ShanghAI Lecture Series
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Design Principles for Intelligent Rehabilitation Robots

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Disadvantage of Manual Training

For the Therapist
- Physically exhausting
- Ergonomically inconvenient

For the Patient
- Limited training duration
- Gait pattern not optimal

SCI Center, Balgrist
Human-Robot Gait Rehabilitation
Gait Rehabilitation "Robots"

GaitTrainer  G-EOM

Haptic Walker  HAL

Lopes  Auto ambulator
ARMin III

Exoskeletal Robot with 7 Degrees of Freedom

ETH Zurich/Balgrist, Hocoma AG
Nef, Riener et al. 2006-2011
Arm Rehabilitation Robots

MIT Manus

Bi-Manu-Track

MGA

Salford PMA

Haptic Master, GENTLE/s

PERCRO Exoskeleton

KIST Arm
Sensory-Motor Interaction

Focus: Exoskeletons for Clinical Rehabilitation
Setups: Lokomat, ARMin
Sensory-Motor Characteristics

To Be Known about Human Physiology

- Nervous system is plastic
Sensory-Motor Characteristics

To Be Known about Human Physiology

- Nervous system is plastic
To Be Known about Human Physiology

- Nervous system is plastic
- Participation increases plasticity
Passive vs Active Training

Limitations of Passive Training of Healthy Subjects

• Physical guidance hinders motor learning of walking balance
  Domingo & Ferris, 2009

• High frequency guiding is detrimental for learning of arm movements (guidance hypothesis)
  Weinstein et al. 1994; Marchal-Crespo & Reinkensmeyer 2008

Assist-as-Needed Training (ANN)

• AAN shows higher level of recovery step number, periodicity, and consistency (27 mice)
  Cai et al. 2006
Lokomat: Patient-Cooperative Control

Path Control

- Robot behaves assistive, corrective or transparent, when needed
- Free timing for patient
- Support patient, but do not restrict patient

Path Control Increases Participation

Muscle Activity

Heart Rate

- Normalized muscle activity (BF)
- Position control
- Path control

Relative increase of heart rate

Init. loading
Mid stance
Term. stance
Pre swing
Init. swing
Mid Swing
Term. swing

11 incomplete SCI subjects

Position control
Path control
Sensory-Motor Characteristics

To Be Known about Human Physiology

- Nervous system is plastic
- Participation increases plasticity
- Repetition without repetition
Path Control Enhances Variability

“Repetition without Repetition”

Position Control

Path Control
Sensory-Motor Characteristics

To Be Known about Human Physiology

- Nervous system is plastic
- Participation increases plasticity
- Repetition without repetition
- Provide large ROM, avoid joint stress
Main Problem with Exoskeletons

Alignment of Robotic and Human Joints
Main Problem with Exoskeletons

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Main Problem with Exoskeletons

Alignment of Robotic and Human Joints
Humerus Motion
Humerus Motion

\[ \Delta y = 124 \text{ mm} \]

\[ \Delta x = 28 \text{ mm} \]

Body height: 1.7 m
ARMin II Shoulder Kinematics

Vertical shoulder displacement

Vertical displacement of main drive
ARMin III: Novel Shoulder Actuation
ARMin III: Novel Shoulder Actuation
ARMin III: Novel Shoulder Actuation

- Axis 1
- Axis 2
- Axis 3
- Axis 4
- Fixation screw
- Force/torque sensor
- 2 Laser pointers

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Sensory-Motor Characteristics

To Be Known about Human Physiology

- Nervous system is plastic
- Participation increases plasticity
- Repetition without repetition
- Provide large ROM, avoid joint stress
- Each patient is different
ARMin III: Adjustments
Lokomat: Adaptive Force Field

Adapt Field with a Iterative Learning Controller

Reference trajectory

Actual trajectory
To Be Known about Human Physiology

- Nervous system is plastic
- Participation increases plasticity
- Repetition without repetition
- Provide large ROM, avoid joint stress
- Each patient is different
- Motivation increases plasticity
Human-Robot Cooperation

- Audiovisual & haptic displays
- Task specific controller
- Force and position recordings
- Psychophysiological recordings

- Stimuli
To Be Known about Human Physiology

• Nervous system is plastic
• Participation increases plasticity
• Repetition without repetition
• Provide large ROM, avoid joint stress
• Each patient is different
• Motivation increases plasticity
• Train activities of daily living
Task Specific Training

Chronic Stroke Patient (FMA=26)
Task Specific Training
Conclusion and Outlook

Taking into Account Human Physiology

- Robots can allow efficient & intensive & individual training
- Robot can cooperate to keep the patient active
- Robots can motivate the patient

Chances

- Improve health status and quality of life (patients)
- Reduce workload of clinical staff (therapists, nurses)

To do

- Clinical evaluation studies on patients