The WalkTrainer—A New Generation of Walking Reeducation Device Combining Orthoses and Muscle Stimulation

Y. Stauffer, Y. Allemand, M. Bouri, J. Fournier, R. Clavel, P. Metrailler, R. Brodard, and F. Reynard

***Abstract*—This paper presents a novel reeducation device for paraplegics that combines hybrid orthoses and closed-loop electrical muscle stimulation. Based on the so called Cyberthosis concept, the WalkTrainer enables an active muscular participation of the subject in the walking reeducation process by the mean of closed-loop muscle stimulation. The WalkTrainer is also equipped with a leg and pelvic orthosis, an active bodyweight support, and motorized wheels to allow true over ground deambulation. This paper will focus on the development of the WalkTrainer, the presentation of the control strategies, and also give some preliminary results of the first clinical trials.**

***Index Terms*—Muscle stimulation, orthoses, rehabilitation, spinal cord injury.**

I. Introduction: Praplegics and Robotics

THE PARAPLEGIC population represents 1 out of 1000 people in industrialized countries. Thanks to a more effective caring right after the accident and because of the evolution of the treatment, up to 80% of the injuries can be limited to a partial lesion of the spinal cord. However, only 10% of these patients can recover autonomous walking [1].

Today paraplegic subjects perform various reeducation tasks, often on treadmill. This enables mobilization and loading of the legs. However, if the subject is too weak or lacks of coordination then several physiotherapists might have to perform the mobilization of the legs and pelvis. This work, while being profitable for the subject, is tiring for the therapist. Furthermore, no quantification of the patient's force or coordination is possible and the performed motions are of course not precise.

For all these reasons, rehabilitation robotics has appeared a couple of decades ago and novel reeducation devices are still beeing developped (Lokomat [2], Autoambulator, POGO [3]). Indeed robots are well suited for performing repetitive tasks and providing precise motions. Furthermore, by using force sensors the interaction with the patient can easily be measured and thus the training and training effect quantified. In most cases, however, these robotic rehabilitation devices only provide motion, this motion can be fixed (i.e., imposed in a so called *passive* way) or controlled to make the training more interactive, this lead to the assist as needed paradigm [4], [5]. This kind of reeducation is called *active*. With the WalkTrainer we are adding closed-loop muscle stimulation to the reeducation in order to obtain an improvement over the classical *active* reeducation. In our case, the active part can come from the patient, if some remaining control is present or from the muscle stimulation. But in general it is a combination of both. The stimulation is adjusted to give the difference between the target force and the force developed by the patient.

The development of this rehabilitation device relies on the three following principles wich are the essence of the Cyberthosis concept. First, active participation of the subject's muscles is wanted. In this context, active means either controlled by the user himself (if possible) or induced by the use of surface electrodes. Second, the motions applied by the orthoses or generated by the muscles have to closely mimic natural movements. Third, chronic patients (i.e., usually associated with an important muscular atrophy) need specific muscular training prior to walking relearning.

Initiated by the "Fondation Suisse pour les Cyberthèses," the Cyberthosis projects[1]enable not only an automated training but actively include the muscles of the patient by the mean of controlled contractions generated by surface electrodes [6]. Thus, the advantages of a perfectly controlled robotic treatment are combined with the benefits provided by electrical-stimulated physical activity [7], [8]. For the patient, such training results in a better muscle contraction as well as an increased proprioceptive feedback (see Fig. 1). The Cyberthosis muscular stimulation however differs from the traditional open loop control performed in other applications. Indeed a bad or coarse muscle control results in jerky motions and fast exhaustion of the subject [9]. Force sensors placed on the leg exoskeleton enable a precise monitoring of the stimulation effect and allow thus a very accurate control of the contraction intensity. This regulation scheme is called: closed-loop or closed loop electrical muscle stimulation (CLEMS).

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[1]MotionMaker, WalkTrainer, WalkMaker, and CLEMS are commercial trademarks of the Swiss Foundation of Cyberthosis (FSC).

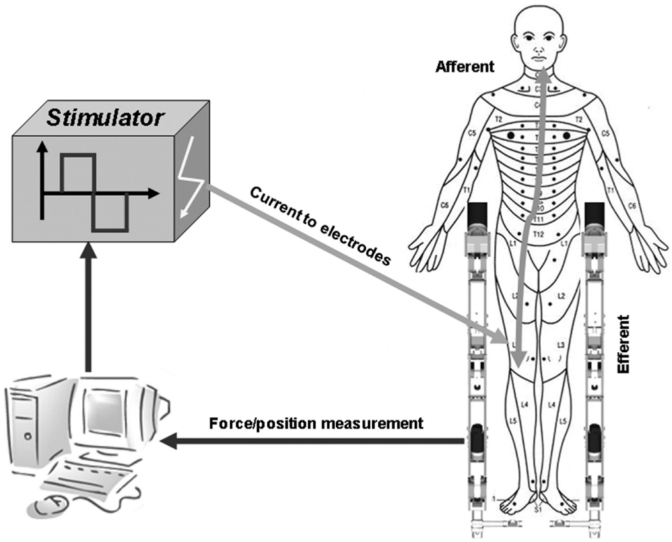

Fig. 1. Schematic of the closed loop muscle stimulation. Interaction forces are measured by the orthoses. The PC computes in realtime the new stimulation currents that need to be applied to the muscles. In addition, the efferent (motor) and afferent (sensory) pathways are shown.

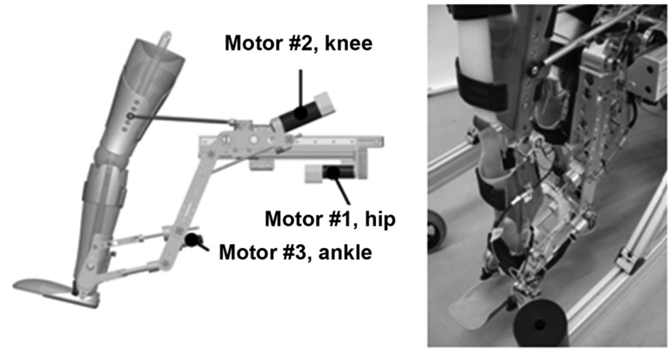

Fig. 2. Schematic of the leg orthosis of the WalkTrainer. The three motors that allow the mobilization of the hip, knee, and ankle in the sagittal plane are highlighted. Force sensors are placed in series with the motors to quantify the subject's participation (left). Mechanical realization of the leg orthosis (right).

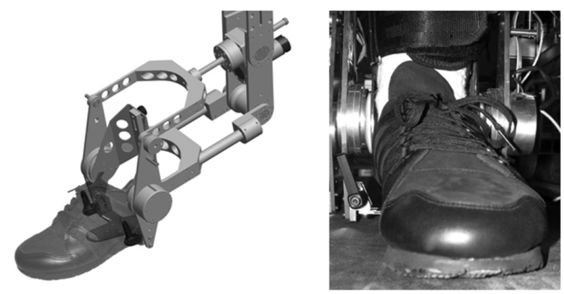

Fig. 3. Close-up of the ankle articulation. A custom modified shoe allows a proper transmission of the force from the robot to the subject.

II. WALKTRAINER

The WalkTrainer is intened for walking reeducation. But as explained in Section I, chronic subjects will first undergo a training program on the MotionMaker (for a detailed description of the device refer to [10] and [11], an overview is given in [6] and [12] and the clinical trials are summarized in [13]). Once the subject will have regained enough controlled muscular force (in the case of an incomplete injury) the second phase of the training will take place on the WalkTrainer. The aim now is to train over ground walking again, in order to regain autonomy and coordination. The rehabilitation device is equipped with leg and pelvic orthoses, active bodyweight support, and a mobile frame that allows the user to perform its training in large corridors and so on. Again closed loop muscle stimulation is present.

A. Components

Sections II-B–II-D will give a brief insight about the different components of the WalkTrainer, their originalities, and their function in the reeducation process.

1) Leg Orthosis: During walking, each segment of the lower limbs moves according to a complex 3-D trajectory. However, for the first prototype, we assumed that the foot progresses in a plane parallel to the sagittal plane. It is also important to have enough lateral stiffness at the ankle to prevent spastic abduction/adduction. On the upper extremity of the lower limb, the pelvis moves in all three directions of motion (i.e., three translations and three rotations). The lateral displacement increases even more during slow walking or at the first step. With all these considerations, a dedicated leg orthosis has been designed (Fig. 2); the key idea is to have a parallel mechanical leg that is placed just in the back of the human leg.

The interface is a lightweight exoskeleton-based orthosis specially designed by an orthopedist. The device is then connected to the powered leg by appropriated bar linkages.

The interface between the feet and the motor driven orthosis consists of modified shoes. A special designed plate is inserted in the sole to have mechanical hold of the foot (Fig. 3).

The hip flexion/extension movement is achieved by a self designed linear axis unit. A rotating ball screw with a belt reduction stage permits linear movement of the two parallel bars connected to the thigh. The spherical bearings at each end of the rod allow lateral movements induced by the pelvis while creating a moment around the hip joint.

The knee joint is actuated by a two stage crank and connecting rod systems. The first is directly driven by a ball screw and a rotating nut. The second rod is attached to the orthosis at the ankle. Finally, the ankle moment is given by a powered parallelogram with the same actuation principle as explained above.

In addition each axis is equipped with a force sensor, thus monitoring the interaction between the user and the orthosis is possible. This information is critical for the closed loop muscle stimulation. And a series of potentiometers allow a redundant position measurement.

The main advantage with this leg orthosis consists of having all the mechanical parts, motors, and cables in the back of the machine, the arms are thus free of moving during gait. This also means that the legs of the patient remain easily accessible by the side. The chosen kinematic imposes high ab/adduction stiffness at the lower extremity of the leg, while allowing a natural motion at the hip joint. Doing this would have been extremely difficult with a purely serial orthosis.

2) Pelvic Orthosis: The pelvis plays an important role in the walking process [14]. For that reason, a six degree-of-freedom

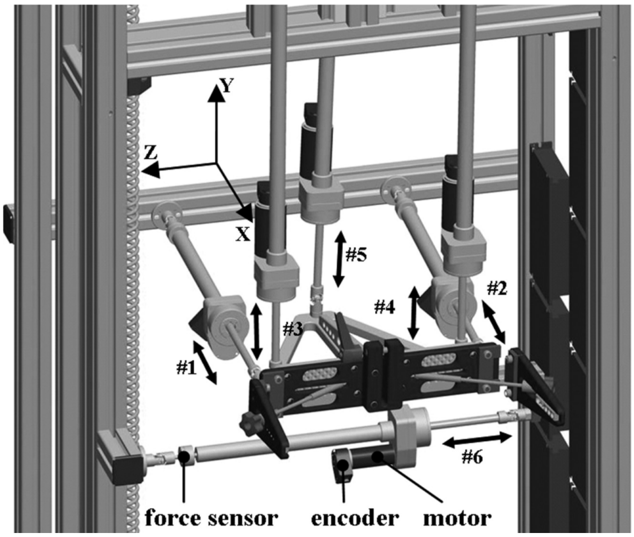

Fig. 4. Close-up of the pelvic orthosis. Each axis (numbered from 1 to 6) is composed of a motor, two position sensors, and a force sensor. Additionally the coordinate frame is shown.

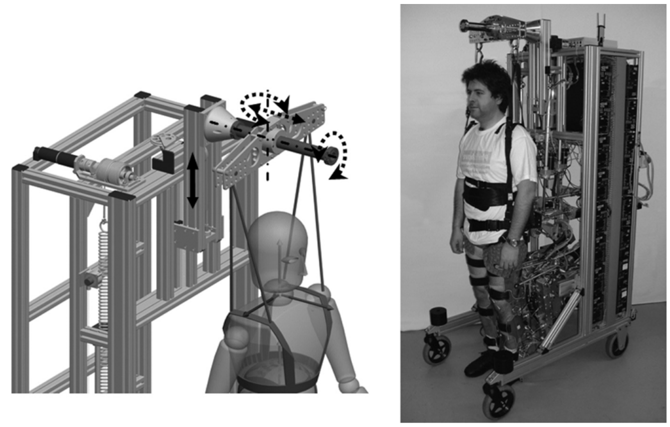

Fig. 5. schematic of the active bodyweight support system. The harness is connected to a pivot itself mounted on a sliding pivot (the rotation axes as well as the translation are indicated). The whole system can move actively up and down by using a numerical axis for precise control plus a preload spring, itself controlled by a numerical axis (left). Able bodied subject mounted in the WalkTrainer, equipped with the leg orthosis, pelvic orthosis, bodyweight support an electrodes (right).

(DOF) robot was designed in order to assist the subject as a therapist would. Mobilizing precisely the subject according to the three translations and three rotations is thus possible. An orthogonal parallel kinematic structure was chosen [11]. It is composed of six actuated axes. Each axis is equipped with a motor, two positions sensors (redundancy is primordial when dealing with medical robotics), and a force sensor. The latter is used for monitoring the interaction between the user and the robot. That information can be used for robotic control or evaluation of the therapy. But more importantly it provides an extra security by setting a maximal force value.

The pelvic motions applied by the orthosis (Fig. 4) have been measured on a population of 20 healthy subjects (see Section II-B1 for more details). Besides a pelvic motion prediction model has also been implemented and tested on the orthosis (see Section II-B2).

Currently focus is given to reducing the mechanical complexity of this orthosis, as well as testing different control algorithms for the reeducation process (selective compliance for instance, Section II-B3).

3) Muscle Stimulator: Commercially available muscle stimulators are not suited for closed loop muscle stimulation; this is even more true if an important number of muscles is involved. For that reason, a twenty-channel real time (with a 0.5 ms reaction time per channel) muscle stimulator was developed. It is able to provide up to 150 mA per channel; its outputs are galvanically insulated. The stimulator is fixed on the top of the WalkTrainer. The cables to the electrodes are regrouped on two connectors per leg (thigh and shank) to allow a fast connection of the subject.

4) Active Bodyweight Support: The weak muscular condition of the legs of paraplegic people requires an unloading of their weight. Additionally, postural muscles control can also lack. For these reasons, a bodyweight support is required (Fig. 5). A motor controlled preload spring enables a constant and energy efficient unloading of the subject (there is a redundant absolute position sensor for this motor). A second motor then enables a precise control of the unloading force during the walking process (there is also a redundant absolute position sensor for this motor), in addition a force sensor is present in the mechanical design and enables a precise monitoring and control of the unloading force.

A custom made adjustable harness was designed for a comfortable unloading of the subject. The harness is fixed to the WalkTrainer by the mean of passive 3 DOF mechanism that consists of a sliding pivot coupled to a pivot, the harness is thus less restraining the subject while walking (Fig. 5).

5) Deambulator: The primary function of the deambulator (frame of the WalkTrainer) is to support the other components and the user while rolling over ground. By using two motorized wheels mounted in a differential way, it is possible to perform straight and curved trajectories, which allow training in hospital corridors or on training tracks. It is believed that proprioceptive feedback can be greatly enhanced with true over ground walking (versus treadmill walking). In addition, visual information is naturally provided to the subject when walking this way.

Of course the deambulator also possesses an onboard PC equipped with PCI axis cards to control the whole system. Wireless communication is of course also provided, the WalkTrainer can thus move freely because it is also equipped with a LiPo battery (2 h of autonomy).

B. Trajectory Generation for Rehabilitation

Pelvic trajectories are available in scientific literature [15], however very few publications provide the six DOF at the same time for a given subject and often the experimental conditions change. Leg trajectories (hip, knee, and ankle articulation in the sagittal plane), on the other hand, are well documented by the scientific literature and can easily be used for trajectory generation [16], [17]. For that reason, pelvic motion measurements had to be done on valid subjects, in order to obtain a useful database for the generation of robotic trajectories and development of orthoses. Second, several models of pelvic motion amplitude

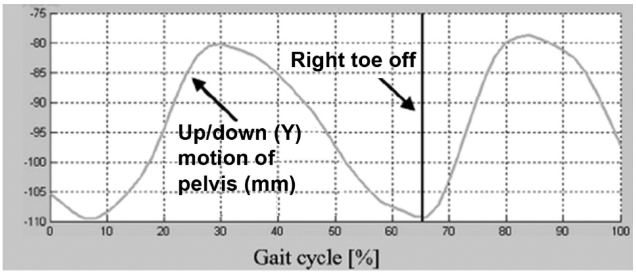

Fig. 6. Delta Y (up/down) motion in mm as a function of the walking cycle. The vertical line indicates the right toe off. Measurements were made on an able bodied subject. The same figures can be obtained for the other DOFs.

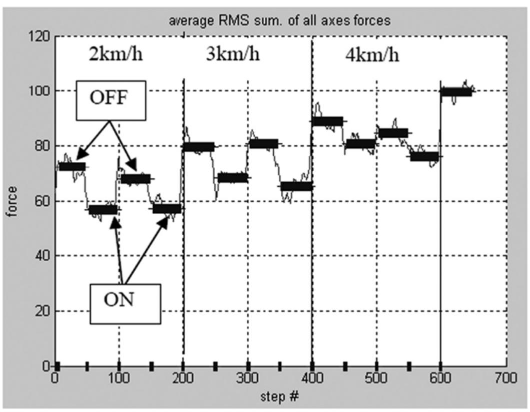

Fig. 7. Ordinate axis indicates the averaged rms force measured on the axes of the pelvic orthosis, the abscissa indicates the step number. The pelvic model is used to adapt the trajectories in step 50–100, 150–200, and so on. The walking speed is increased from 2, to 3 and 4 km/h every 200 steps. Observe that the interaction force is smaller when the pelvic trajectories are adapted.

prediction models were proposed and analyzed, these models are then used to enhance the trajectory generation. Third, a selective compliance control algorithm was developed and introduced in the control loop.

1) Measuring the Pelvic Motion: In this section, the WalkTrainer is converted to a mobile 6 DOF motion measuring device. Only the mobile frame is used; the different orthoses are put in a "park" position. Also, a six DOF camera (easyTrack from the company Atracsys) is placed on the deambulator, the subject is equipped with footswitches, and an active marker that is viewed by the camera. In addition two string potentiometers are connected between the WalkTrainer and the subject and provide speed and heading information for the steering of the mobile frame.

Each of the 20 subjects performs several runs at slow (0.4 m/s), average (0.8 m/s), and fast (1.4 m/s) walking speed. Each run is done on a distance of about 30 m and allows to have on average 15–20 full steps at the wanted speed. The 30 m limitation comes from the size of the building used. After the last run, a calibration procedure is performed in order to determine the exact position of the active marker on the subject's pelvis. For that procedure, a second marker is used to point on the left and right anterior spinae iliaca superior of the subject as well as the midpoint of the two posterior spinae iliaca superior.

The measured trajectories are then analyzed by a custom made Matlab based program. Each DOF can be obtained as a function of the walking cycle (as shown in Fig. 6), time and so on. Simple statistic tools have also been built in as well as exporting to Excel for instance.

2) Development and Test of the Pelvic Amplitude Model: Reference pelvic trajectories are now available. However, generating user specific trajectories would be of great interest. Several models that would predict the peak-to-peak amplitude of each DOF were proposed. Six different parameters were used, the main being walking speed, size of subject, and gender. And the models are linear or linear with interaction. However, only one model was finally implemented on the pelvic orthosis of the WalkTrainer. The chosen model was dependent on walking speed, a parameter that could easily be varied for any given subject.

For the chosen model the peak-to–peak amplitude A_i (subscript i is for delta X, 2 for delta $Y, \ldots,$ 6 for theta Z, refer to Fig. 4 for the definition of the axes) is given by the following equation:

$$A_i = a_{0i} + a_{1i} \cdot v \tag{1}$$

where a_0 is a constant, a_1 the influence factor of speed, and v the walking speed (in meters per second). Each DOF uses the same equation, but with different parameters. The parameters are obtained by curve fitting (least square method).

This equation is now used as predictor for the peak-to-peak amplitude of the trajectories that have to be applied by the pelvic orthosis on the user. Again a footswitch is fixed on his heel. This sensor provides the timing information to the trajectory generator; that has to synchronize the pelvic orthosis with the user (this means the orthosis is not forcing the pace of the subject).

The user is then asked to walk at a given speed and the interaction forces are recorded by the force sensors of the pelvic orthosis. The experiment is repeated several times. Sometime the pelvic motion amplitude is adapted by using the model and sometime the fixed (so-called reference) trajectories are used.

The interaction forces are then analyzed. It is possible to observe the force on the axis side of the orthosis or project them (by using the Jacobian matrix of the structure [18]) in the operational space of the user (the three translations and three rotations). A revealing plot is the averaged sum of the root mean square (rms) force measured on the axes of the pelvic orthosis as a function of the number of step (Fig. 7).

Indeed in Fig. 7 it can be seen that when the model is used in the trajectory generation the interaction forces are reduced. It is true that the reduction is only in the order of 20%, however the model is also extremely simple [19].

Further tests could be done with one of the more complex model or a different kind of algorithm. Such as interpolation between different reference curves for instance.

Now a novel way of generating precise and customized pelvic trajectories is available, however applying them as such to the user can result in high forces and thus be felt as disturbing for the subject. For that reason, a selective compliance algorithm was developed.

3) Selective Compliance for Rehabilitation: Selective compliance means that the physician, or engineer can decide what DOFs should be made compliant and how (spring effect, damper effect, or a combination of both, etc.). This is simply realized by placing a virtual spring/damper in the operational space (i.e., user space) and projecting the resultant force in the articular space of the robot, by using the Jacobian of the kinematic structure [18]. This projected force is then generated by the motors of the pelvic orthosis and the user feels as if there was actually a spring/damper connected between him and the end effector organ of the orthosis.

Selective compliance is wanted for the three following reasons. First, when the orthosis are mobilizing the subjects high forces could occur if stiff trajectories were to be applied. For that reason, one wants to control precisely what DOF should be made compliant. Second, by using selective compliance the control strategy can easily be personalized for each patient. Depending on its ability to do certain motions, DOFs can be made compliant or stiff. Third, six motorized axes are required for the pelvic orthosis. By using the selective compliance, one can easily determine what axes could be removed or replaced by a pure passive mechanism (spring and/or damper).

C. Muscle Stimulation

Muscle stimulation is commonly used in clinical environments, mainly for strengthening purposes but also for prevention of disuse atrophy and in neurological field for muscles contractures prevention, regulation of spasticity, and improvement of function [20], [21]. Muscle stimulation has been implemented for cycling [22], rowing [23], and also walking [24], [25]. Inducing walking with muscle stimulation requires a precise control of the muscle stimulations to avoid jerky motions and fast exhaustion of the subject[2] [9].

1) Muscle Model and Identification: A first muscle model dependent of the muscle stimulation, position, and velocity has been implemented [26]–[28]. The identification time for this model is of about 10–15 min per session. For that reason a simplified version was finally adopted.

The is model captures only the force (torque actually, [Nm]) versus stimulation intensity relation (current [A]) and is identified around the main working point (position, [rad]). The working position of the muscle can be found by inspection of EMG measurements performed on able-bodied subjects walking

$$M = f_{\theta_0}(I) \tag{2}$$

with M the output torque in Nm (along the Z axis, shown in Fig. 4), I the intensity in mA, and θ_0 the identification position.

For the identification of the model the user's leg is moved by the leg orthosis to the working point of the muscle. Then the stimulation is increased by steps of 5 mA (30 Hz, pulse width of 300 μs) and the output torque measured at the hip, knee, and ankle (there is a delay of about 400 ms between the intensity change and measurement to avoid the transitory phase). This procedure is applied to the seven musles of both legs (Gluteus Maximus, Vastus Medialis, Vastus Lateralis, Rectus Femoris, Biceps Femoris, Tibialis Anterior, and Gastrocnemius).

[2]An advantage of coupling muscle stimulation and robotic orthoses as on the WalkTrainer is that the motions are smoothened by the robotic exoskeleton. And if the user is not able to generate enough force (by his own contractions or by the muscle stimulation) the robot can help performing the motion.

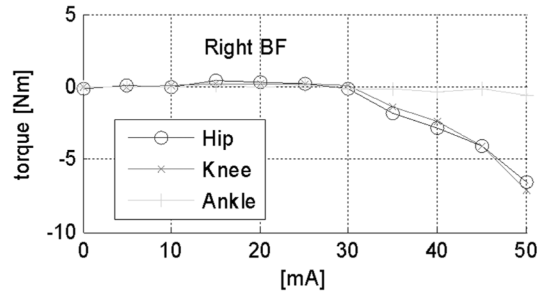

Fig. 8. Muscle identification result for the Biceps Femoris muscle of a paraplegic subject. The stimulation is increased by steps of 5 mA (horizontal axis) and the generated torque measured on the leg orthosis is plotted on the vertical axis (in [Nm]). This muscle is biarticular, and acts as expected on the hip and knee but not on the ankle articulation.

Typical identification results of the Biceps Femoris of a paraplegic subject is shown in Fig. 8.

The stimulation parameters used for the reeducation are a stimulation frequency of 30 Hz, pulse width of 200 μs and stimulation intensity is comprised in the range of 0–100 mA. The intensity is computed by using the model in combination with the stimulation strategy.

2) Stimulation Strategy: The implemented muscle stimulation strategy relies on EMG measurements performed offline on able bodied walking subjects. For each muscle, these EMG patterns define an *activity* window in which the muscle is supposed to work (and thus can be stimulated).

The training begins with the muscle identification as described above. Then the orthoses start the walking process; and the force sensors placed on the leg orthosis allow the measurement of the interaction forces between the user and the WalkTrainer. To the contrary of other reeducation programs [29] where the trajectory is adapted to the users intentions. Here, the muscle stimulation is updated to minimize the forces that the user is applying to the orthosis. This means that the user will have a leg motion that is as close as possible to our reference (assumed to be ideal) walking pattern. Another possibility, instead of simply minimizing the interaction torques another strategy consisted in modulating the desired torques as a function of the gait cycle, for instance to obtain a strong push of at toe off or have a greater foot clearance during the swing phase.

In practice the interaction torques (hip, knee, and ankle) are measured over one step. The torques are then converted in stimulation changes to be applied to the muscles (this is done by using a projection function based on the muscle-articulation relationship). This procedure is applied for every step in an iterative way. The use of the model allows having an effective feedforward controller, and a faster convergence.

D. Clinical Trials

From February to May 2008 six paraplegic subjects (ASIA A: 2, ASIA C: 1 and ASIA D: 3). Took part in the preliminary clinical trials with the WalkTrainer, there was no dropout.

A typical training session begins with a warm-up program; the electrodes are placed on the subject's muscles and for 10 min low-frequency (10 Hz) stimulation is applied (the intensity is selected so that a perceptible contraction is observed). At the

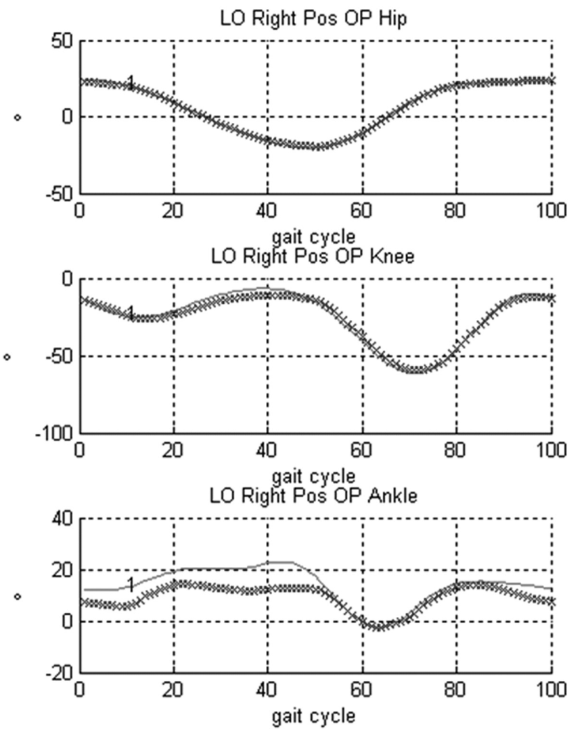

Fig. 9. Trajectories applied by the leg orthosis to the paraplegic subject's right leg in degrees as a function of the gait cycle, averaged over five complete cycles. Top: hip; middle: knee; bottom: ankle. The thick curve represents the computed target trajectory and the thin curve the measured trajectory. A voluntary deviation is observed at the ankle articulation (bottom), this is due to the fact that the controller is made slightly compliant during the stance phase.

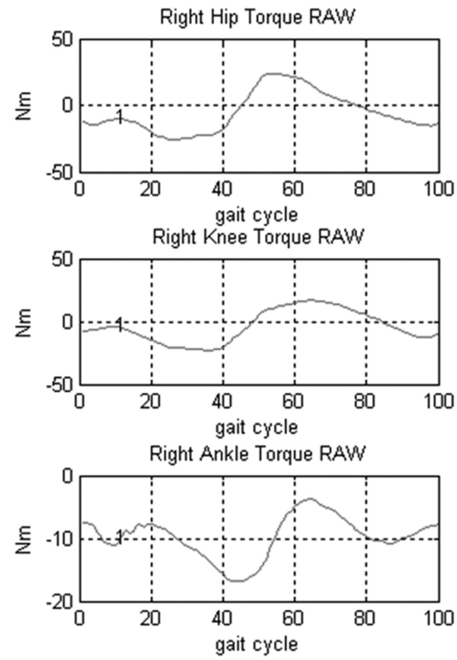

Fig. 10. Torques measured by the leg orthosis (in [Nm]) that are applied by the exoskeleton to the right leg of a paraplegic subject as a function of the gait cycle (average over five complete cycles). Top: hip, middle: knee; bottom: ankle.

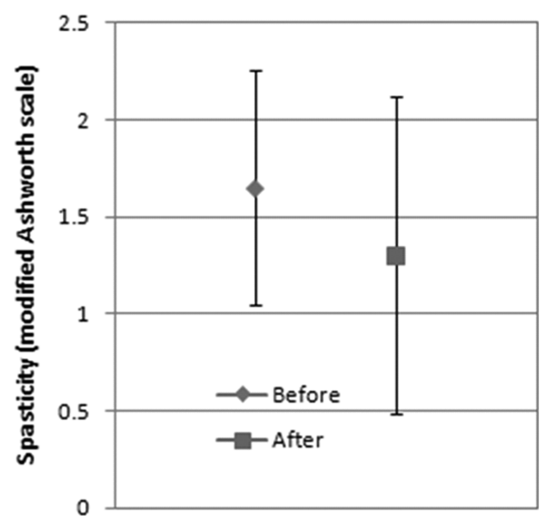

Fig. 11. Average spasticity of the six subjects (modified Ashworth scale) before (left) and after the treatment (right). A reduction of spasticity can be observed. The high variability (before and after) can be explained by the broad range of subjects that were involved in the study (ASIA A, C, D).

same time the user is equipped with the exoskeleton and the harness. The subject is then placed in the WalkTrainer and performs the walking training for about 1 h. This training consists of over ground deambulation with muscle stimulation, the algorithm used is the one explained in the Section II-C2. The legs (applied positions: Fig. 9, applied torques: Fig. 10) and pelvis are mobilized by their respective orthoses. The bodyweight support is adjusted depending on the user's ability to support its own weight. At the end of the training the exoskeleton is removed and the patient undergoes a cool-down of 10 min; the stimulation parameters are the same as for the warm-up.

This first short term preliminary clinical trial allowed to show the feasibility of getting paraplegic subjects to walk in the WalkTrainer. The low training rate (one session per week) did not allow seeing a significant increase in force or coordination. However, a reduction in spasticity was observed (Fig. 11). A new series of tests, which a higher training load and more strict inclusion criteria will be held soon to highlight more clinical benefits of the WalkTrainer.

III. Conclusion

The Cyberthosis project aims at developing a new generation of rehabilitation devices for paraplegic subjects by combining robotics and closed loop muscle stimulation. An active participation of the patients' muscle is the cornerstone of the concept. The advantages of that method were clearly shown in the clinical trials made on the MotionMaker in 2005 [13]. An improvement in force could be observed but also a higher proprioceptive feedback was reported by the patients.

The WalkTrainer reeducation device as well as the control strategy were presented in this paper. Followed by the preliminary clinical trials with the WalkTrainer were done at the beginning of 2008. They involved six paraplegic patients. It was successfully shown that getting patients to walk again in the WalkTrainer; assisted by the orthoses and muscle stimulation was feasible. A new series of tests will be undertaken soon to highlight more clinical benefits of the WalkTrainer.

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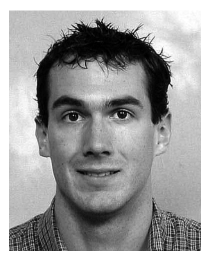

Y. Stauffer started microengineering studies at EPFL, in 2000. He spent his third year at Carnegie Mellon University, Pittsburgh, PA, and received the M.S. degree in microengineering 2005. The same year he started the Ph.D. thesis at the LSRO.

His work include muscle stimulation, modeling and motor control on the WalkTrainer.

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He then joined the LSRO as an assistant on the WalkTrainer project. He is now working as Mechanical Engineer at the FSC. His main tasks include modeling and development of mechanized orthoses.

M. Bouri the M.S. degree in electrical engineering from the National Polytechnic school of Algeria, in 1992, and the Ph.D. degree in industrial automation from the National Institute of Applied Sciences of Lyon, INSA, Lyon, France, in 1997.

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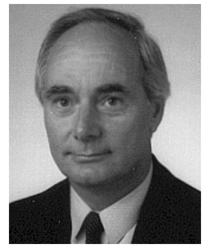
After having worked for a telecommunication company in Zurich he is hired by the Institute of Microengineering at PEFL as Research and Development Engineer. In 1980, he undertakes a postgrad formation in technical informatics and in 1991 he follows a cycle for admission to the engineer registry (REG A). He now is Senior Electrical Engineer in the domains of medical instrumentation and micro robotics.

R. Clavel received the degree in mechanical engineering at the Swiss Federal Institute of Technology of Lausanne (EPFL), Switzerland, in 1973.

After nine years of gathered experience in industrial plants, he was appointed professor at the EPFL. He is Director of the Laboratoire de Systèmes Robotiques (LSRO). His present research topics are high speed and high precision robotics, medical robotics applications, surgical instrumentation, and precision mechanisms.

P. Metrailler received the M.S. degree in microengineering at EPFL, in 2000. He received the Ph.D. degree in microengineering, in 2005.

He worked on the control aspects of the MotionMaker, which also included closed-loop muscle stimulation. He is now product and clinical application manager at Swortec SA.



R. Brodard is an expert in electrical neuromuscular stimulation established the concept of Cyberthosis: MotionMaker, WalkTrainer, WalkMaker He is currently the General Secretary and CEO of the FSC.

F. Reynard graduated in physiotherapy in 1996 and received the M.S. degree in motricity sciences from Grenoble University, France, in 2007.

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