Rehabilitation Applications of Robotic Technology

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We move you
Neuroplasticity

The brain's natural ability to form new connections in order to compensate for injury or changes in one's environment  

“One of the most extraordinary discoveries of the twentieth century”

(Norman Doidge)
Neuroplasticity

Lesion: Waller degeneration

"Sprouting" (molecular, biochemical, electrophysiological process)

Collaterals of healthy neurons cover synapses: "Unmasking"

take over functions

structural reorganisation: changes in cortical representation (not complete restoration)
Neurorehabilitation

“Modern clinical neurorehabilitation is grounded in the premise that activity is beneficial to persons with central nervous system injury”

Goal Setting in Neuro-Rehab: S.M.A.R.T

Specific
Measurable
Achievable
Relevant
Timely
Functional Recovery

- **Functional recovery** is influenced by a variety of biological and environmental factors (Bach-y-Rita et al., 1990)

- Recovery profiles are characterized by a **high interindividual variability**

- Several **clinical and demographic variables** may be valid predictors of general functional recovery, including neurologic factors such as consciousness at onset, disorientation in time and place, sitting balance, and severity of motor deficits (Kwakkel et al., 1996)
Motor Learning – Key facts

- Functional training helps recover function
- Training beyond the present capability
- Active participation
- Afferent feedback is stimulating reorganization of the CNS
- More training leads to greater success
- Motivation

(Kwakkel et al., 1999; Nelles, 2004; Butefisch et al., 1995; Bayona et al., 2005)
Manual assisted treadmill training

Mimics functional movement but has limitations:

• Not a very intensive training
• Training time is limited to PT
• Gait pattern is not reproducible
• Gait pattern is not optimal
• Physical strain
• Ergonomically bad position
• Can use up to 3 physiotherapists

Video courtesy of University Hospital Balgrist, Zurich
Robots for healthy Individuals

“Yagn’s running aid”  
(Yagn, 1890)

“General Electric’s Hardiman”  
(Fick & Mackinson, 1971)

“Bleex”  
(Kazerooni & Steger, 2006)
Early Active Orthosis

Cobb’s “wind-up” orthosis (Cobb, 1935)

Pupin Institute “complete” exoskeleton (Vukobratovic, 1990)

Wisconsin exoskeleton orthosis (Seireg & Grundmann, 1981)
Actuated Leg and Gait Orthosis

“Cyberthosis”  
(Schmitt et al., EPFL)

“HAL” (Hybrid Assistive Limb)  
(Yohikuyi Sankai et al., Tsukuba University, JP)
International Congress for Rehabilitation Robotics 2007

“Lopes”
University of Twente, Holland

“Alex”
University of Delaware, USA
International Congress for Rehabilitation Robotics 2007

“Haptic Walker”, Frauenhofer Institut Berlin, Germany
Human Centered Robotics

A Human-centered Robot should be

- Safe
- Compliant, gentle, adaptive
- Easy to use, entertaining
- Communicative
- Humanoid in his behaviour & appearance

A Human-centered Rehabilitation Robot should

- Be able to detect intention and support patient motion
- \textit{Not} bind patient to a predetermined motion
- Motivate the patient
Outline

Basics of Neurorehabilitation

Evolution of robotic devices

Robotic devices for rehabilitation of lower Extremities

Robotic devices for rehabilitation of upper Extremities
Robotic devices for lower extremity

Lokomat® System

Gait Trainer

REOAmbulator
Lokomat® System

**Treadmill**
- Speed range: 0 – 5 km/h
- Parallel bar with adjustable height and width

**Lokobasis**
- Body weight support system (BWSS)

**Lokomat**
- Adjustable driven gait orthosis
- Treadmill training speed: 1 – 3.2 km/h
Lokomat® - Spinal cord injury patient

Before Lokomat training

After 2 wks BWSTT

Video courtesy of the University of Texas SW, Dallas, U.S.
Lokomat® - Spinal cord injury patient

During Lokomat training

Video courtesy of the University of Texas SW, Dallas, U.S.
Lokomat® - Spinal cord injury patient

After Lokomat training

Video courtesy of the University of Texas SW, Dallas, U.S.
Control-Strategy

- Position Control

\[ \varphi_1 \text{ (hip angle)} \]

\[ \varphi_2 \text{ (knee angle)} \]

stancephase  swingphase
Control-Strategy

- Impedance Control

$\phi_1$ (hip angle)
$\phi_2$ (knee angle)

(Riener et al. 2005)
Assessments are important

**Neurological Injury**
spinal cord injury, brain injury, stroke

**Overview**

**General Effect**

- Reduced voluntary muscle force
- Increased involuntary muscle force

**Specific Effect**

- General weakness
- Weakness during walking
- Spasticity, Contractures

**Assessment Tools**

- L-FORCE
- L-WALK
- L-STIFF
- L-ROM
Assessment tools (L-WALK)

Interaction between Lokomat and patient can be measured

- Biofeedback
- Control of progress
- Outcome measures
- Research
Lokomat Assessment tools

**L-FORCE**
- The isometric force (torque) generated by the subject while in a static position
Lokomat Assessment tools

L-STIFF

- The mechanical stiffness of the patient's joints while the legs are passively moved in a specific pattern (Outcome-Value: Nm/degree)
Pediatric Lokomat®

Photo courtesy of Children's University Hospital Zurich, Switzerland
What do we need in the future?

Augmented Feedback

- Motivation ↑
- Augmented Feedback ↑
- Task-oriented nature ↑
- Task Complexity ↑

CNS Plasticity

Carryover to Real World

Justification of using Virtual reality

- Training is important for rehabilitation.
- Motivation is essential for active training.
- Interactive feedback can support motivation.
- Robotic and computer technology can supply interactive feedback.

- Key concepts of rehabilitation:
  - frequent repetitive practise
  - functional feedback to patients
  - Increase motivation

- Several studies show improved therapy results with the use of virtual reality technologies, or at least the potential of benefits.
Lokomat Augmented Feedback Module

• Components
  - additional software for displaying and controlling virtual environments
  - large screen monitor (or optional projection) with stereo sound
  - additional computer

• Features
  - The patients receive feedback on their walking behaviour in the Lokomat by movements in a virtual environment. The movements of the patients’ representation – the so called “avatar” – can be controlled by the patients through their leg movements.
  - The patient have to perform certain tasks (e.g. collect objects).
  - The therapist can adjust the system before and during the training to the patients’ preferences and needs.

• The module is still under development. Software updates are included.
Future: Augmented feedback

Video courtesy of University Hospital Balgrist, Zurich
Lokomat Augmented Feedback Module
Augmented Feedback
Evidence based data

- Lokomat therapy improves gait symmetry, increases aerobic metabolism and muscle tissue in stroke patients (*Husemann et al.*, 2007)

- Lokomat intervention demonstrated to improve walking speed, endurance, muscle strength and muscle tone compared to conventional physical therapy in stroke patients (*Mayr et al.*, 2007)

- Intensive locomotor training with the Lokomat results in improved overground walking in chronic incomplete SCI patients (*Wirz et al.*, 2005)

- Intensive task-specific training, such as Lokomat therapy, can promote supraspinal plasticity in the motor centers known to be involved in locomotion of SCI patients (*Winchester et al.*, 2007)

- Lokomat training is feasible for children with central gait impairments from 4 years of age and leads to significant improvement in velocity, endurance and motor function (*Meyer-Heim et al.*, 2007)
Outline

Basics of Neurorehabilitation

Evolution of robotic devices

Robots for rehabilitation of lower Extremities

Robots for rehabilitation of upper Extremities
Robots for upper Extremity

Endefferctor-Based

- Easy to adjust to patient
- Arm posture is not fully determined, no full extension
- Risk of joint injury

Exoskeleton

- Joint axes fully determined
- Robot axes have to align with anatomical axes
- Challenging at shoulder
EU Project: GENTLE/s

Hocoma
The PECRO Exoskeleton

(Dario et al., St‘Anna, Pisa, Italy)
ARMin

(Riener et al., ETH Zürich, Switzerland)
Devices for upper extremity

Armeo®

Reo™ System

InMotion Shoulder-Elbow Robot
Armeo®
Functional upper extremity therapy

The Armeo combines:

- An **adjustable arm support** that counterbalances the weight of the patient’s arm

- **Augmented feedback** for improved motivation and assessment of the patient’s progress

- A **large 3-D workspace** that allows functional therapy exercises in a virtual reality environment
Armeo® - Stroke patient

- Functional exercises with arm support
- Augmented feedback
- Enhanced motivation

Stroke patient
Efficacy of Armeo® training: Results

Subjective evaluation of Armeo
- Less boring
- More likely to complete at home
- Tracking progress

Comparison of Armeo Therapy with conventional Therapy

Data from the study conducted at RIC under Prof. D. Reinkensmeyer and S. Housman
Efficacy of Armeo® training: Summary

- Significant improvements in quality and amount of arm use at follow up only in the Armeo group
- Significant functional improvements (Fugl Meyer Score) in both groups
- Significant improvement in active range of motion only in the Armeo group
- Armeo is the favored therapy approach: Higher motivation and satisfaction with therapy in the Armeo group

Data from the study conducted at RIC under Prof. D. Reinkensmeyer and S. Housman
Conclusion

• There is increasing experimental evidence that individuals receiving more therapy with a robotic device can recover more movement ability.
• Robotic devices are opening up new opportunities and therapies which might enhance conventional therapy approaches.
• The correct use of these new devices will be crucial to ensure most effective treatments.
• Robotic devices should be understood as assistants which will not replace therapists.
Thank you for your attention