Recovery of walking ability using a robotic device

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Summary

The Lokomat is a device consisting of a treadmill, body weight support system and two robotic orthoses which can guide the legs of severely affected neurological patients during walking on the treadmill. The goal of this thesis was to evaluate the use of the Lokomat in rehabilitation after stroke and spinal cord injury. We studied the effectiveness of the Lokomat in improving walking ability (**chapter 4 & 7**), assessed the effects of walking in the Lokomat on the cardiorespiratory system (**chapter 3 & 6**), examined muscle activation patterns during walking in the Lokomat (**chapter 2**) and studied the association between recovery of strength of the paretic leg and balance (**chapter 5**). **Chapters 2 to 5** were focused on stroke patients, whereas **chapters 6 & 7** were focused on patients with spinal cord injury.

To evaluate the influence of the assistance of the Lokomat and the limited degrees of freedom in terms of muscle activity we compared electromyography of leg muscles in stroke patients during walking in the Lokomat and during overground walking (**chapter 2**). Furthermore, a set of 'normative' muscle activity patterns was assessed in healthy subjects walking unassisted. Results showed that, in most muscles, activity was equal or lower than during overground walking. Furthermore, for some muscles, activity seemed less associated with a pattern of muscle activity corresponding to that of healthy individuals walking overground. We concluded that training in the Lokomat may elicit lower muscle activity and changes in the naturally occurring muscle activation patterns during walking in some muscles. These results may be explained by the body weight support, by the assistance provided by the orthoses and by the limitations in degrees of freedom of the Lokomat.

In **chapter 3**, we studied the influence of the assistance of the Lokomat and the limited degrees of freedom during walking in the Lokomat on the cardiorespiratory system by comparing heart rate (HR) and oxygen consumption ($\dot{V}O_2$) during walking in the Lokomat and during overground walking. We concluded that exercise intensity levels during walking in the Lokomat were 'light' according to general exercise recommendations and lower compared to overground walking in the group of stroke patients participating in this experiment. These results suggest that, using this type of therapy, patients will probably not substantially improve in cardiorespiratory fitness. Furthermore, we demonstrated that more challenging settings of the Lokomat did not lead to higher cardiorespiratory intensities during walking in the Lokomat in healthy subjects. These results may suggest that it is unlikely that patients with stroke achieve substantial exercise intensity during walking in the Lokomat with the combination of settings used in this experiment.

In **chapter 4**, we studied the effectiveness of the Lokomat relative to conventional therapies in improving walking ability in non-ambulatory stroke subjects involved in inpatient rehabilitation. The patients in the intervention group received 8 weeks of Lokomat therapy twice a week, together with 3 times 30 minutes a week of conventional overground therapy. A control group received conventional assisted overground therapy during a similar amount of time. Outcome of therapy was assessed at study entry, after the intervention, and at wk24 and wk36 after baseline assessment. Patients showed significant improvements in walking speed, function and mobility, and strength of the paretic leg relative to baseline values at all assessments, but we found no significant differences between Lokomat and conventional training in improvements in any of the variables at any time during the study. Moreover, effect sizes of the differences in the improvements over the intervention period between groups were small in all outcome measures. We therefore concluded that Lokomat training is as effective as conventional training for increasing walking ability in non-ambulatory stroke patients.

In **chapter 5**, we evaluated the association of balance and strength of the knee extensors at multiple assessments during the rehabilitation process after stroke. Balance and strength can both be clearly affected after stroke. In several cross-sectional studies, performance of functional activities and measures of strength of the paretic leg have been shown to be related. However, during the rehabilitation process, both improve, and we have poor understanding of the course of the association of balance and strength of the knee extensors during the rehabilitation process. We demonstrated that there is a positive and significant relationship between these variables at all assessments. We observed that the association between balance and strength seems to improve over time, which is possibly due to the combination of two findings in the literature on recovery after stroke: the relationship between initial impairments and reductions in impairment and, secondly, the presence of compensation strategies that allow patients to improve (on average) relatively more in performance of functional activities than in impairment. Moreover, we found a significant association between changes in balance and changes in strength of the knee extensors over the period of wk1-wk10 of the study (relatively early after stroke), whereas there was no significant association over the period of wk10-wk24 of the study (relatively late after stroke). These findings may suggest that improvements of performance of functional activities are more related to improvements in voluntary activation than to improvements in cross-sectional area of the muscle. Alternatively, inter-individual differences in improvements in balance or improvements in other impairments which may affect balance (such as sensory function) may explain our results.

Interventions to promote physical activity in the spinal cord injury population are becoming increasingly important since being physically active may improve general health. In **chapter 6**, we studied the effect of a period of robot-assisted gait training on cardiorespiratory fitness. The training program consisted of a total of 24 training sessions on the Lokomat with additional conventional therapy. To assess the intensity of the training program, $\dot{V}O_2$ and HR were measured during training sessions. Cardiorespiratory fitness was assessed before and after the intervention in a graded arm crank exercise test. Results suggested that, participants exercised at 'light' intensity according to general exercise recommendations. Analyses of data of the exercise test however, showed that submaximal and resting HR was significantly lower after the intervention, with no significant changes in $\dot{V}O_2$ suggesting higher stroke volume. However, oxygen pulse did not significantly change. We concluded that in spite of the low exercise intensity of Lokomat therapy, this intervention may have a positive effect on cardiorespiratory fitness. However, likely improvements in cardiorespiratory fitness are small.

In **chapter 7**, we studied the effects of an intervention of 24 sessions of Lokomat therapy with additional overground walking over 4 months on ambulatory function, balance, participation and general health. Although at group level some results showed significant improvements between pre- and post test, there was quite some variation in the size of improvement among subjects. Moreover, the lack of an effect in all gait related outcome measured suggested that improvements were small. We concluded that during our intervention with Lokomat therapy with additional overground walking patients improve some aspects of walking ability, however, in most patients, gains in walking ability are small.

Finally, implications of present insights and recommendations for future research are discussed in **chapter 8**. Literature on animal studies and motor learning suggest that recovery of function after neurological injury is possible through practice. However, there is still a gap between the suggested potential for recovery after stroke and spinal cord injury and what we have accomplished so far by interventions. Research needs to focus on how to optimize therapy based on current knowledge. Moreover, it is essential to gain knowledge about how to optimally employ the Lokomat in terms of adjusting settings such as speed, amount of body weight support duration, amount and type of assistance of the orthoses and frequency of training before a final verdict can be made on the effectiveness of the Lokomat, or any such device. Research should also focus on identifying possible subgroups of patients who might benefit from this therapy. In order to succeed in this, particularly in a small country as the Netherlands, collaboration between several rehabilitation institutes in gathering such information is essential. Moreover, further into the future, new treatments will be developed, probably combining our present knowledge of motor learning with newly developed therapies (e.g. with brain or spinal cord stimulation or pharmacological substances). In these future developments, robotic systems may have an important role.