair

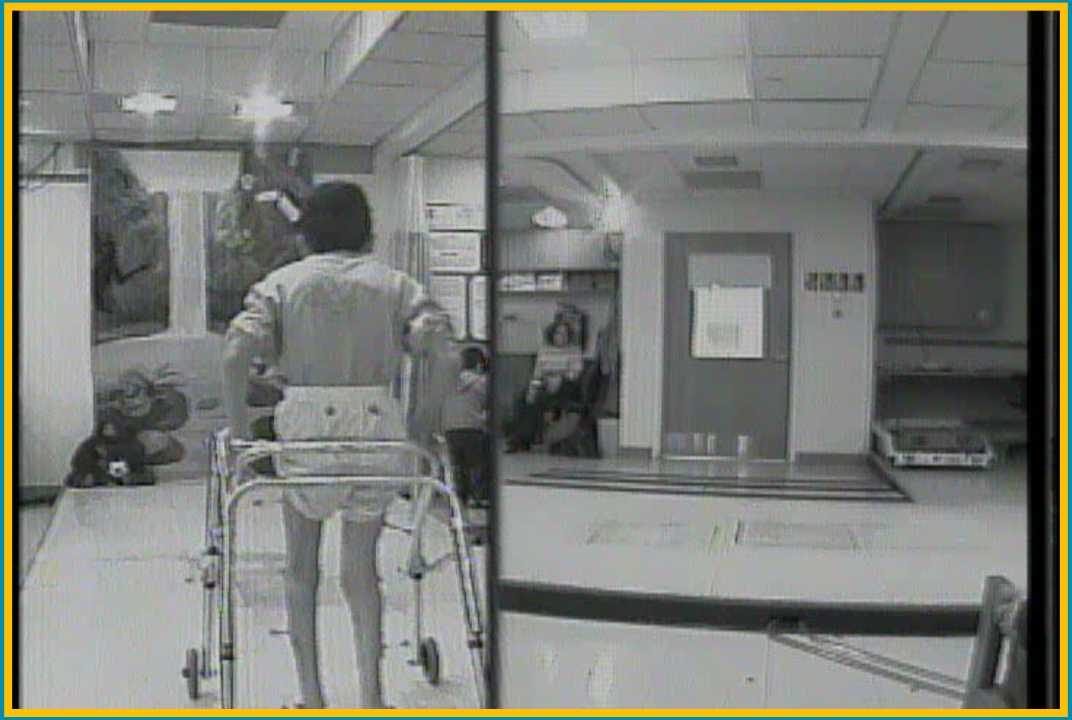
Experiments show that animals in which a CNS lesion has been induced recover better if they are exposed to a stimulating environment vs. a control environment in which they receive no stimulation. In other terms, “more of movement” is better than “less movement”.

What Can We Infer from Animal Experiments?

Courtesy of James Fawcett, Cambridge University, Centre for Brain Repair

Experiments show that recovery of motor function is “specific”. For instance, when training animals after inducing a stroke, results are better if the task used for training mimics somehow the task one wants the animal to “get better at”.

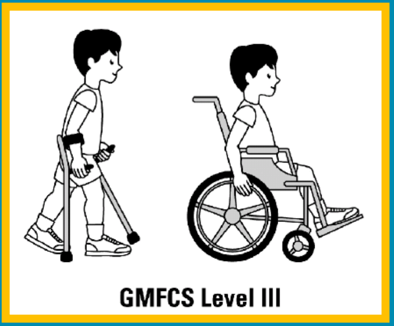
Is Exercise Prescription Good Enough?



When impairments and functional limitations are severe only limited improvements are possible with an "exercise prescription". The subject has to be provided with "error feedback" if one wants to achieve improvements in motor patterns.

Subjects

- 20 subjects (12 boys, 8 girls)
- Mean age 9.3 years (range 5-13 years)
  - diagnosis of spastic diplegia due to cerebral palsy
  - ambulatory but have difficulty walking
  - ability to walk 50’ (with an assistive device)
  - medically stable



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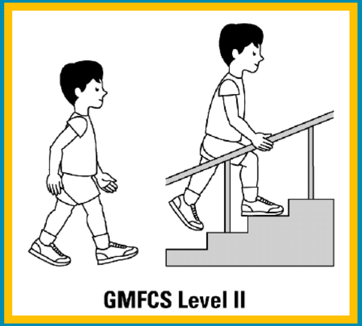

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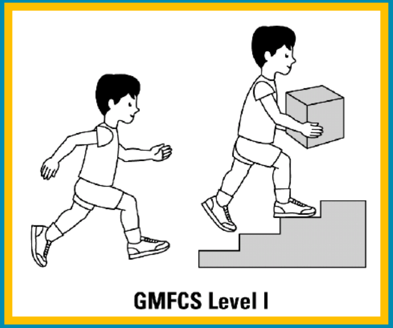


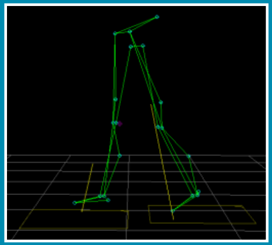
n = 2

Protocol

PRE-EVAL

1 week

PT evaluation
GMFM D & E
10m walk
6min walk



Gait analysis

GAIT TRAINING

6 weeks

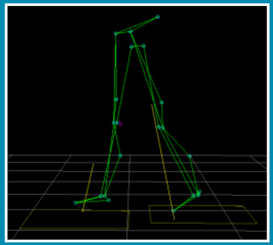
18 sessions

3 x 1 hr sessions/week 30 min walking/session 3 x 10 min

POST-EVAL

1 week

PT evaluation
GMFM D & E
10m walk
6min walk

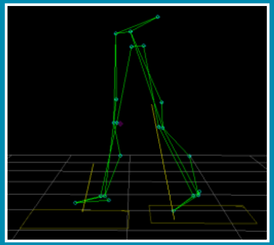


Gait analysis

FOLLOW-UP

3 months

PT evaluation
GMFM D & E
10m walk
6min walk

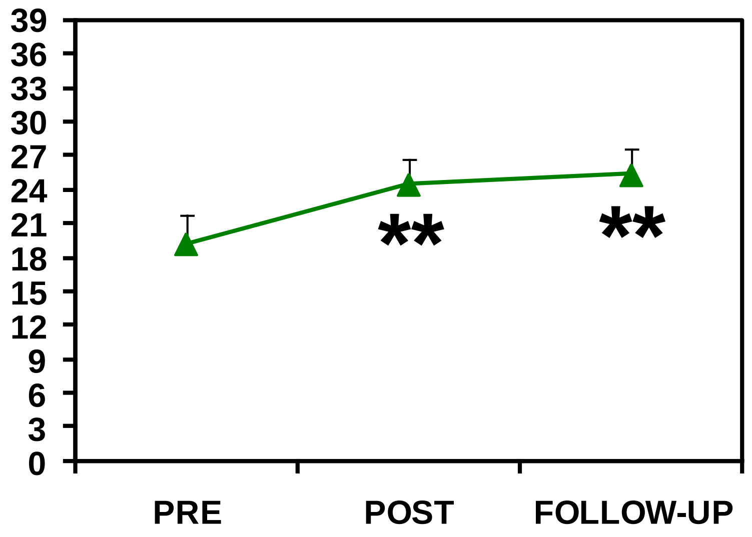


Gait analysis

No targeted gait training or anti-spastic medication

Clinical Measures

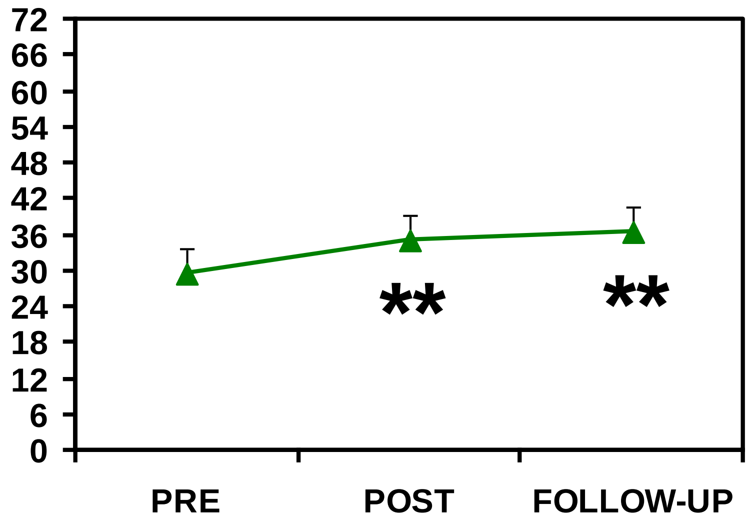
Standing Function
GMFM Item D



pre x post: 27% increase

pre x follow-up: 32% increase

Walking Function
GMFM Item E



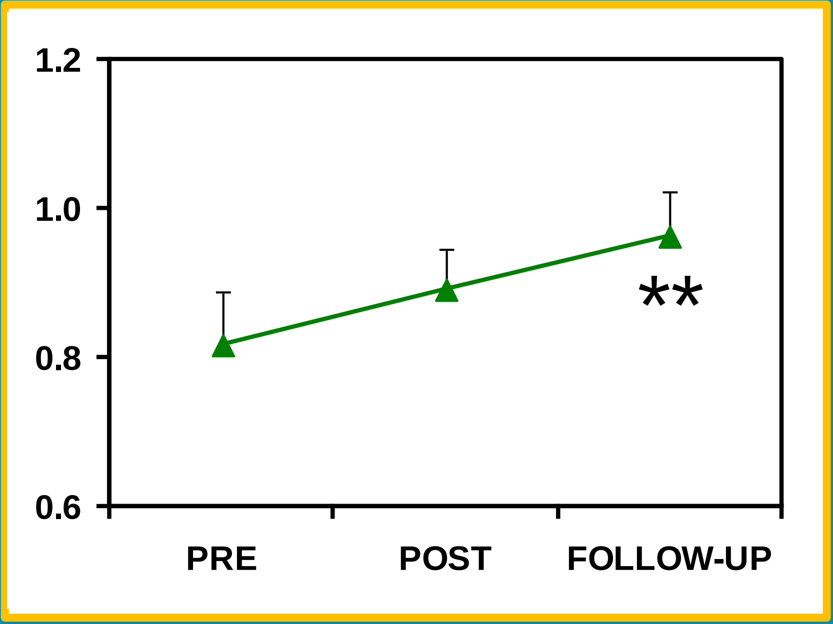
pre x post: 18% increase

pre x follow-up: 24% increase

Clinical Measures

Walking Speed (m/s)

10m Walk Test

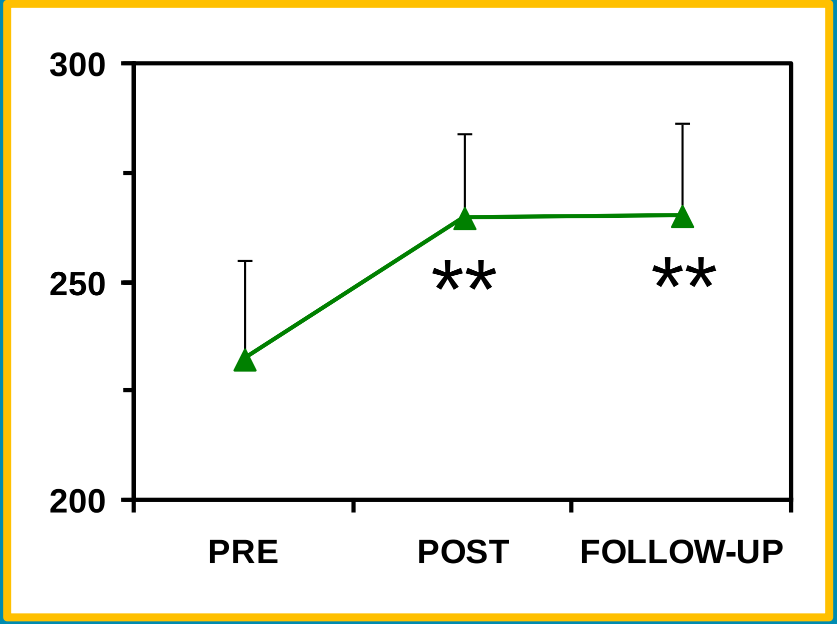


pre x post: 9% increase

pre x follow-up: 18% increase

Walking Endurance (m)

6 min Walk Test

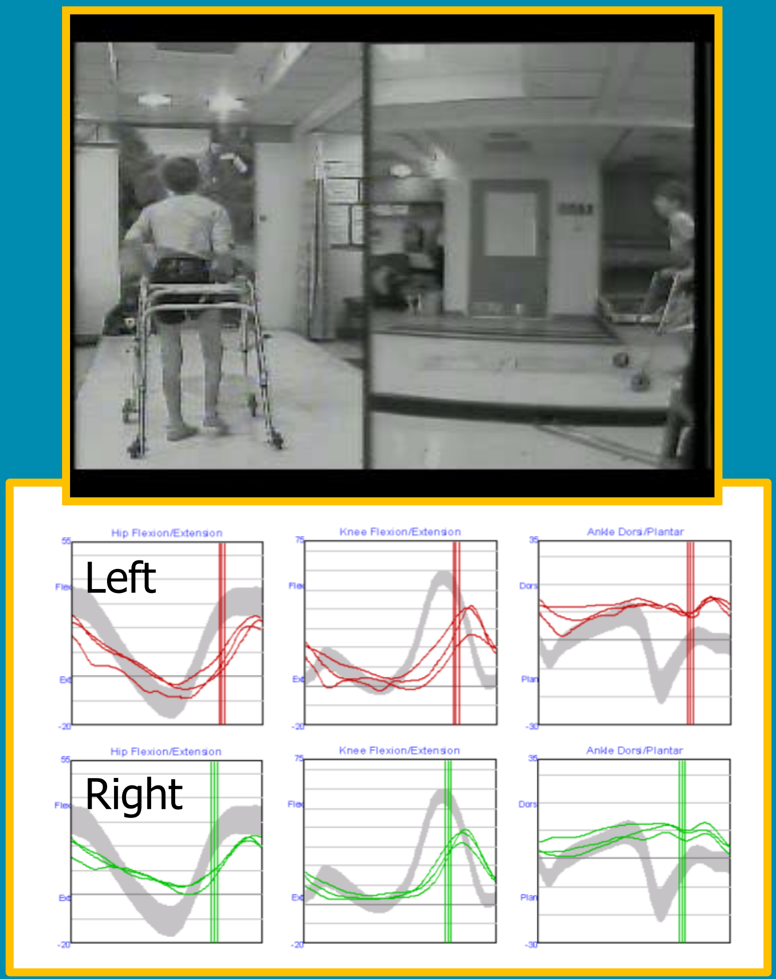


pre x post: 14% increase

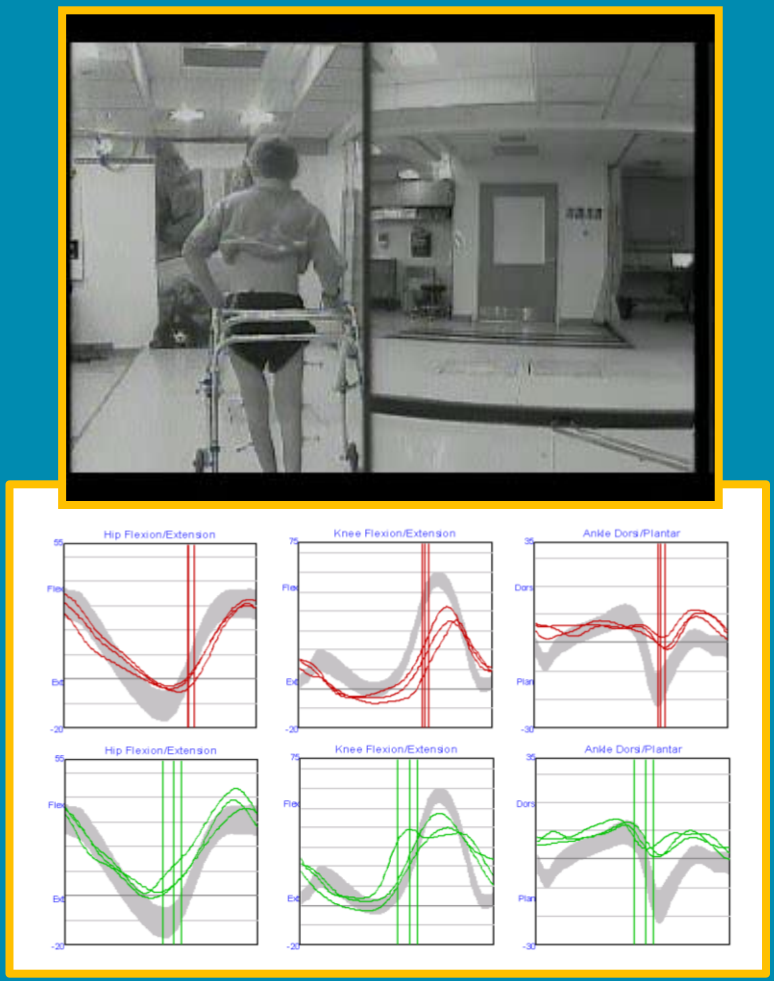
pre x follow-up: 14% increase

Gait Analysis

Pre-Training

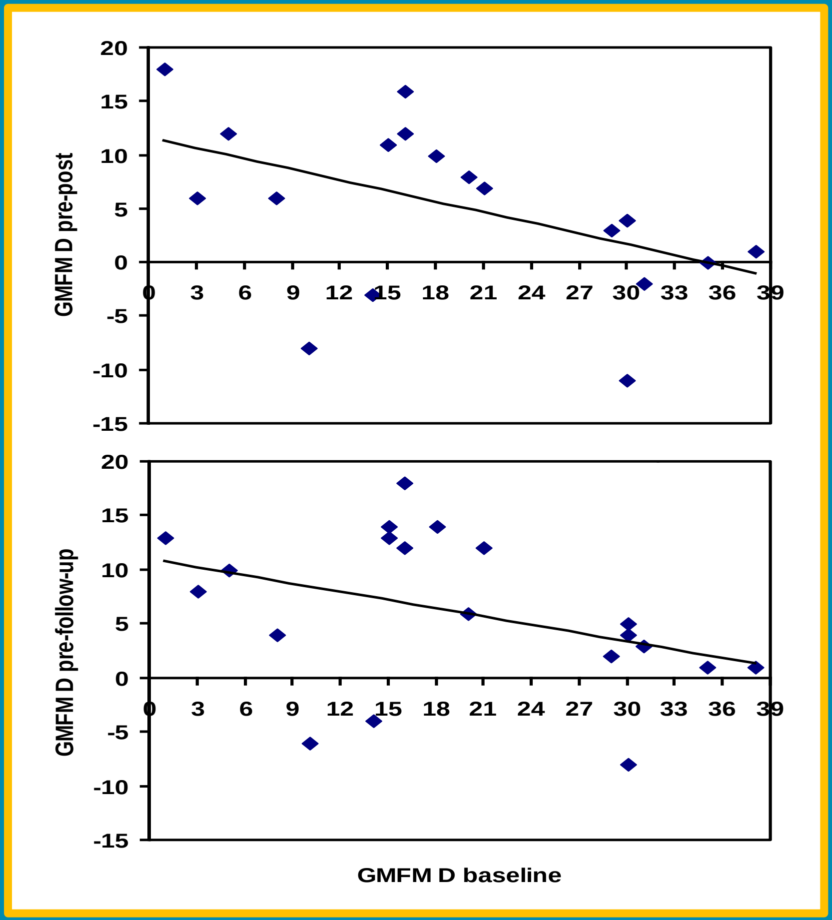


Post-Training

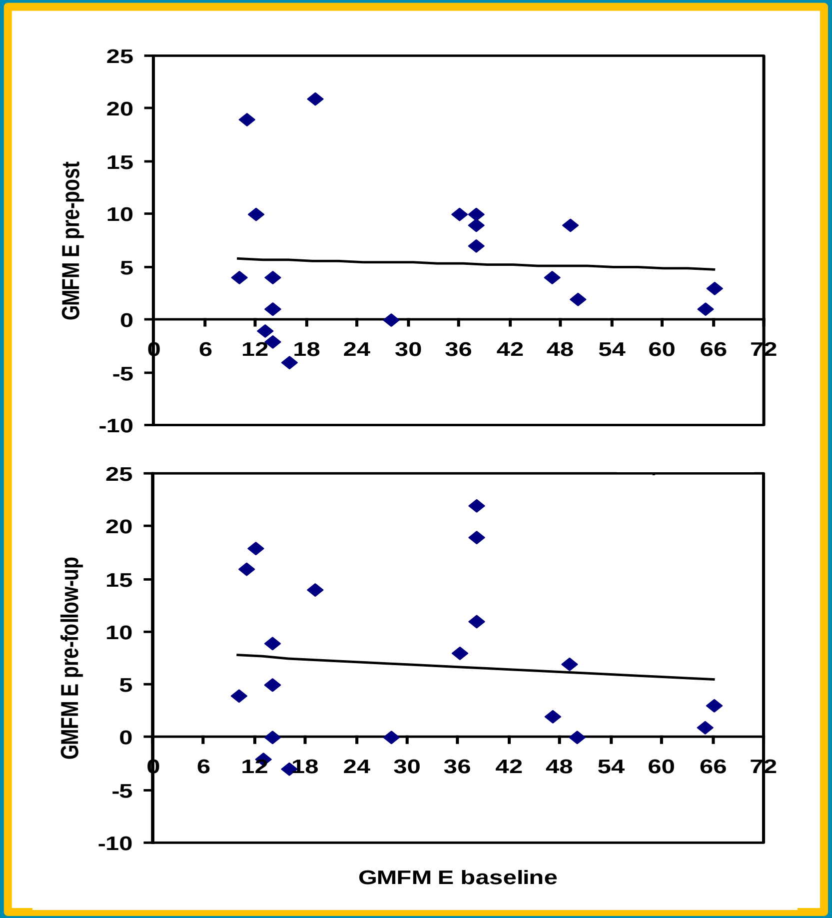


Motor Gains vs. Baseline Values

Standing Function
GMFM Item D



Walking Function
GMFM Item E



How To Improve Outcomes in "Non-Respondents"

Several factors have the potential to account for differences observed across subjects in response to gait training.

1) More stringent inclusion/exclusion criteria could lead to more consistent results across subjects.

2) Tools could be developed to maximize (while monitoring) the level of "engagement" of the child during the gait training session.

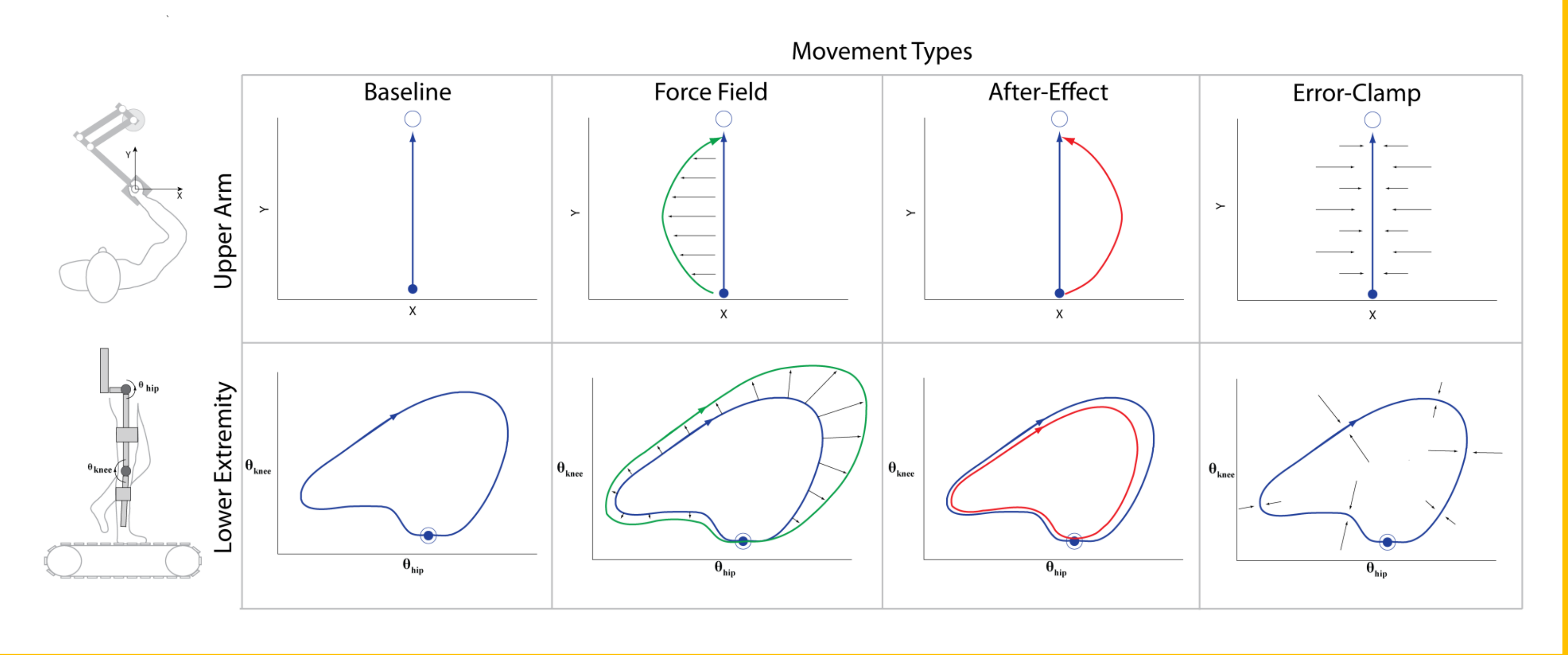
3) Gait deviations that are currently not addressed by commercially-available systems could be targeted by new robotic devices.

4) Adaptive strategies could be developed if we gained a better understanding of the interactions between the child and the robotic system.

Developing Adaptive Training Strategies?

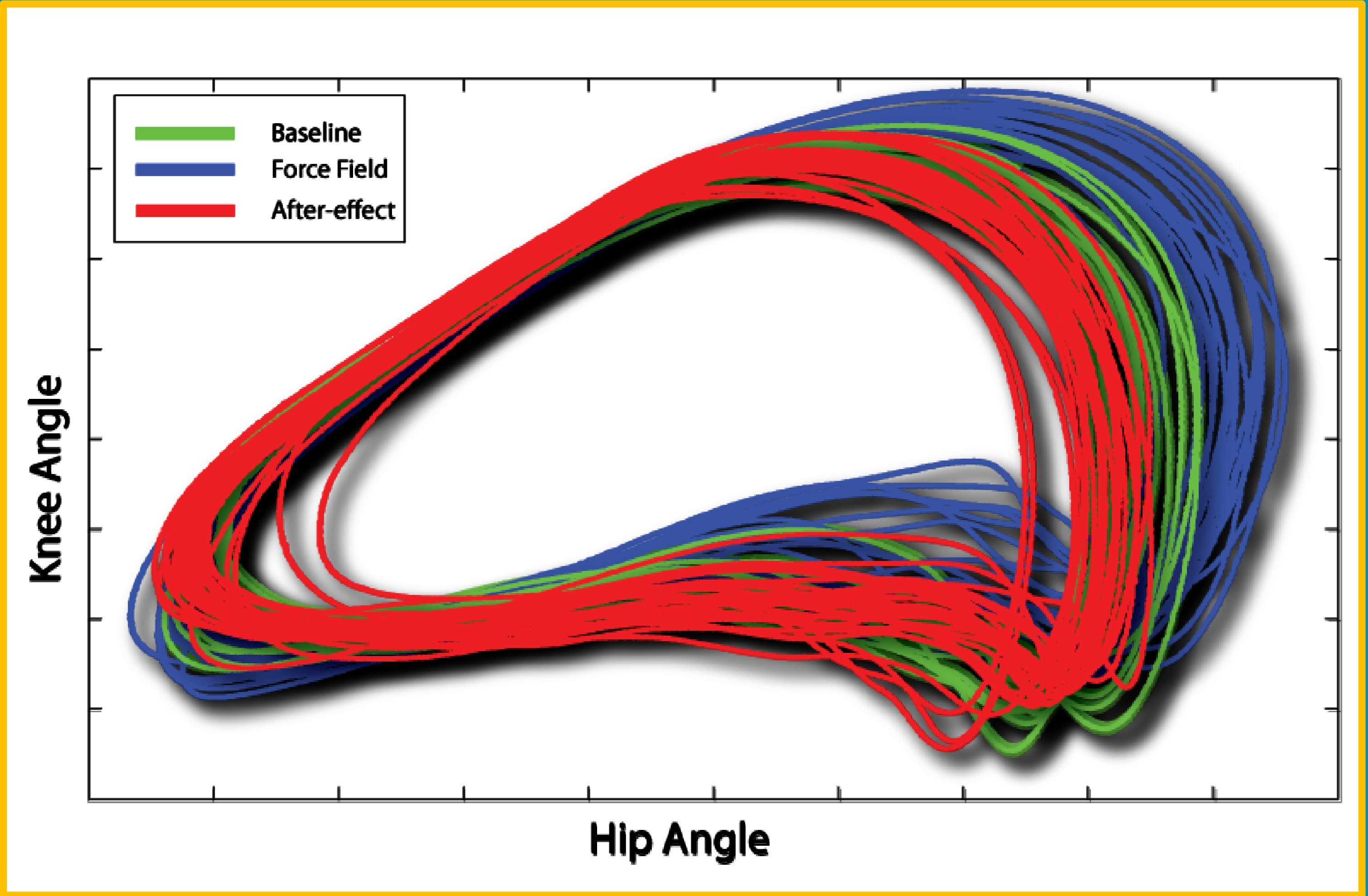
… can we infer the potential for motor learning from the interaction between the child and the robotic system?

Lower-Limb Motor Adaptations

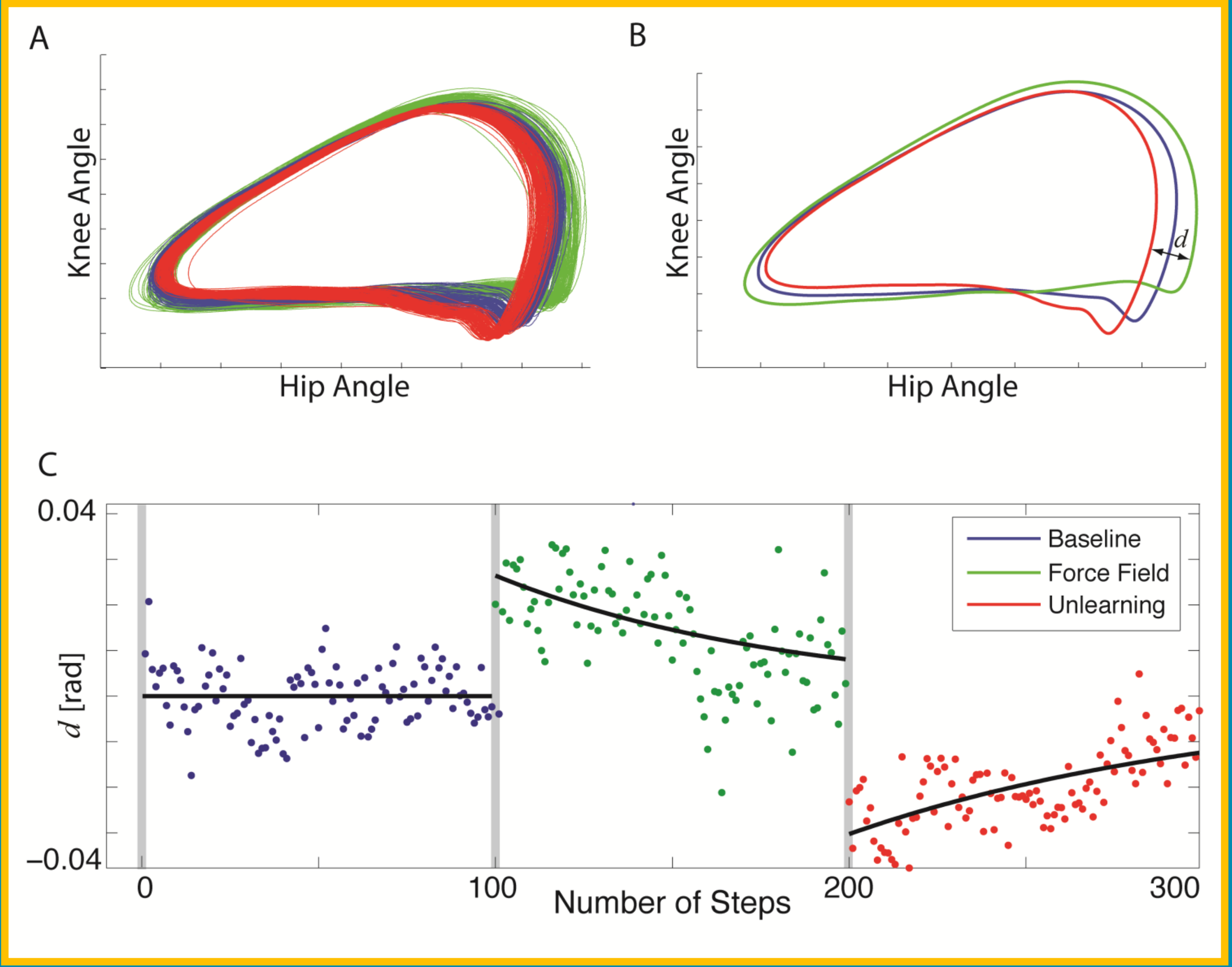


The upper-limb force field adaptation paradigm can be extended to the lower limbs by considering the trajectory of movement associated with gait in the knee vs. hip joint coordinate space and by introducing a perturbation orthogonal to the direction of movement in this space.

Lower-Limb Motor Adaptations



Lower-Limb Motor Adaptations



Motor Adaptations vs. Clinical Outcomes

- **Surprisingly, we know very little about the relationship between the ability of patients to generate motor adaptation strategies and the clinical outcomes of rehabilitation interventions.**

- **It is conceivable that assessing the ability of individuals to generate motor adaptation strategies could lead to targeted interventions thus resulting in better clinical outcomes.**

Developing New Robotic-Assisted Therapies

- Are patients who do not respond to robotic-assisted gait training those who are unable to generate motor adaptation strategies?
- What can we do in patients who show no or limited ability to generate motor adaptation strategies?

Transcranial direct current stimulation

Various modalities of peripheral stimulation

Pharmacotherapy in combination with physical therapy

Discussion Points …

- While the need for motor rehabilitation is obvious, the way to go about it is not. A simple "exercise prescription" is clearly not sufficient to achieve satisfactory motor gains.
- Intensity and specificity of training appear to be key in motor training. Interactive games are not "good enough" per se.
- Robot-assisted motor training is promising, but existing systems need to be improved and the interaction between patient and robot better understood.
- Since not everybody responds to error feedback, the achievement of motor gains requires ways to elicit motor adaptations.

Part II: Assessing Outcomes via Mobile Health Technology

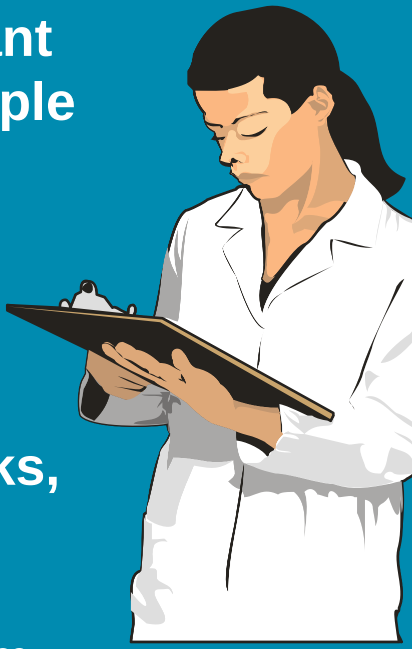
Clinical Scales

- **Impairment Scales**

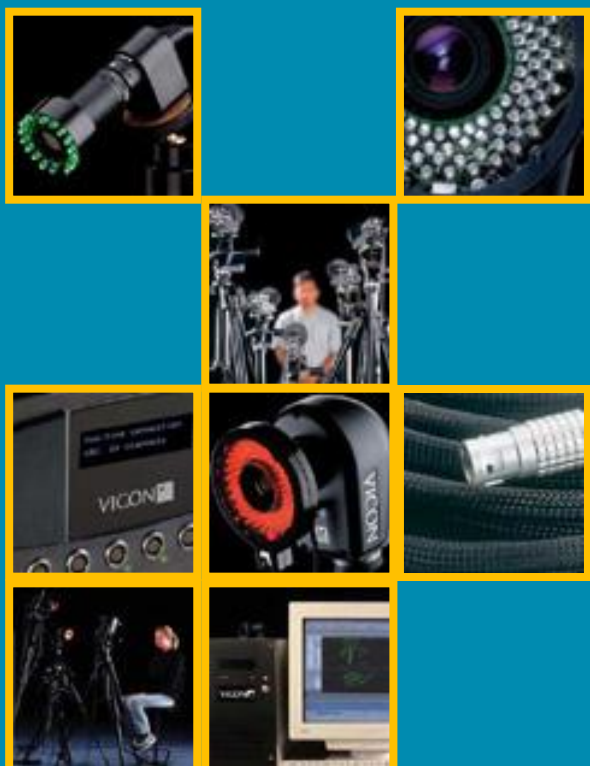
  A first set of clinical scales aim at assessing the patients' ability/inability to perform physiological movements. For instance, clinicians would want to assess the ability of an individual to de-couple the control of joints of a limb.

- **Functional Scales**

  A second set of scales aim at assessing the ability of individuals to perform functional tasks, namely activities of daily living. For instance, clinicians would want to know if a patient can pick up objects on a table and manipulate them.

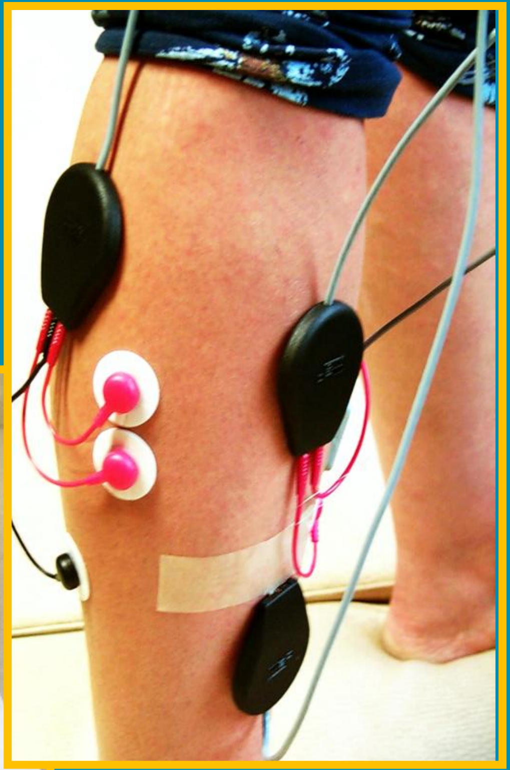


Camera-Based Motion Analysis Systems

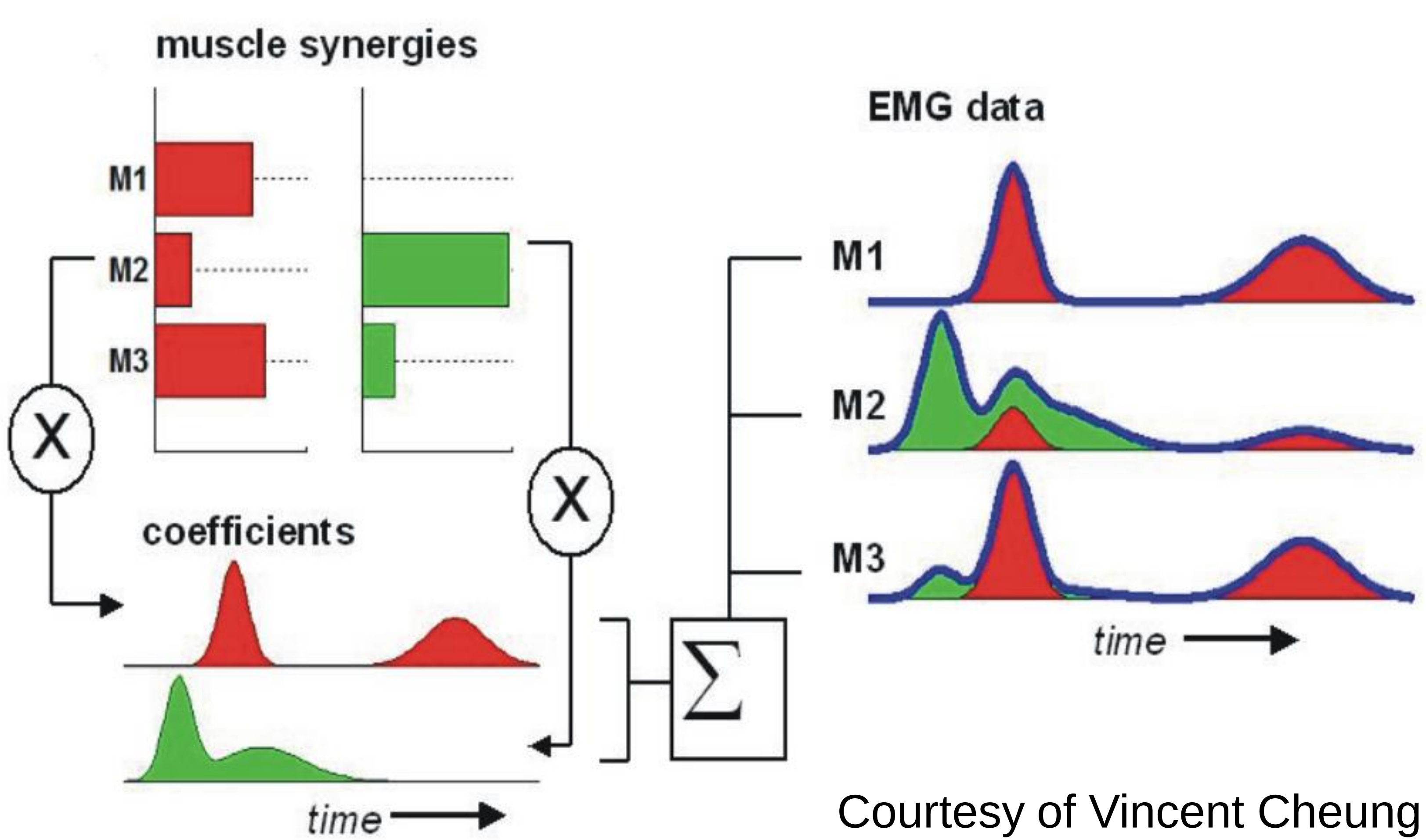


EMG Recordings



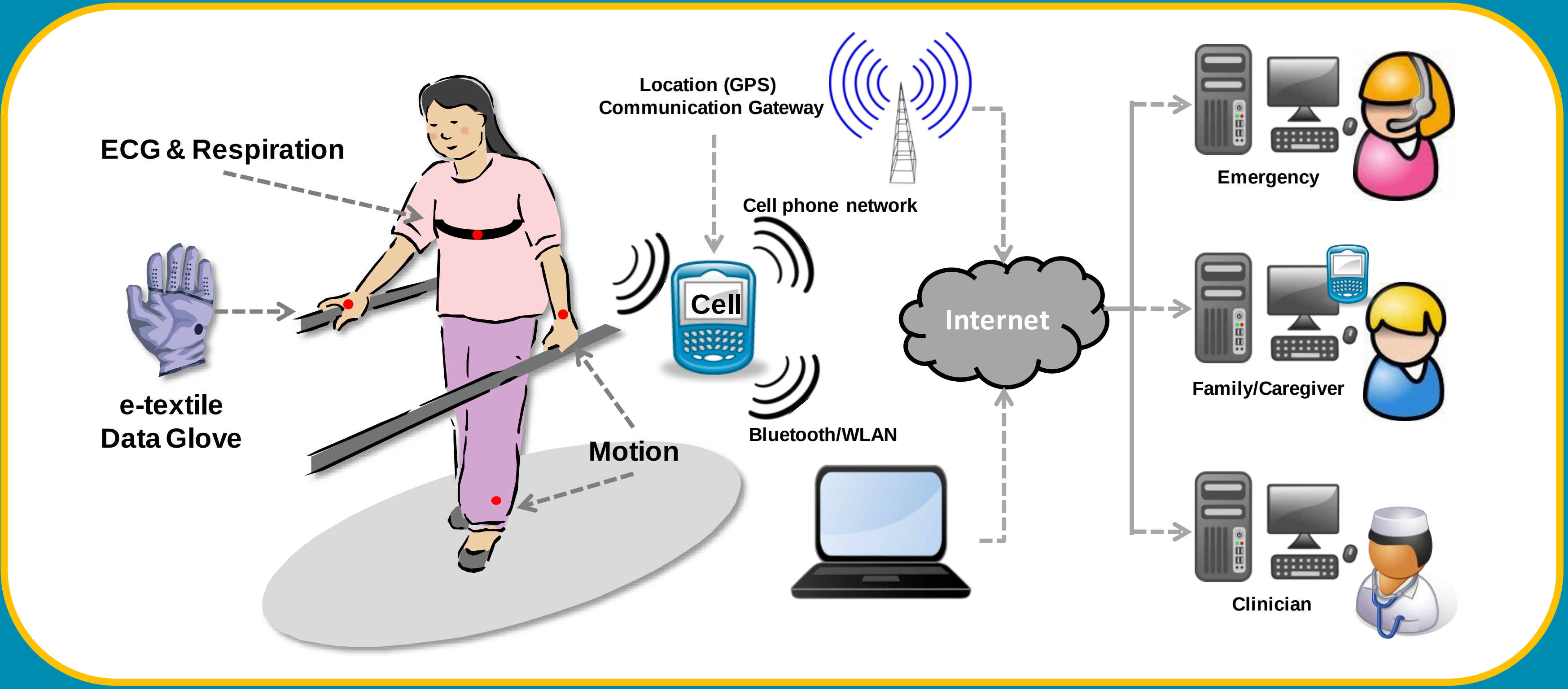



Muscle Synergies



Courtesy of Vincent Cheung

Home Monitoring

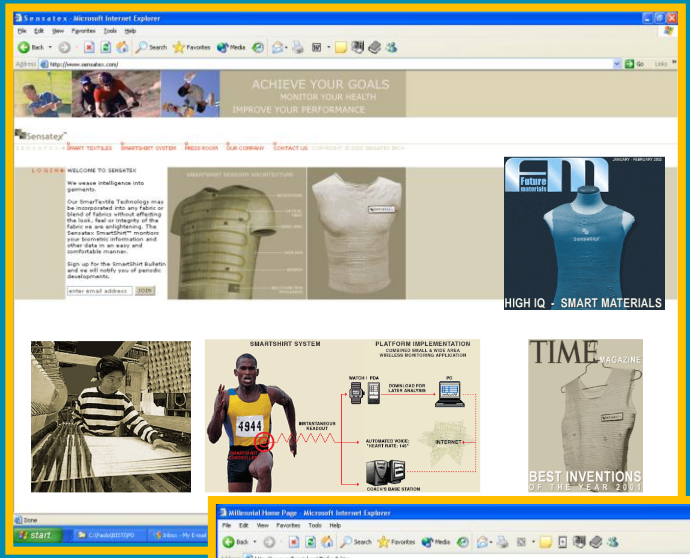


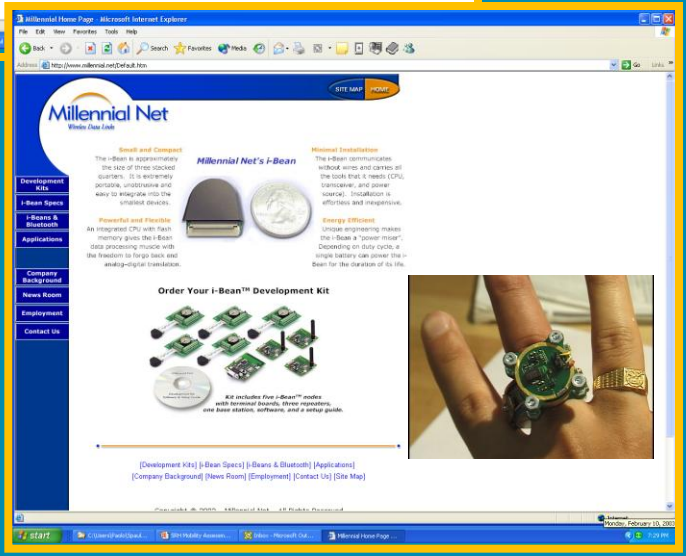
Continuous Physiological Monitoring

The concept of continuous physiological monitoring has been around since 1949, when Norman Holter proposed to pursue electrocardiographic monitoring via a rather obtrusive but revolutionary system to record cardiac activity.

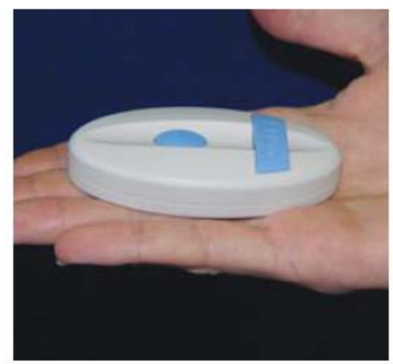
Wearable Sensors and Systems

Wearable systems leverage sensor technology, wireless communication, and e-textile solutions to monitor patients in the home and community settings. Various systems have been developed over the past ten years. Most notably, Jayaraman and his team developed e-textile solutions such as the Smart Shirt and Asada's group developed the Ring Sensor.



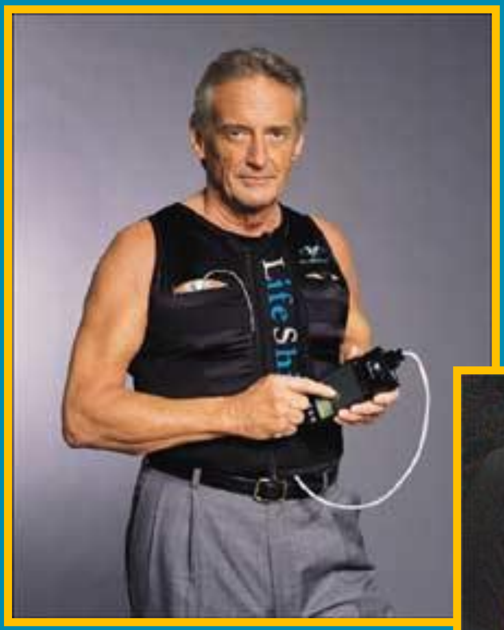


Wireless Physiological Monitoring

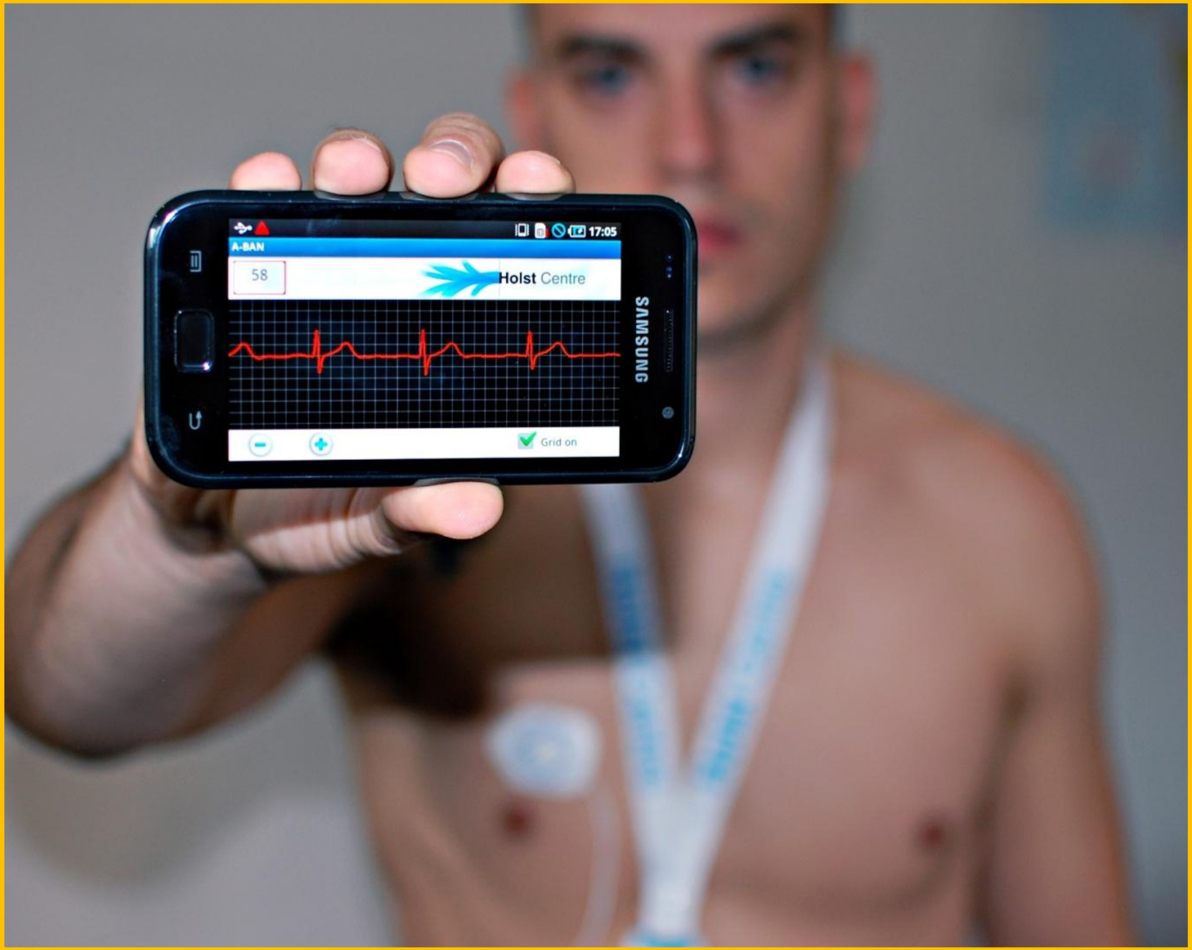


Courtesy of Nat Sims

E-Textile-Based Physiological Monitoring



Wearable Sensors and Systems



Courtesy of IMEC, Human ++ Program - Project Coordinator, Julien Penders

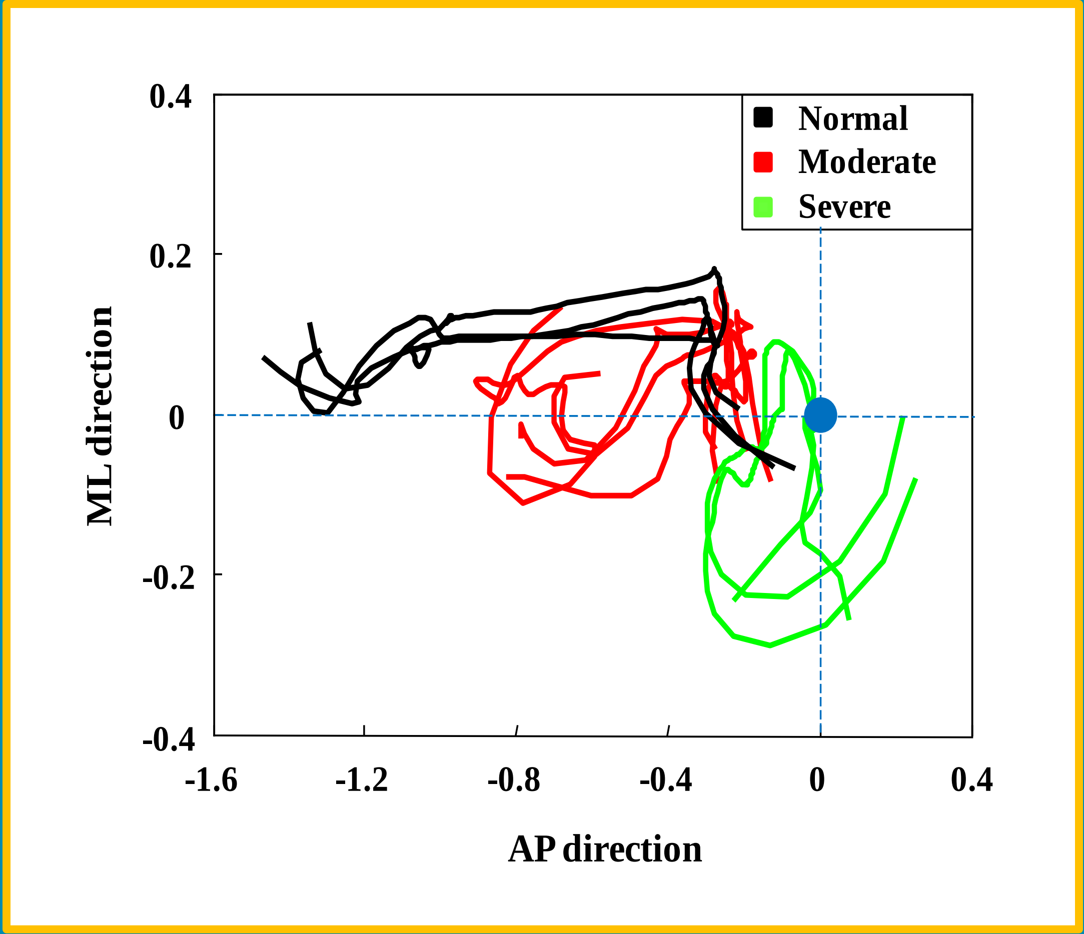
Home Monitoring of Children with CP

- Complementing traditional outcome measures gathered in the outpatient setting with data collected in the field

- Wearable technology has the potential to allow one to assess gait abnormalities in the field.

Home Monitoring of Children with CP

- Pilot study relying on gait analysis data from force platforms
- We developed procedures to estimate clinical scores of gait abnormalities from shoe data.

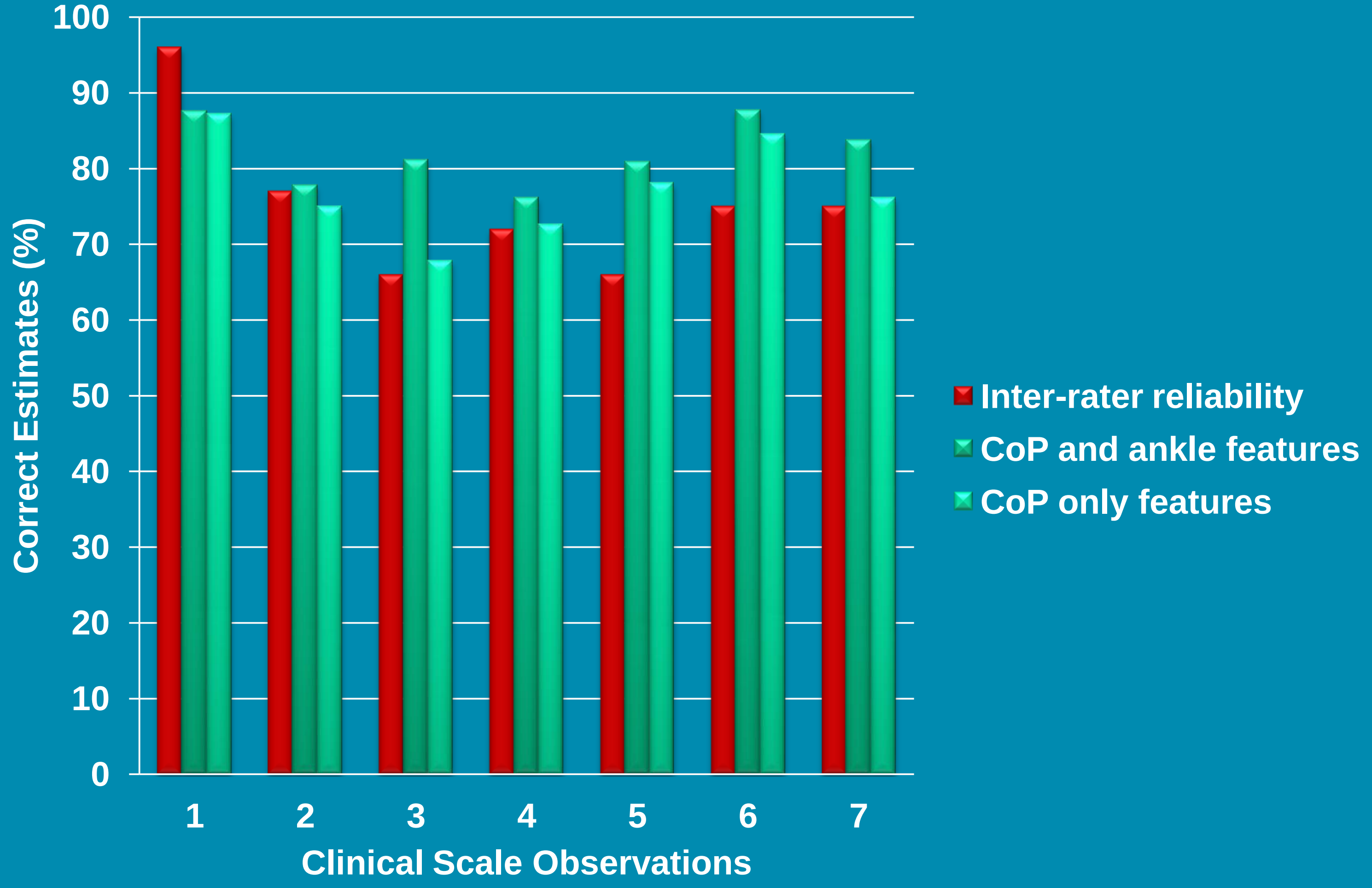


Estimating Edinburgh Visual Scale Scores

Observations 1-7:

		2	1	0	1	2
1	Initial contact	/	/	Heel contact	Flatfoot contact	Toe contact
2	Heel lift	No forefoot contact	Delayed	Normal	Early	No heel contact
3	Max ankle dorsiflexion in stance	Excessive dorsiflexion (> 40° df)	Increased dorsiflexion (26° – 40° df)	Normal dorsiflexion (5° – 25° df)	Reduced dorsiflexion (10° pl – 4° df)	Marked plantarflexion (> 10° pf)
4	Hindfoot varus/valgus in stance	Severe valgus	Moderate valgus	Neutral / Slight valgus	Mild varus	Severe varus
5	Foot rotation in stance	Marked ext > KPA (by > 40°)	Mod ext > KPA (by 21 – 40°)	More ext than KPA (by 0° – 20°)	Mod int > KPA (by 1° – 25°)	Marked int > KPA (by > 25°)
6	Clearance in swing		High steps	Full	Reduced	None
7	Max ankle dorsiflexion in swing	Excessive dorsiflexion (> 30° df)	Increased dorsiflexion (16° – 30° df)	Normal dorsiflexion (15° df – 5° pf)	Reduced dorsiflexion (6°– 20° pf)	Marked plantarflexion (> 20° pf)

Estimating Edinburgh Visual Scale Scores



Toward Application in the Clinic …

Challenge #1
To embed sensors in "easy-to-wear" items.

Challenge #2
To minimize power requirements.

Challenge #3
To process data in a clinically meaningful way.

Challenge #4
To provide information via electronic health records.

Challenge #5
To integrate wearable/ambient sensors and portable/wearable devices.

http://srh-mal.net/

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