Robot-aided assessment of walking recovery

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Introduction

Walking recovery, defined as the regaining of ability to walk independently in the community (functional walking) is among the highly desired goals of the rehabilitation for patients after stroke and spinal cord injury. Valid, reliable and sensitive assessments of walking-related functions for everyday clinical practice are needed for therapy adjustment even before the patient is actually able to walk.
Robotic gait trainers have become established as a valuable strategy for gait rehabilitation after neurological injury. The Lokomat (Hocoma AG) provides therapy under controlled and repeatable conditions while supporting patients with severe walking impairments. Robot-aided assessment and robot-aided training can be combined with the Lokomat. Because of the adjustable assistance that the Lokomat can provide, robotic assessments can be administered even if the patient is not able to perform the movement without support. This can enlarge the measureable range of impairment and improve sensitivity.
The long-term goal is the development of an objective and quantitative assessment of walking recovery available in the Lokomat that targets the early rehabilitation population and that can be used during everyday clinical practice.
In this study a novel adaptive control algorithm has been developed in order to provide a safe framework for assessing patients with different levels of gait impairments while at the same time challenging them to perform at the best of their capacity. The hypothesis is that the robotic support (joint mechanical impedance and unloading) converges to a level that is indicative of the patient's impairment.
The validity and reliability of the method has been studied first on healthy subjects.

Methods

The mechanical impedance (*guidance force* - GF) of the Lokomat joints and the unloading of the body weight are normally adjusted manually by the therapist to match the level of support required from the patient. Here an "assist-as-needed" approach based on Iterative Learning Control has been applied: at the beginning of each stride n the GF and the unloading are updated based on the control error e during the previous stride multiplied by a learning gain g and on a forgetting term (f <1) that prevents the excessive reliance on the robot assistance:

$$GF(n+1,w) = f \cdot GF(n,w) + g \cdot e(n,w)$$

Two mechanisms act separately on the GF and on the unloading based on two different error metrics. The GF is adapted in an almost continuous way (28 windows per gait cycle) based on the absolute deviation of the hip and knee angles from the reference angular trajectories in each window w. Physiological deviations from the reference trajectory are allowed and not considered as errors. The error metric for the unloading mechanism is based on the difference between reference and actual height of the hip center of rotation. Two values of unloading are calculated and applied separately for the left and right stance phases.
Initially the GF is set at 100% (corresponding to a stiffness of 1200 Nm/rad) and the unloading at 90% of the body weight. The subjects are asked first to walk normally and then to simulate a passive condition (trying to rely solely on the device assistance).

Results

Results from five healthy subjects will be presented. The assessment procedure was perceived as smooth and safe and no stumble was detected by the safety mechanisms of the device. The guidance force reached a low value (less than 10% of the initial value averaged on the gait cycle) after 25 steps in the active condition. When the subjects simulated weakness the stiffness profile was shaped according to the kinematic error and converged to a profile representative of the support needed in the different gait phases (25% of the initial value on average). Similarly, the unloading decreased until the minimum amount (5 kg) when the subjects walked actively, while it was maintained high in the passive condition.

Conclusion

The Lokomat control with adaptive GF and unloading is a promising approach for assessing gait recovery during therapy in a standardised condition. The almost continuous shaping of the GF is potentially able to identify and quantify the impairments of the patients in the different gait phases and monitor their progression over time, while the amount of unloading can provide a measure of weight bearing ability. This approach could represent a safe and fast assessment procedure that can be easily integrated in clinical practice and provide therapists with objective assessments. A further study including chronic spinal cord injury patients with different level of walking impairment is foreseen in order to validate the assessment algorithm in a neurologic population.