NORTHERN NEW JERSEY SPINAL CORD INJURY SYSTEM

Spinal Cord Injury Grand Rounds Series

This packet contains materials presented as part of the Spinal Cord Injury Grand Rounds Series hosted by the Northern New Jersey Spinal Cord Injury System with support from the National Institute on Disability and Rehabilitation Research, U.S. Department of Education, Grant #H133N110020.

The SCI Grand Rounds Series is a forum in which to learn about innovative research and cutting-edge clinical practice from experts in the field. We hope you will find these materials to be informative and helpful.

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The NNJSCIS is a cooperative effort of Kessler Foundation, Kessler Institute for Rehabilitation, Rutgers New Jersey Medical School and University Hospital, Newark.

MOTOR LEARNING STRATEGIES APPLIED TO NEUROREHABILITATION

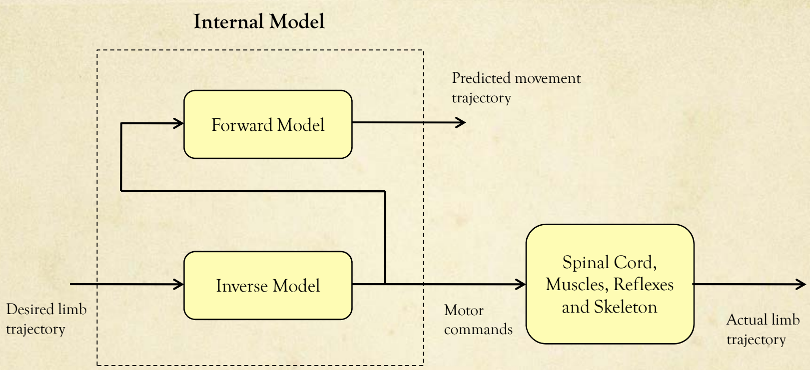
Joe Hidler, PhD

Aretech, LLC, Ashburn, VA

"Rehabilitation needs to emphasize techniques that promote the formation of appropriate internal models and not just repetition of movements"

John Krakauer, Current Opinion in Neurology, 2006

Motor Control System: Intact

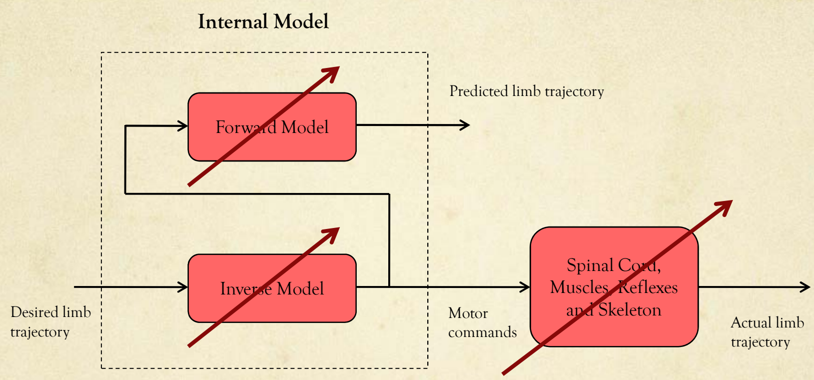


Kuwato, '99

Internal model formation begins at birth

And continues to evolve…

Motor Control System: Post-CNS Injury



Example of Inefficient Motor Control

Motor learning principles applied to rehabilitation

- The degree of improvement is often dependent on the amount of practice where one tries to minimize task error
- Variability of tasks and task variability in the acquisition phase improves performance in subsequent sessions and helps in the generalization of learning new tasks.

"IT IS THE GOAL NOT THE MOVEMENT THAT HAS TO BE REPEATED."

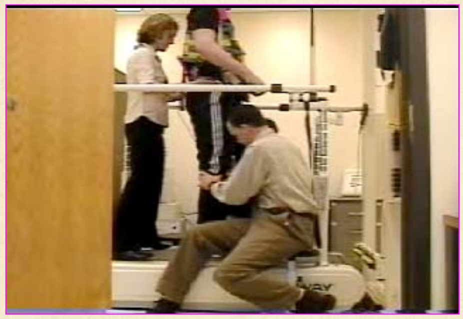
Strategy: Recovery vs Compensation?

- Recovery: damaged neural substrates recover and innervate the same muscles used before the injury.
- Compensation: spared pathways innervate alternative muscles to accomplish the task goal.

Do patients get better through recovery or compensation?

How does this fit in with Rehabilitation?

Manual-assisted gait training with body-weight support



Video courtesy of Rehab Institute of Chicago

Potential Advantages of BWSTT

- Unloading of weak lower extremities allows individuals to safely practice gait earlier after stroke (timing)
- The volume of steps can far exceed over-ground gait training (intensity)
- Stationary positioning of the subject convenient for therapist assistance

L.E.A.P.S. Trial, Sub-Acute Stroke (Duncan et al., 2011)

- Hemiparetic stroke subjects (n = 408) were stratified to one of 3 groups 2 months after their stroke
    1. Treadmill training with body-weight support beginning 2 months after their stroke occurred
    2. Treadmill training with body-weight support beginning 6 months after their stroke occurred
    3. Home exercise program 2 months after stroke

- All subjects completed 36 sessions, 90 mins each

Results

- All groups had similar improvements in walking speed, motor recovery, balance, functional status and quality of life.

Table 2. Functional Status and Quality of Life at Baseline (2 Months) and Change from Baseline at 6 Months and 12 Months.*

Variable	Early LT (N=139)	Late LT (N=143)	HE (N=126)	P Value
Baseline	0.37±0.22	0.38±0.23	0.39±0.22	0.62
6 mo	0.25±0.21	0.13±0.14	0.23±0.20	<0.001
Mean distance walked in 6 min — meters				
Change from baseline				
6 mo	81.8±62.8	41.0±47.4	75.9±69.3	<0.001
12 mo	73.2±69.4	79.0±75.1	85.2±72.9	0.45

Results

• Subjects in the treadmill training groups experienced higher frequency of dizziness and fainting during treatment.

• Subjects in the home exercise program fell significantly less than the treadmill training groups.

Similar findings in chronic spinal cord injury

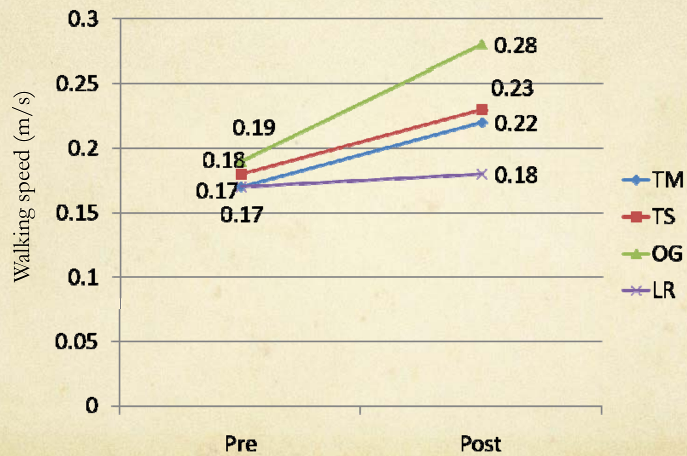
(Field-Fote and Roach, 2011)

• Seventy-four individuals with chronic SCI (> 1 year) were assigned to one of 4 groups:

1. Manual-assisted treadmill training (TM)
2. Treadmill training with stimulation (TS)
3. Overground gait training with stimulation (OG)
4. Treadmill-based robotic-assisted training (LR)

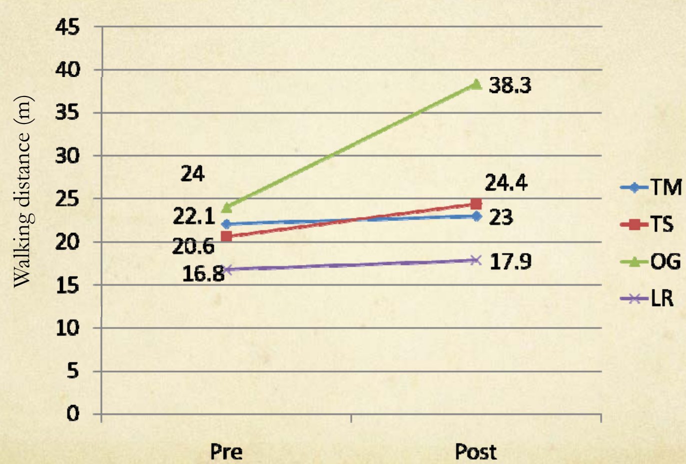
- All subjects trained 5 days/week for 12 weeks
- Primary outcomes included overground walking speed and distance walked (6 minute)

Changes in Walking Speed by Intervention Group



Field-Fote EC and Roach KE 2010

Changes in Walking Distance by Intervention Group



Field-Fote EC and Roach KE 2010

Lokomat (Hocoma AG, Volketswil, Switzerland)

Robotic Gait Training: Potential Benefits

- Because the devices are actuated with motors, training sessions can be longer and more consistent.
- For the Lokomat, the kinematics of the limb are well-controlled allowing clinicians and therapists to train each subject with custom specified trajectories
- Subject's can get up walking earlier in their rehabilitation program because of the security the devices provide.
- Because of this security, patients can concentrate on re-establishing natural gait patterns rather than having to concern themselves with falling down.

Goal

Determine whether robotic-assisted gait training with the Lokomat leads to higher functional returns in walking capability when compared to conventional rehabilitation.

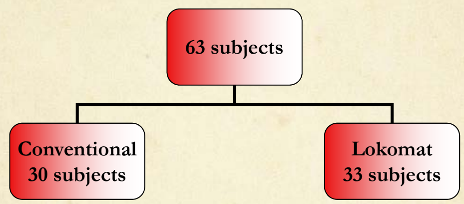
Subjects

- Inclusion criteria:
  - unilateral brain lesion
  - age > 18 years
  - within 6 months post-injury
  - cannot be receiving any other outpatient or home therapy targeting the lower limbs
  - demonstration of hemiparesis (e.g. motor dysfunction in lower limb)
  - be able to walk a short distance without physical therapist assistance (5-meters)
  - self-selected over-ground walking speed (0.1-0.6 m/s)

- Exclusion criteria:
  - severe osteoporosis
  - contracture limiting range of motion
  - not ambulating prior to stroke
  - severe cardiac disease (New York Heart Association classification II-IV)
  - uncontrolled hypertension (systolic>200 mm Hg, diastolic>110 mm Hg)
  - stroke of the brainstem or cerebellum
  - seizures
  - presence of a lower-limb non-healing ulcer
  - history of lower limb amputation
  - uncontrolled diabetes
  - significant cognitive or communication impairment which could impede the understanding of the purpose or procedures of the study (MMSE ≤ 22)
  - signs of clinical depression (CES-D ≥ 16)

Subject Assignments

- Subjects recruited to the study were randomized to one of two groups: Group 1: conventional rehabilitation, Group 2: Lokomat



- All subject groups received 24 sessions of training (3x/week) over a 10-week period

Experimental Procedures

<u>Conventional Training</u>

- Subjects participated in 1 hour of traditional physical therapy treatment, with focus on strength training and full weight-bearing ambulation.

- With PT assistance, subjects performed a standardized regimen of exercises emphasizing strengthening of the lower extremities as well as over-ground ambulation training, using parallel bars and other mechanical aids.

Experimental Procedures

Robotic-Assisted Gait Training with Biofeedback

- Subjects were securely attached to the Lokomat and unloading system, after which the Lokomat initiated the gait pattern. Subjects were instructed to match the Lokomat's gait pattern.
- The minimum amount of body-weight support was provided so that the subject could successfully execute stepping.
- Walking speed began at approximately 1.75 km/hr, and was increased after the subject was able to support at least 30% of their body-weight.
- Subjects progressively increased their walking time until reaching 45 minutes of total gait training.

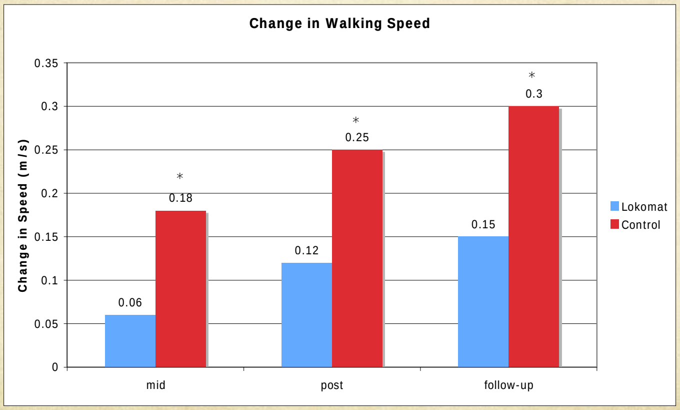
Data Analysis

- Assessment of impairment, functional limitations, and degree of disability and societal limitations was performed before training, after sessions 12 & 24, as well as at 3 months after completing the training.

Stroke Impairment -NIH Stroke Scale **Gait Impairment** -Functional Ambulation Category -Walking Speed over 5 meters -Clinical Gait Assessment (Gait Rite or Gait Mat) **Motor Function** -Motor Assessment Scale **Balance** -Berg Balance **Mobility** -Rivermead Mobility Index **Strength** -Manual Muscle Test	**Spasticity** -Modified Ashworth Scale **Endurance** -6-minute walk test **Measures of Activities of Daily Living** -Frenchay Activities Index **Health Status** -SF-36 Health Survey **Depression Scale** -Center for Epidemiologic Studies Depression Scale (CES-D), NIMH **Cognitive Status** -Folstein Mini-Mental State Exam

Results

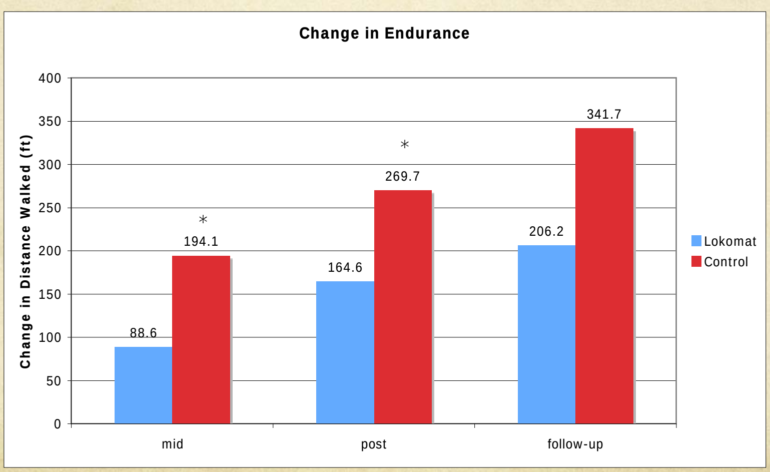
• Subjects in the conventional improved their walking speed to a greater extent than subjects in the Lokomat group



* Indicates significantly different, $p < 0.05$

Results

• Subjects in the conventional improved their endurance to a greater extent than subjects in the Lokomat group



* Indicates significantly different, $p < 0.05$

Results

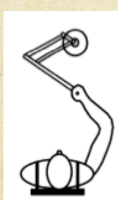
- No differences between groups were observed for measures of balance, strength, spasticity or quality of life.
- For conventional subjects, cadence improved 3x as much as the Lokomat group

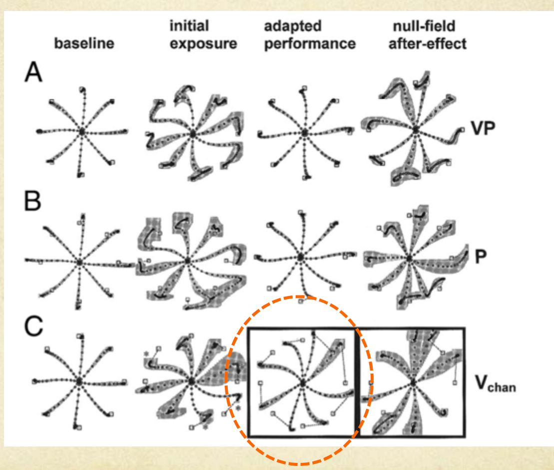
Reference

J. Hidler, D. Nichols, M. Pelliccio, K. Brady, D. Campbell, J. Kahn, and T.G. Hornby "Multicenter randomized clinical trial evaluating the effectiveness of the Lokomat in subacute stroke." ***Neurorehabilitation and Neural Repair***, 23:5-19, 2009

Why are these interventions failing to produce superior outcomes?

Importance of visual feedback in learning

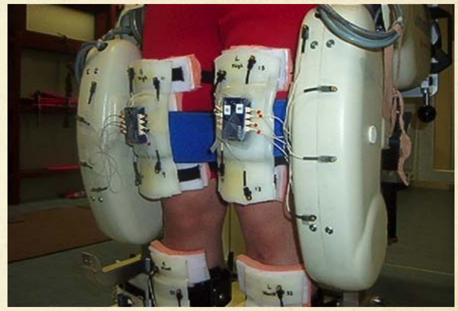




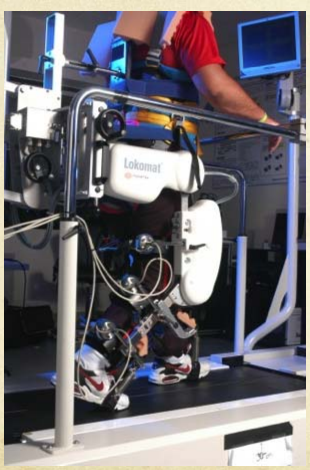
(Scheidt et al., 2005)

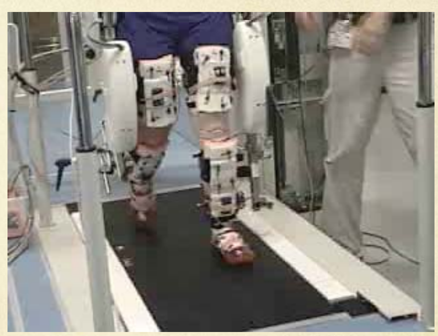
Quantitative Assessment of Gait During Robotic Walking (Neckel et al, 2008)

- CodaMotion active marker system, camera 1m in front of subject
- Plastic "bases" slip under cuffs
- Rigid marker cluster "caps" firmly attach on top



Robotic-Assessment of Gait Impairments



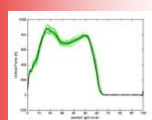


Methods: Algorithms

Codamotion Marker Positions → Visual 3D Subject-Specific Models (C-Motion, Rockville MD)

JOINT KINEMATICS

Ground Reaction Forces

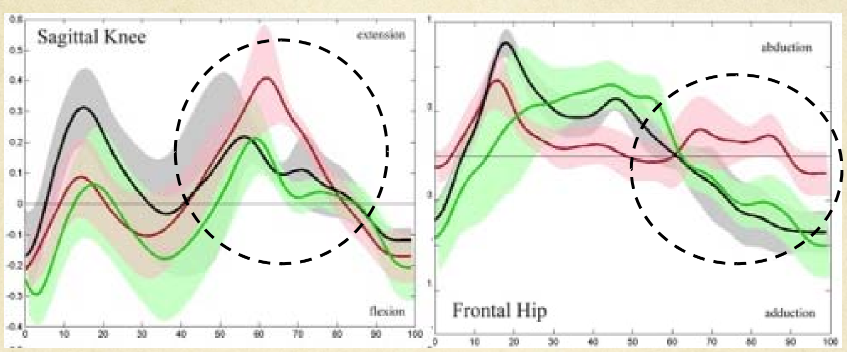


MATLAB

Leg cuff forces
Foot lifter forces

JOINT MOMENTS

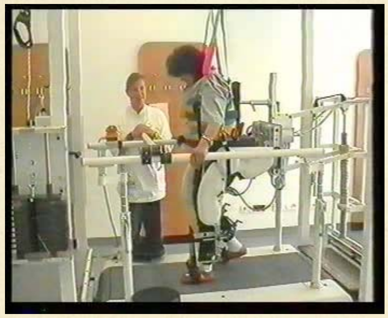
Joint moments exhibited during robotic walking



Neckel et al., 2008

Black = control
Green = unimpaired
Red = impaired

Patients only see the resulting leg movements, do not know how much the robot 'helped'. Not having the proper error signal will prevent motor learning.



Similar issues with manual-assisted treadmill training

Can patients distinguish their contribution from the therapist's contribution in achieving a step?

What principles of motor learning should be used in rehabilitation?

• DIVERSITY: Therapeutic interventions need to incorporate various tasks.

• VARIABILITY: Most repetitive therapies focus too much on repetition, not 'the goal'.

• ERROR FEEDBACK: Patients need to be provided error feedback of their performance, not the combined performance of the therapist or robot with their performance.

What role can robots play in rehabilitation?

We believe robotic systems can promote motor learning principles within rehabilitation

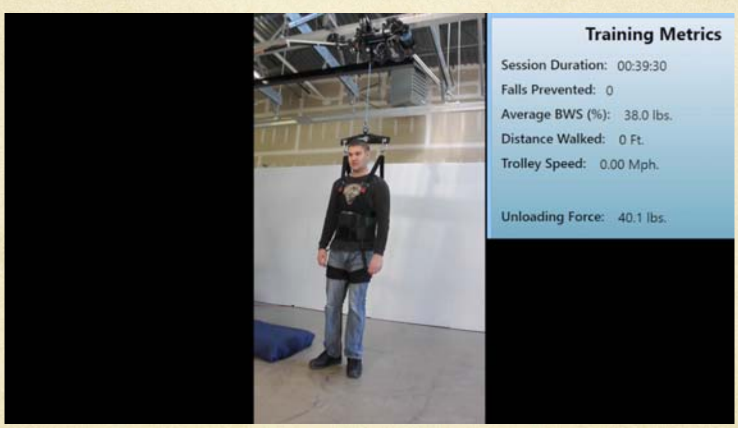
- Allow failure: let patients explore their workspace and learn how to use residual pathways to best accomplish specific tasks (i.e. walking), but safely!
- Error Feedback: Let patients see how they are doing at a task through biofeedback and indications of performance
- Progressive: allow patients to start simple and then progress the level of difficulty as they improve performance
- Task variability: let patients practice lots of activities
- Variability of task: let patients explore their workspace

ZeroG® Gait and Balance Training System

Dynamic Body-Weight Support

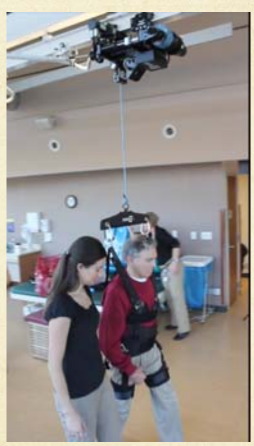
- The patient is unloaded by a percentage of their body-weight
  - For example at 50% BWS, the patient will feel as though they weigh 50% less than their true weight even during vertical movement
- As the patient gets better, therapist can reduce the amount of support so the patient does more.
- Dynamic body-weight support is important since it feels more natural and allows patient to practice activities requiring large vertical movements (sit to stand, getting off the floor)
- ZeroG has up to 200 lbs dynamic BWS capacity (up to 400 lbs static)

Dynamic Body-Weight Support Demo



Experiencing 100% Body-Weight Support

Robotic Trolley Tracking



Trolley tracking up to 6 mph

Possible Benefits of ZeroG

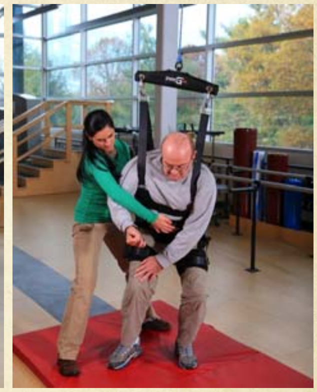
- Patients can begin practicing early after neurological injuries at high intensity levels, factors known to relate to best outcomes (Horn et al., 2005)
- Dynamic BWS allows for partial compensation of weakness, spasticity and abnormal coordination
- Practice functional activities
- Removing the fear of falling helps prevent the formation of compensatory strategies

Possible Benefits of ZeroG

- No barriers between therapist and subject -> encourages interaction
- Lowers the risk of injury to patients and therapists

Wide Range of Patient Sizes

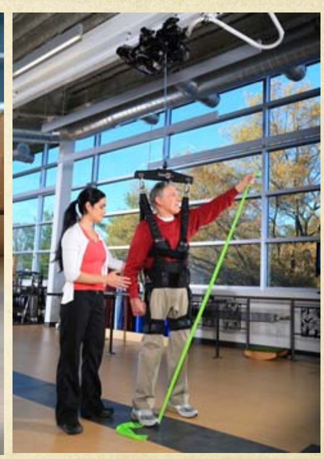




Patient Limitations: 20 – 400 lbs

Wide Range of Patient Diagnoses





Stroke, TBI, SCI, CP, MS, Amputees, Orthopedic, Geriatric, Cardiac

Wide Range of Patient Activities

Overground Walking | Balance and Postural Control | Sit to Stand | Floor Transfers | Stairs | Treadmill Ambulation

Chronic Stroke Patient

Without ZeroG, this patient is at a high risk for falls, walks slowly, and has difficulty with left foot clearance

With ZeroG, he is safe and walks with a more natural gait pattern

Acute Stroke Patient

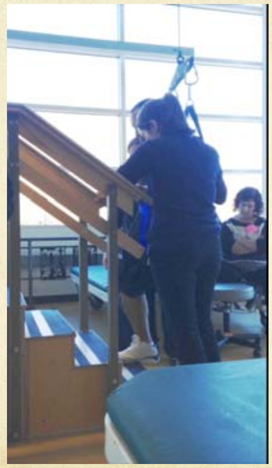
1st Time Walking After Stroke

After 1 Week

Amputee Training

ZeroG can be used by a wide range of patients, including stroke, traumatic brain injury, spinal cord injury, cerebral palsy, multiple sclerosis, orthopedic injuries and amputees

Stairs



Sit to Stand

Incomplete SCI

Incomplete SCI

Interactive Balance Programs

- Target matching
- Biofeedback
- Anticipatory balance training

Unique to ZeroG!

Interactive Balance Programs

- Target matching in both the medial-lateral and anterior-posterior planes

Games

- Fun, yet cognitively & physically challenging

Unique to ZeroG!

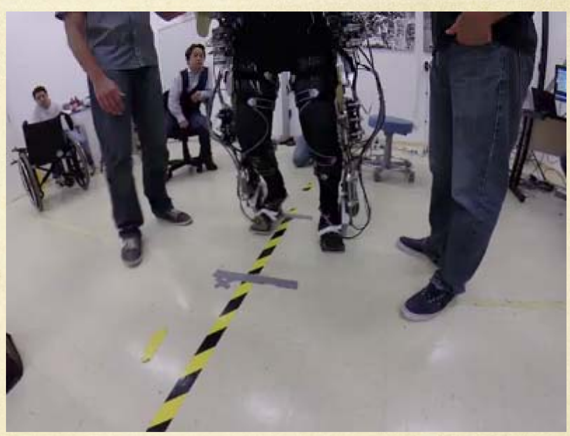
Games

- Tetris, Break Out, Catch

Sample of Current ZeroG Research

- The Walk Again Project
  - Miguel Nicolelis, Lumy Sawaki - AACD, Sao Paulo, Brazil
- Overground Gait Training with a Novel Dynamic Body-Weight Support System, ZeroG
  - Susan Ryerson (National Rehabilitation Hospital, Washington, DC)
- Early Gait and Balance Training in Toddlers with Cerebral Palsy
  - Laura Prosser (Children's Hospital of Philadelphia
- Dynamic Over-ground Body Weight Support Training in Patients with Pusher Syndrome after Stroke: Case Series
  - Debra Ness (Mayo Clinic, Rochester, MN)
- Comparison of Oxygen Demands and Muscle Activity Patterns During Different Forms of Body Weight Supported Locomotion in Individuals With Incomplete SCI
  - Alyssa Fenuta and Audrey Hicks (McMaster University, Hamilton, Ontario, Canada)

The Walk Again Project



Miguel Nicolelis, Lumy Sawaki
AACD, Sao Paulo, Brazil

Novel mobility training intervention in infants and toddlers with cerebral palsy

LAURA A. PROSSER[1], LAURIE B. OHLRICH[2], LINDSEY A. CURATALO[2], KATHARINE E. ALTER[2,3], & DIANE L. DAMIANO[2]

The coolest part of all of this???

ZeroG now at Kessler!

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