Bern University
of Applied Sciences

Research Group
IRPT – Rehabilitation Engineering

Overview

Our interdisciplinary research focusses on neural control of movement in clinical populations with neurological deficits resulting from spinal cord injury, stroke and other causes. Combining rehabilitation technology and cognitive performance feedbacks our goal is to reinforce the patient's volitional drive and to exploit the central nervous system's lifelong capacity for plasticity, regeneration and repair. This approach promotes cardiopulmonary and musculoskeletal health and supports a CNS environment in which positive neurological adaptations can occur.

The work harnesses multidisciplinary expertise in engineering, neurosciences, sports and exercise science and medicine to address prevention and management of the progressive secondary complications of spinal cord injury and stroke and a wide range of further neurological conditions and to promote neurological recovery for improved motor control, sensation and autonomic function.

Competences

The group develops new technical devices and extends the functionality of existing products. New developments include novel rehabilitation tricycles for adults and children with neurological impairment. Our new generation of tricycles combines novel drivetrain technology using electric drives with functional electrical stimulation (FES) of paralysed muscle groups.

The functionality of existing robotics-assisted rehabilitation devices, including treadmills and tilt tables, has been extended to cover application for cardiopulmonary rehabilitation. This involves biofeedback of patient effort, volitional control of mechanical work rate, together with automatic feedback control of physiological outcome variables including heart rate, oxygen uptake and metabolic work rate.
A key feature of our work is the employment of methods and protocols from sports and exercise physiology and the adaptation of these to the rehabilitation setting.

These approaches are applied in the clinic for rehabilitation of people with various neurological problems including stroke and spinal cord injury.

Key Projects

The following selection of research and clinical projects gives an overview of the spectrum of research activities of the group:

- Cardiopulmonary rehabilitation of stroke patients using robotics-assisted treadmill exercise (RATE)
- Active control and neurological stimulation of the ankle joint during RATE
- Cardiopulmonary rehabilitation of patients with incomplete spinal cord injury using a robotics-assisted tilt table
- Rehabilitation tricycle incorporating FES and motorized assistance
- Physiological responses to μ-vibration of the foot soles during gait-like motion

Infrastructure

The IRPT has an excellent infrastructure for research including a dedicated research lab within the Reha Rheinfelden. Robotics-assisted devices include a treadmill (Lokomat) and tilt table (Erigo) by Hocoma. We also have modern cardio-respiratory monitoring systems. Initial research and development work is carried out in our labs in Burgdorf.

Publications

The following is a selection of recent publications by K. J. Hunt in the area of rehabilitation engineering:

[1] L. P. Jack, M. Purcell, D. B. Allan, and K. J. Hunt, The metabolic cost of passive walking during robotics-assisted treadmill exercise, Technology and Health Care, vol. 19, January 2011.
[2] L. Bichsel, M. Sommer, and K. J. Hunt, Weiterentwicklung eines automatisierten Kipptisches mit Beinantrieb für die Regelung der Patientenbelastung, in Proc. Automed 2010, (Zürich), October 2010.
[3] L. P. Jack, M. Purcell, D. B. Allan, and K. J. Hunt, Comparison of peak cardiopulmonary responses during robotics-assisted treadmill exercise and arm-crank ergometry in incomplete spinal cord injury, Technology and Health Care, vol. 18, no. 4/5, pp. 285-296, 2010.
[4] A. Pennycott and K. J. Hunt, Cadence control system for paediatric functional electrical stimulation cycling, Biomed. Signal Process. Control, vol. 5, pp. 237-242, July 2010.
[5] A. Pennycott, K. J. Hunt, S. Coupaud, D. B. Allan, and T. H. Kakebeeke, Feedback control of oxygen uptake during robot-assisted gait, IEEE Trans. Control Sys. Tech., vol. 18, pp. 136-142, January 2010.

[6] C. G. A. McRae, T. E. Johnston, R. T. Lauer, A. M. Tokay, S. C. K. Lee, and K. J. Hunt, Cycling for children with neuromuscular impairments using electrical stimulation - development of tricycle-based systems, Med. Eng. Phys., vol. 31, pp. 650-659, July 2009.
[7] K. J. Hunt and D. B. Allan, A stochastic Hammerstein model for control of oxygen uptake during robotics-assisted gait, Int. J. Adaptive Control Signal Process., vol. 23, pp. 472-484, May 2009.
[8] A. Pennycott, K. J. Hunt, L. P. Jack, C. Perret, and T. H. Kakebeeke, Estimation and volitional feedback control of active work rate during robot-assisted gait, Control Eng. Practice, vol. 17, pp. 322-328, February 2009.
[9] H. R. Berry, C. Perret, B. A. Saunders, T. H. Kakebeeke, N. Donaldson, D. B. Allan, and K. J. Hunt, Cardiorespiratory and power adaptations to stimulated cycle training in paraplegia, Med. Sci. Sports Exerc., vol. 40, pp. 1573-1580, September 2008.
[10] L. P. Jamieson, K. J. Hunt, and D. B. Allan, A treadmill control protocol combining nonlinear, equally smooth increases in speed and gradient: exercise testing for subjects with gait and exercise limitations, Med. Eng. Phys., vol. 30, pp. 747-754, July 2008.
[11] K. J. Hunt, B. Stone, and D. B. Allan, Feedback control of oxygen uptake during stimulated cycle ergometry in subjects with paraplegia, IET Control Theory Appl., vol. 2, pp. 488-495, June 2008.
[12] K. J. Hunt, L. P. Jack, A. Pennycott, C. Perret, M. Baumberger, and T. H. Kakebeeke, Control of work-rate-driven exercise facilitates cardiopulmonary training and assessment during robot-assisted gait in incomplete spinal cord injury, Biomed. Signal Process. Control, vol. 3, pp. 19-28, January 2008.
[13] K. J. Hunt, B. A. Saunders, C. Perret, H. Berry, D. B. Allan, N. Donaldson, and T. H. Kakebeeke, Energetics of paraplegic cycling: a new theoretical framework and efficiency characterisation for untrained subjects, Eur. J. Appl. Physiol., vol. 101, pp. 277-285, October 2007.
[14] C. Ferrario, K. J. Hunt, S. Grant, A. N. McLean, M. H. Fraser, and D. B. Allan, Control approach for high sensitivity cardiopulmonary exercise testing during stimulated cycle ergometry in spinal cord injured subjects, Biomed. Signal Process. Control, vol. 2, pp. 311-322, October 2007.
[15] K. J. Hunt, C. Ferrario, S. Grant, B. Stone, A. N. McLean, M. H. Fraser, and D. B. Allan, Comparison of stimulation patterns for FES-cycling using measures of oxygen cost and stimulation cost, Med. Eng. Phys., vol. 28, pp. 710-718, September 2006.

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Research Group
IRPT – Sports Engineering

Overview

The sports engineering group focuses on interdisciplinary research on advanced feedback control methods for treadmill automation. The work builds on multidisciplinary expertise in engineering and sports and exercise science.
The work deals mainly with high-end performance, but many of the methods have also been translated successfully into our rehabilitation engineering activities.

Competences

We have developed feedback control algorithms that allow exercise intensity to be specified for training and testing via automatic regulation of heart rate, oxygen uptake, or metabolic work rate. In each case, a target profile for the controlled variable is selected. During the exercise, treadmill speed and slope are automatically adjusted so that the target response is achieved.

Also high-precision positioning algorithms have been developed. This allows users to select their own walking or running speed, while the feedback control continuously adjusts treadmill speed to maintain a reference position.
These applications are available for walking, running and cycling on a treadmill.

Key Projects

The following selection of research and development projects gives an overview of the spectrum of research activities of the group:

- Feedback control of heart rate, oxygen uptake or metabolic work rate during treadmill exercise
- Automatic position control for walking and running
- Automatic control of position and physiological variables while cycling on a treadmill

Infrastructure

Our labs in Burgdorf are equipped with a high-performance treadmill (Venus by h/p/cosmos). Various position monitoring sensors, including ultrasound and laser and a real-time communication protocol give complete control over the treadmill through a computer. We also have modern cardio-respiratory monitoring systems for on-line breath-by-breath recording.

Publications

The following is a selection of recent publications by K. J. Hunt in the area of sports engineering:

[1] M. Schindelholz, R. Rodriguez, and K. J. Hunt, Laufbandautomatisierung: Positionsregelung und Herzratenregelung, in Proc. Automed 2010, (Zürich), October 2010.
[2] K. J. Hunt, O. Ajayi, H. Gollee, and L. Jamieson, Feedback control of oxygen uptake during treadmill exercise, IEEE Trans. Control Sys. Tech., vol. 16, pp. 624-635, July 2008.
[3] K. J. Hunt, Treadmill control protocols for arbitrary work rate profiles combining simultaneous nonlinear changes in speed and angle, Biomed. Signal Process. Control, vol. 3, pp. 278-282, July 2008.
[4] L. P. Jamieson, K. J. Hunt, and D. B. Allan, A treadmill control protocol combining nonlinear, equally smooth increases in speed and gradient: exercise testing for subjects with gait and exercise limitations, Med. Eng. Phys., vol. 30, pp. 747-754, July 2008.

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IRPT – Sports Engineering

Position control on a treadmill using automatic speed adaptation

Lead of the Project

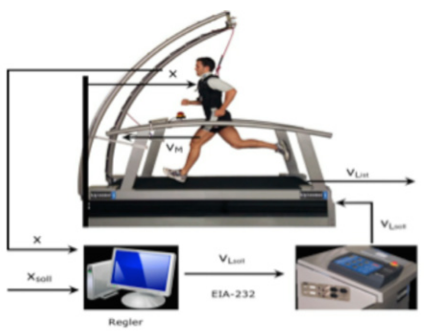
A high performance treadmill was enhanced with a feedback control system which keeps the runner close to a reference position by automatically adapting the treadmill speed. The runner can change his own running speed at any time while training; the treadmill speed is changed accordingly.

Background

Typically, a runner on a treadmill has to adapt his speed to the speed of the treadmill belt. The runner has to concentrate constantly on maintaining his speed at the given level and to stay at a safe position on the treadmill, which limits his autonomy. To vary his speed the runner has to manually set the speed of the treadmill or programme a certain speed profile in advance.
This limitation of treadmills can be overcome by applying an automatic position control system. By automatic adaption of the treadmill speed, such a system will make sure that the runner is always kept close to a reference position on the treadmill belt, regardless of his own running speed. The user can now change his running speed at any time with the treadmill adapting accordingly. This significantly extends the range of possible applications of treadmills. Athletes, for example, can train at different speeds autonomously, or therapeutic use of treadmill exercise can be optimized.

Aims

To enhance a treadmill with a position feedback control system which constantly adapts the belt speed to the running speed of the user: autonomous change of running speed becomes possible at any time during exercise.



Methods

A position measurement system detects the actual position of the runner on the belt in real time and feeds this value into a controller which compares it to a given reference position, calculates the required corrective change in belt speed (control variable) and feeds it to the treadmill. Hence the preset reference position is always maintained. For position measurement an ultrasonic sensor, an optical sensor (laser triangulation) and a wire-draw encoder have been tested. The controller was designed by the method of pole placement. System identification and modelling were used to take the dynamics of the treadmill motor into account. By changing the rise time of the closed loop control system the controller bandwidth can be adjusted, which helps to tailor the controller dynamics to the runner. Technical validation including a number of test runners showed excellent controller performance.

Project Partner

h/p/cosmos GmbH

Project Collaborator at IRPT

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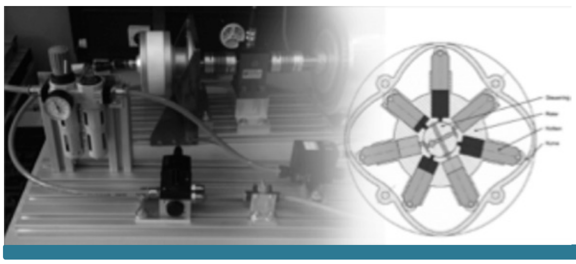
Research Group
IRPT – Rehabilitation Engineering
Optimisation of air motor drive dynamics

Lead of the Project
The development of an autonomous control unit for air motors, which allows control of both rotational speed and positioning of a linear axis, will improve the drive dynamics of the motors and open up new fields of industrial applications.

Background
Air motors exhibit large variations in rotational speed due to changes in load, which limits their use for industrial applications.

Aims
The aim of this KTI project is to improve the drive dynamics of air motors with a universal control unit that provides feedback control of both rotational speed and position of a linear axis. The industrial project partner (Soldati AG, Emmen, Switzerland) aims to open up new fields of application for air motors.

Methods
Using a custom test bed for air motors, different modes of motor operation can be created. Controllers, different types of actuators (electronically triggered pressure and flow control valves) and different types of rotational speed measurement sensors can be tested and compactly integrated into the control unit. Thanks to highly robust model based controllers using pole placement methods, no additional system identification is necessary for applying this new air motor control unit to different industrial systems.



Publications
M. Grob, Optimales Antriebsverhalten eines Luftmotors, Bachelor thesis Bern University of Applied Sciences Engineering and Information Technology, July 2011.

Project Partner
Soldati AG (CH), KTI (Swiss Commission for Technology and Innovation)

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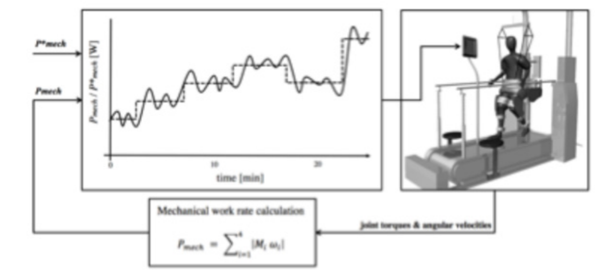
Research Group
IRPT – Rehabilitation Engineering
Lokomat

Lead of the Project
This project is developing techniques and protocols for cardiopulmonary rehabilitation using robotics-assisted treadmill exercise (RATE). The methods are clinically applied for patients following stroke and spinal cord injury.

Background
Around 75% of post-stroke patients suffer from cardiac disease. Most of these have low exercise endurance due to the cerebrovascular event, and as secondary reaction to immobility. Previous studies have shown the beneficial effects of aerobic exercise in chronic stroke. Less is known about the impact of cardiovascular exercise early after stroke. Methods for assessment of aerobic capacity in severely affected stroke patients are lacking.

Aims
The aim of the project is to evaluate the feasibility of using feedback-controlled robotics-assisted treadmill exercise (RATE) to influence and assess aerobic capacity early after stroke. We are interested in gaining preliminary evidence on the clinical efficacy of the method and focus on retention rates, suitability of inclusion/exclusion criteria, data processing, and ability to process subjects with available resources.

Methods
In-patients after stroke undergo constant load and incremental exercise testing using a human-in-the-loop feedback system in automated robotic gait orthoses integrated with a treadmill and a dynamic body-weight unloading system (Lokomat, Hocoma AG). Inclusion criteria are stable medical condition, appropriate cognitive function and moderate control of the lower limbs to voluntarily produce forces within the exoskeleton. Exercise capacity is measured using breath-by-breath pulmonary gas exchange monitoring and heart rate telemetry. Outcome measures are oxygen uptake kinetics, peak oxygen uptake, peak work rate, peak heart rate, gas exchange threshold, and work rate variability. Additionally, adherence and data processing will be evaluated.



Future directions
Following completion of a two-phase pilot study, we are now proceeding with a randomised controlled trial in the clinical setting. This work is carried out at our clinical partner Reha Rheinfelden and involves patients at an early stage of rehabilitation following stroke.

Publications
[1] M. Schindelholz and K. J. Hunt, 2012, Feedback control of heart rate during robotics-assisted treadmill exercise, Technology and Health Care, 20(3), pp 179-194.
[2] O. Stoller, E. D. de Bruin, R. H. Knols, and K. J. Hunt, 2012, Effects of cardiovascular exercise early after stroke: systematic review and meta-analysis, BMC Neurology, 12(45). doi:10.1186/1471-2377-12-45.
[3] K. J. Hunt and A. Bugmann, 2012, Feedback control of human metabolic work rate during robotics assisted treadmill exercise, Biomedical Signal Processing and Control, vol. 7, pp. 537–541. doi:10.1016/j.bspc.2011.11.001.

Project Partner
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Research Group
IRPT – Rehabilitation Engineering
Erigo

Lead of the Project
A tilt table therapy device with robotics assistance for neurological patients was enhanced with force sensors and cognitive feedback systems to allow active physiological loading of the patient, as well as objective cardiovascular testing and training. This facilitates therapeutic intervention early in the rehabilitation process.

Background
In rehabilitation of patients with spinal cord injury, stroke or other neurological conditions, early mobilisation is important. A specific and target-orientated rehabilitation strategy improves the process of recovery significantly while reducing the negative effects of immobility.

Aims
The aim of the project was to modify an existing robotics-assisted tilt table therapy device (Erigo) by implementation of force sensors and a cognitive feedback system. This should allow physiological loading of patients, as well as guided training and objective testing, thus improving target-orientated rehabilitation.

Methods
Technical development and validation was carried out to implement the new functionality. The implementation of the exercise-intensity control system and the newly designed protocols for cardiopulmonary rehabilitation was tested successfully.
A further study is investigating the influence of different tilt table settings on the physiological reaction of subjects undergoing constant work load exercise. It is also testing the quality of automatic work load control with preset physiological loading. Clinical applicability will be evaluated in a pilot study with patients shortly after stroke.

Publications
L. Bichsel, M. Sommer, and K. J. Hunt, 2010, Entwicklung eines Biofeedback-Systems zur Regelung der Leistung, Herzrate und Sauerstoffaufnahme für robotische Kipptisch-Therapie, at – Automatisierungstechnik, vol. 59, pp. 622-628.

Project Partner
Reha Rheinfelden (Switzerland)

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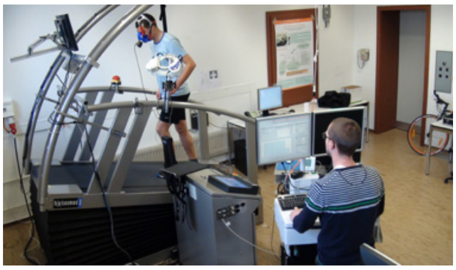
Research Group
IRPT – Sports Engineering
Treadmill and Physiological Control Systems

Project Description

Within the field of high-performance sports, it is common practice to evaluate an athlete's physical training status by carrying out a «max-test» on a treadmill or cycle ergometer. The aim is to take the athlete gradually to their limit of functional capacity, i.e. to exhaustion, over a short period of time.

Cardiopulmonary exercise testing delivers two key outcomes which describe the functional status of the heart and lungs: the Gold Standard for describing the limit of aerobic capacity, which is obtained from a max-test, is the maximal oxygen uptake (VO2-max); the maximal heart rate, HR-max, is also recorded.



When using a treadmill, the speed and slope are gradually increased with the aim of reaching maximal performance in around 10 minutes. The athlete has to run on the treadmill while the exercise intensity gradually increases, until he signals that he has reached his limit and can no longer continue – the test is then terminated.

The IRPT has applied its expertise in control systems engineering to develop an automatic positioning system for the treadmill: with this system, the runner can freely choose his own speed. The runner’s position on the treadmill belt is continuously monitored and the feedback system automatically adapts the treadmill speed to keep the runner at a desired position.

Self-Paced Max-Test

This approach allows a so-called «self-paced» max-test to be implemented, potentially resulting in higher peak VO2 and HR values.

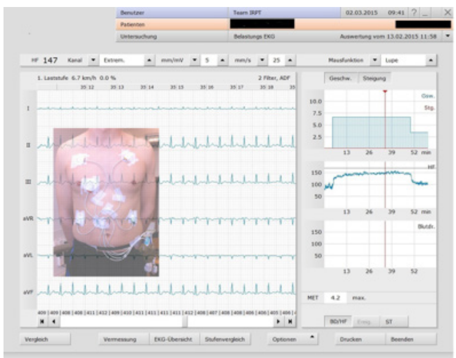
VO2-max is measured using a breath-by-breath spirometry system which involves the athlete wearing a face mask and a heart rate chest belt. The volumetric rate at which oxygen is taken up at the lungs (VO2) and carbon dioxide is expelled (VCO2) are measured. VO2-max gives a direct indication of the body's ability to extract oxygen from the air, and to transport it via blood circulation to the muscles doing the work during exercise: doing this well depends on the integrative capacity of both central and peripheral physiological systems, including the heart, lungs and muscles.

Training Intensity and HR Control

The reason measuring VO2-max is important is that, because it reflects the efficiency of interactions between the cardiovascular, pulmonary and neuromuscular systems, it gives a very direct indication of the athlete's overall fitness. This information can be used in two ways: to assess the effects of a training programme over time, by periodically re-evaluating VO2-max; and to prescribe an appropriate level for training intensity, because this is often recommended to take place at a certain frequency and duration and at some percentage of VO2-max, HR-max or HR-reserve.

To allow the implementation of high-precision training protocols which use heart rate prescription, the IRPT has developed automatic HR control system both for the treadmill and for outdoor running.

A fundamental difficulty in HR control is to ensure the HR tracking is precise, but at the same time that unwanted oscillations in the speed command do not occur. Using ECG measurements and spectral analysis techniques, the IRPT has carried out a pioneering investigation of very-low-frequency heart rate variability, and has used this information to design robust, stable and high-accuracy HR control systems.



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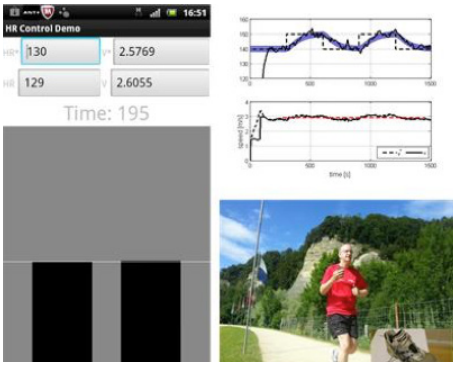
To implement feedback control of HR during outdoor running, the IRPT has employed smartphone and wearable sensor technology. This allows HR and running speed to be monitored in real time: a control algorithm running in the smartphone then updates a speed command signal displayed to the runner to make sure the target HR is maintained.



This work has shown that, even during outdoor running, very precise tracking of HR profiles can be achieved, with root-mean-square tracking errors of less than 2 beats per minute.

Implementation potential

The application of state-of-the-art feedback control technologies has extended the maximum achievable performance during treadmill testing, and has made feasible the implementation of accurate and specific training programmes during both indoor and outdoor exercise.

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Research Group
IRPT – Rehabilitation Engineering
Robotics-Assisted Technology for Cardiopulmonary Rehabilitations

Abstract
Maintenance of fitness is vital for health and well-being, but how can patients with severe disability participate in exercise? The Institute for Rehabilitation and Performance Technology (IRPT), together with clinical partner Reha Rheinfelden, has developed robotic systems for exercise testing and training.

Fig. 1: G-EO System end-effector rehabilitation robot

Aim
This research programme focus is developing techniques and protocols for cardiopulmonary rehabilitation using robotics-assisted technology. The methods are clinically applied for patients following stroke and spinal cord injury to obtain crucial data on fitness and to allow the informed prescription of an exercise training programme.

Background
Because patients with serious impairments cannot use a conventional system like a treadmill or a cycle ergometer, the IRPT has focused its research programme on the development of robotic rehabilitation systems which facilitate exercise testing and training, and on the translation of assessment protocols from high-performance sports to this new and very challenging context.

The key is to adapt robotic systems so that the patient is able to perform an increasing amount of work over a short time by volitional activation of their available muscles. To do this, we provide patients with a biofeedback system which shows them a target level of exercise intensity together with a visualization of their own performance: the target intensity increases steadily over about 10 minutes while the patient is instructed to exert themselves more and more to keep following the target. The test stops when it is clear that the patient has reached his limit.

Results
We have used this principle to adapt several systems: the G-EO-System, an end-effector robotic device for walking and stair climbing (Fig. 1) [1]; the Lokomat, an exoskeleton-based system for treadmill walking (Fig. 2) [2-4]; and the Erigo-System, a robotics-assisted tilt table (Figs. 3-4) [5,6]. For the most severely disabled patients, the Erigo allows the exercise intervention and assessments to start at the earliest possible stage of rehabilitation.

Fig. 2: Lokomat exoskeleton rehabilitation robot.

In collaboration with our clinical partners at the Reha Rheinfelden, we recently completed a breakthrough clinical study where a group of severely disabled stroke patients trained for four weeks using the augmented Lokomat system. Overall fitness was assessed using cardiopulmonary exercise testing implemented on the Lokomat [3]. We found that cardiovascular fitness, i.e. the maximal oxygen uptake (VO2-max), increased on average by 20% even though the four-week training period was relatively short and the training intensity was moderate [2,3]: this is a rapid and substantial improvement in cardiopulmonary fitness early after stroke.

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Fig. 3: Erigo robotic tilt table for early rehabilitation.

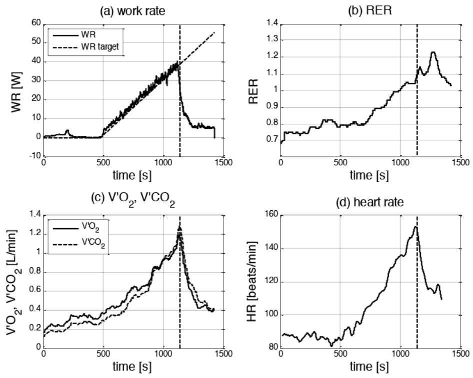

Fig. 4: Typical cardiopulmonary responses from a stroke patient – maximal exercise test on the Erigo.

Clinical potential

These very promising new results represent the successful translation of methods and protocols from the field of high-performance sports to the context of neurological rehabilitation. These are important and necessary steps towards the clinical implementation of effective cardiopulmonary exercise training and accurate assessments in patients with severe impairments.

Selected Publications

[1] O. Stoller, M. Schindelholz, L. Bichsel, and K. J. Hunt, Cardiopulmonary responses to robotic end-effector-based walking and stair climbing, Med Eng Phys, 2014.

[2] O. Stoller, E. D. de Bruin, M. Schindelholz, C. Schuster-Amft, R. A. de Bie, and K. J. Hunt, Efficacy of feedback-controlled robotics-assisted treadmill exercise to improve cardiovascular fitness early after stroke: a randomised controlled pilot trial, J Neurol Phys Ther, 2015.

[3] O. Stoller, E. D. de Bruin, M. Schindelholz, C. Schuster-Amft, R. A. de Bie, and K. J. Hunt, Cardiopulmonary exercise testing early after stroke using feedback-controlled robotics-assisted treadmill exercise: test-retest reliability and repeatability, J Neuroeng Rehabil, 2014.

[4] M. Schindelholz and K. J. Hunt, Feedback control of oxygen uptake profiles during robotics-assisted treadmill exercise, IET Control Theory & Applications, 2015.

[5] J. Saengsuwan, T. Nef, M. Laubacher, and K. J. Hunt, Comparison of peak cardiopulmonary performance parameters on a robotics-assisted tilt table, a cycle and a treadmill, PloS ONE, 2015.

[6] M. Laubacher, C. Perret, and K. J. Hunt, Work-rate-guided exercise testing in patients with incomplete spinal cord injury using a robotics-assisted tilt-table, Disabil Rehabil: Assistive Technology, 2014.

Project Partner

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Dr. Corina Schuster-Amft, Head of Research

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