Robot-aided gait training in neurological patients with the LOPES device

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Overview

- Impaired walking ability in Spinal Cord Injury (SCI)
- Robot aided gait training in SCI
- Challenges in robot aided gait training
- Robot aided gait training with LOPES
  - Selective support of subtasks to increase patient participation
  - First clinical trial in chronic stroke survivors
- Future directions
Walking in spinal cord injury

- Spinal cord injury results in impaired walking ability due to:
  - Reduced coordination
  - Leg paresis
  - Impaired balance
- Improvements in function
  - Neural plasticity
  - Regeneration and neural repair
  - Muscle strength
  - Compensation
- High priority for restoration of walking [Ditunno et al, 2008]
## Prognosis of regaining walking ability

<table>
<thead>
<tr>
<th></th>
<th>Regaining ambulation</th>
<th>Dobkin et Al (2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A – sensory-motor complete</td>
<td>3% (some ambulatory function)</td>
<td></td>
</tr>
<tr>
<td>B – motor complete, sensory incomplete</td>
<td>50%</td>
<td>35%</td>
</tr>
<tr>
<td>C – sensory-motor incomplete, little strength</td>
<td>75%</td>
<td>92%</td>
</tr>
<tr>
<td>D – sensory-motor incomplete, little impairment</td>
<td>95%</td>
<td>92%</td>
</tr>
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</table>
Regaining walking ability

Van Hedel et al, 2009
Robot aided gait training – Rational

- Control of locomotion
  - Central Pattern Generators (CPG): generate rhythmic spatiotemporal muscle activity patterns based on sensory input (load receptors and hip angle)
  - Supraspinal input
  - Robots can provide afferent stimuli to drive CPG

Robots can provide task specific and intensive training without placing a heavy physical burden on therapists

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Effectiveness of robot aided gait training

- 20 chronic montor incomplete SCI patient (ASIA C and D)
- Pre-post design
- 3 to 5 training sessions with the Lokomat per week over 8 weeks

Wirz et al, 2005

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Overview of Effectiveness

- Cochrane review Mehrholz (2008)
  - No statistical beneficial effect of
    - Robotic assistance
    - Functional electrical stimulation

- Very limited number of randomized clinical trials,
  - Different studies in progress:
    - Hornby
    - Fieldfote
    - Behrman
    - Van Nunen (RCA, Amsterdam)

Further optimization of therapy required
Metabolic cost is lower during robotic-assisted treadmill training than during manual-assisted training.

Lower metabolic cost during quiet stance due to stabilization provided by the robot.
Robot aided gait training – Challenges

- Incorporate knowledge about motor learning/recovery in design and control of robots
  - Improve active participation
  - Allow subject to make errors
  - Support different recovery mechanisms
    - Recovery
    - Compensation

Design controllers that only “assist as needed”
Assist as needed

- Assist As Needed requires interactive control
  - Control interaction forces between robot and patient (impedance and or admittance control)

- Imposes new challenges
  - Appropriate type: what should be supported?
  - Appropriate timing: when should the subject be supported?
    - Critical in walking
  - Appropriate level: how much support should be given?
Basic idea: apply assistance of specific subtasks

- Gait consists of different subtasks that have to be accomplished successfully to progress without falling
- Support each subtask during the appropriate phase of walking
Proof of principle for selective control of subtasks
Proof of principle: selective support of subtasks in healthy subjects

- Algorithms developed for
  - Support in foot clearance
  - Support in making a step
  - Support in weight bearing

- Control algorithms were implemented in LOPES

- Tested in healthy subjects and chronic stroke survivors

LOPES: light weight impedance controlled device with 8 degrees of freedom

Veneman et al [2007]
Selective support by using Virtual Model Control
Explained for step height support

- Generate reference trajectory
- Calculate virtual force
  \[ z < z_{\text{ref}} \Rightarrow F_z = K_z (z_{\text{ref}} - z) \]
  \[ z > z_{\text{ref}} \Rightarrow F_z = 0 \]
- Calculate desired joint torques
  \[
  \begin{pmatrix}
    \tau_{\text{hip}} \\
    \tau_{\text{knee}}
  \end{pmatrix}
  = a \frac{h}{J}^T \begin{pmatrix} 0 \\ F_z \end{pmatrix}
  \]
Healthy subject walking with support of step height
Support of step height only affects step height and leaves remaining of walking pattern unaffected.

8 subjects walking with LOPES and receiving support during random trials.

A lower virtual stiffness requires a larger contribution of the subject to reach the target step height.

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Chronic stroke survivor walking in LOPES
Selective support of step height induces effects in supported and unsupported degrees of freedom that outlast the exposure time.

Chronic ambulatory stroke survivor with stiff knee gait

Maximal knee flexion

Maximal hip abduction

10 steps before support
First 10 steps with support
Last 10 steps with support
First 10 after support
Conventional body weight support

- Conventional: Body weight support by using harness and overhead suspension system.
  - Provides stability to trunk
  - Provides support to both legs
  - Reduces input to load sensors of feet

- Weight support is coupled to balance control
Selective support of body weight

- Provide knee and hip torques to support the weight at a joint level.
  - Provide a virtual downward force at the ankle
    - Set as a percentage of body weight
    - Set for each leg individually
Selective weight support results in increased knee and hip extension during midstance

Interspersed catch trials show exaggerated flexion, which indicates adaptation to the support.

7 subjects walking with LOPES and receiving continuous support (30% of weight)

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Selective weight support leaves other gait parameters unaffected.
Summary proof of principle for selective control of subtasks

- The implemented control algorithms allow us to selectively support
  - Step height
  - Step length
  - Body weight support
- Stroke survivors experienced the support as comfortable and the support encouraged them to improve the performance of the subtask
- Control algorithms for other subtasks are under development
- Selective support of subtasks provides support with
  - Appropriate type
  - Appropriate timing
  - ? Appropriate amount

How to provide the subject with the appropriate amount of support?

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Clinical trial in chronic stroke survivors
First clinical effect study with LOPES

- Research questions:
  - Does robot aided gait training result in improved knee flexion during overground walking in stroke survivors with stiff knee gait?
  - Can possible improvements be ascribed to the received support?

- Evaluation
  - Clinical gait analysis

Diagram:
- 5 stroke survivors
  - Training, Training, Training, Test, Training, Training, Training, Test
- 4 stroke survivors
  - Training, Training, Training, Test, Training, Training, Training

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Robotic support does not have a clear beneficial effect in improving knee flexion during swing

Clinical gait analysis before and after 18 sessions of robot-aided gait training.

Group receiving support of step height

Group receiving no specific support

Change in knee flexion could partly be ascribed to change in walking velocity.
Robot aided gait training can result in a partly restoration of movement patterns to premorbid levels in chronic stroke survivors.

- In the small group of subjects, the kind of support did not seem to influence whether recovery occurred or not
- Improvements were subject dependent
  - What determines whether subjects can still improve
- Changes were rather small
  - Limited room in chronic stroke survivors for recovery
    - Should compensation strategies be restrained?

Open questions:
- What will the effect of this kind of support be in subacute stroke survivors?
Summary incorporate automatic adaptation of amount of support into selective control of subtasks

- Incorporation of automatic adaptation of impedance in the selective support control:
  - Appropriate type
  - Appropriate timing
  - Appropriate amount: reduces the need for the therapist/operator to set the amount of support on a trial and error basis

- Optimal settings of adaptation algorithm are yet unknown

Does the support result in lasting effects in stroke survivors?
Future directions

- LOPES is going to be redesigned and placed in rehabilitation centers (Roessingh, Sint Maartenskliniek)
- Application in other patient populations will be investigated
  - Spinal cord injury!
    - Additional requirements?
      - Spasms
      - Clonus
      - Bilateral
- Different support algorithms will be investigated to determine the optimal way to facilitate recovery
  - Subject specific!
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