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## A novel verticalized reeducation device for spinal cord injuries: the WalkTrainer, from design to clinical trials

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### 1. Introduction

In industrialized countries, 2 persons out of 100'000 undergo a spinal cord injury (SCI) every year. Which brings the total population in these countries to roughly 70 persons for 100'000 inhabitants. A lesion to the spinal cord results in a partial or complete loss of motor and/or sensory control below injury. Fortunately in over 50% of the cases some functions are spared (Jackson, 2008). The loss of motor control is only one of the consequence of such a lesion. Indeed cardiovascular weakness, muscular atrophy, osteoporosis appear rapidly after the injury and may severely impede the reeducation of the patient (Freeman-Somers, 2001).

Treadmill training assisted by therapists, standing or swimming are part of the currently used reeducation techniques (Figure 2b). For walking relearning the manually provided assistance can require up to three therapists (Grundy, 2002). Their work is of course strenuous, especially in the case of a spastic patient. In addition no quantification of their effort is possible and the applied mobilization may differ from one session to another.

In that context robotic assistive devices have been developed and are now being introduced in clinical environments (Colombo et al., 2000) (Schmidt et al., 2007) (Metrailler et al., 2006) (Figure 2a & Figure 2c). Such robots can advantageously provide long training, with quantifiable mobilization (force and position). But in the event of a complete lesion the patient's muscles remain completely passive. To overcome that issue electrical muscle stimulation can be employed (Dohring & Daly, 2008). The complex nature of the muscles associated to the dynamics of walking, require subtle stimulation schemes which rely on position and force information provided by the robot.

The combination of muscle stimulation (preferably in a closed loop manner to avoid rapid exhaustion and guarantee better control) and robotic mobilization optimizes the afferent feedback provided to the subject and allows an effective muscle training. The WalkTrainer, that is one of these reeducation devices, will be extensively presented in this chapter (Stauffer & al., 2009).

## 2. Generalities

### 2.1. Medullar lesions

The spinal cord serves as a bidirectional communication link between the brain and the rest of the body (Germann, 2001). In the event of a lesion, orders will be prevented from being sent to the muscles (efferent) and sensory information will of course also not be able to reach the brain (afferent). Depending on the severity of the lesion some information can still be transmitted, in that case the lesion is referred to as incomplete. In addition the level (height) of the lesion also matters. Lesion at the cervical level result into tetraplegia (the four limbs are affected), whereas lower lesions lead to paraplegia (only the legs are affected) (Freeman-Somers, 2001).

The absence of voluntary muscle control is only the most well known consequence of SCI (Freeman-Somers, 2001) (Aito, 2003). The more recurrent issues are summarized below (Figure 1):

- Cardiovascular: autonomous pathway can lose the supervision from the brain, alteration of heart control. Absence of muscular pumping: bad venous return, can cause blood clots and other complications (pressure sores on the skin for instance).
- Respiratory: weakened inspiration, results in less effective oxygenation of the blood. Weakened expiration can cause the building up of secretion in the lungs, which results in infections.
- Osteopenial (osteoporosis): bone density decreases fast after SCI, which leads to fracture prone conditions.
- Muscle fatigue: the muscle masse diminishes and muscle fibers become less fatigue resistant.
- Bladder and bowel issues: sphincter muscle control can be lost. As a consequence retention can occur, which can lead to incontinence.

### 2.2. Mobilization and electrical muscle stimulation

Current reeducation of paraplegic subjects mostly relies on mobilization of the lower limbs. The motion can be applied either by physiotherapists or by a robotic device (Colombo et al., 2000) (Schmidt et al., 2007) (Figs. 1a-1c). With the development of smaller and more effective sensors and the increase of computational power, the second option, namely robotic reeducation devices, is more and more present. Not only can the device move the subjects' limbs in a predefined way for a longer time than therapists. But these robots can also adapt to the effort provided by the patient, as a therapist would (Jezernik, 2003). Such treatment is beneficial for:

- maintenance of the articulation mobility,
- maintenance of muscle compliance,
- bone loading,
- stimulation of intestinal regulation by the vertical posture.

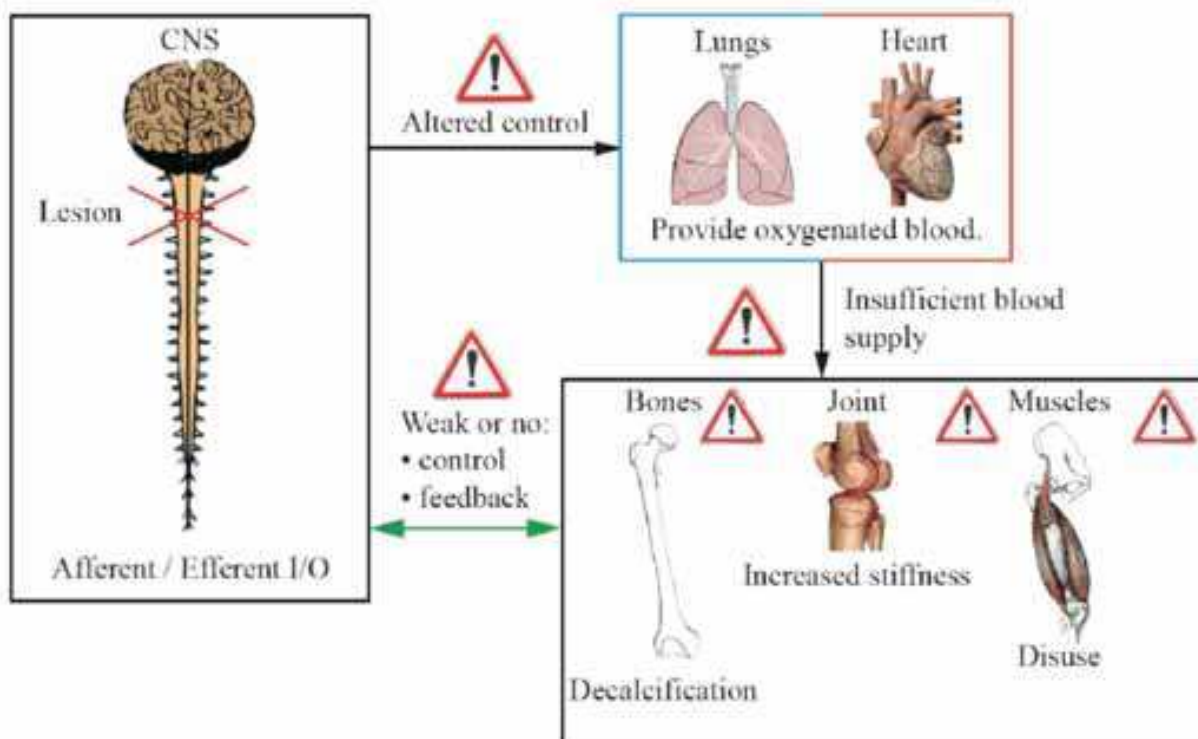


Fig. 1. Consequences of SCI greatly affect the walking capabilities.

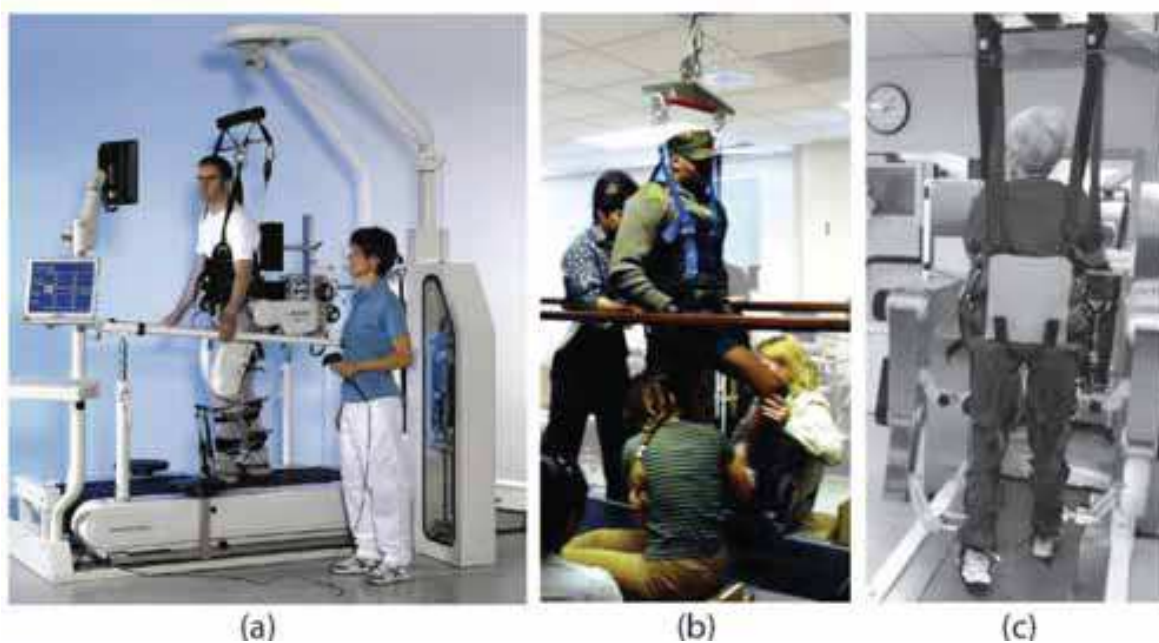


Fig. 2. Walking training: (a) Lokomat from Hocoma. (b) Manual training with three therapists. (c) AutoAmbulator.

However, if the patient is unable to initiate the motion by himself or if his voluntary control is too weak, the training is completely passive. In the sense that the robot provides the whole effort. In addition the muscle spindle stretch reflex can actually cause the muscles to

contract, but in opposition to the desired motion. For instance if the robot is applying a knee flexion motion. This can trigger the muscles spindles of the quadriceps muscles (involved in knee extension). Their information is sent to the spinal cord where two actions are performed. First, the quadriceps muscles are ordered to contract. Second, the hamstrings (involved in knee flexion) are ordered to relax. As a consequence not only are the wrong muscles contracting, but the muscle that should contract is relaxing (Figure 3a).

In order to overcome these issues functional electrical stimulation (FES) can be applied. By using surface, intramuscular or implanted electrodes, electrical pulses are generated to elicit an action potential on the motor neuron of the concerned muscle. In other words, the electrodes are replacing the lacking commands in order to generate a muscular contraction. In addition to stimulating the motor neuron, the Ia fibers from the muscle spindles (i.e. fibers that send the position/velocity information back to the spinal cord) are also stimulated. This has two important implications. First it causes the motor neuron of the stimulated muscle to become more receptive to voluntary control. Second, it inhibits the antagonistic muscle (Frischknecht & Chantraine, 1989) (Figure 3b).

Unfortunately controlling muscles precisely with FES is not trivial. Also muscles of paraplegic subjects are usually weak (atrophied) and FES tends to induce fast fatigue (high stimulation frequencies have to be applied to obtain a fused contraction and fatigable muscle fibers are recruited first).

Up to day using purely FES based strategies for autonomy enhancement of paraplegic subjects have failed, or allow only very limited walking distances (Graupe, 2003). But they provide advantages in terms of muscular contractions and enhanced proprioceptive feedback. On the other hand robotized reeducation devices can now be trained to assist the patient only as much as needed. The combination of FES and robotics is thus a logical choice for generating new reeducation devices.

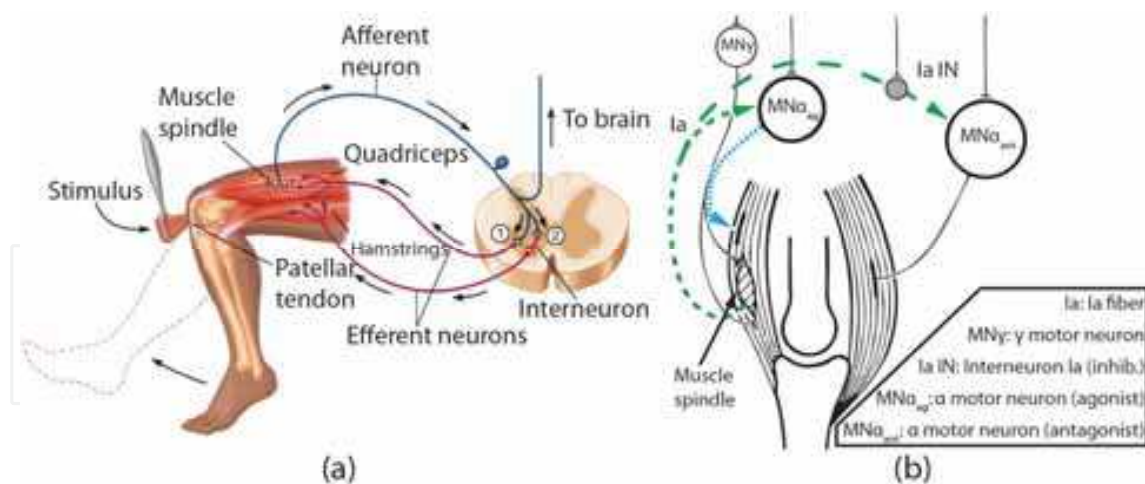


Fig. 3. (a) Muscle spindle stretch reflex (Germann, 2001). (b) FES and reciprocal inhibition. Small dashed arrow (blue): effect of FES on agonist muscle contraction. Average arrow (green): positive feedback on agonist motor neuron. Large dashed arrow (green): antagonist inhibition. (Frischknecht & Chantraine, 1989).

### 2.3. Plasticity and central pattern generators

Plasticity refers to the ability of a system to adapt to a changing environment. In the case of

the nervous system, such plasticity is of course very active during childhood, but remains active during the whole life of a subject. Plasticity can occur at different levels, in the brain, the spinal cord or even at the neuromuscular junctions. If a motor neuron is injured another motor neuron can reinervate the muscle fibers. In that case one would speak of axon sprouting. In other occasions the strength of a synaptic connection is adapted. Such processes can be dependent on feedback from the effector organs in order to calibrate the strength of the input output connection. This is of great importance for incomplete SCI. In that case plasticity can cause the connections to adapt in a way that enables the person to have a better control of her limbs.

It has been shown that involving the patient actively in the therapy (i.e. asking him to do the motion) leads to greater outcomes (Kaelin-Lane, 2005). The same has been observed if training modalities are combined. For instance, treadmill, with body weight support and FES (Barbeau, 1998). Which means that plasticity can be stimulated by summing various stimulation modalities. As a summary plasticity is "improved" if the patient is participating to the training (*supervision*) and if the training stimulates many senses coherently (*summation*). These two considerations have of course to be taken into account when developing reeducation devices.

Central pattern generators (CPG) are present in the lower regions of the voluntary control hierarchy (brainstem and spinal cord) of animals. These structures are able to generate cyclic signals autonomously. Their activity is modulated by the brain and by feedback from the limbs. Spinalized cats can be placed on a treadmill and walking motions can be generated. If the treadmill speed is increased the gait shifts to trot and eventually gallop. For humans the possible existence of a CPG was first observed by (Calancie et al., 1994). Later walking activity during treadmill walking was also reported (Dietz, 1995)(Dobkin, 1995). In addition rhythmic motions seem to have positive effects on neural plasticity (Pearson, 2000). Such motions are thus employed on rehabilitation devices such as the Lokomat (Jezernik et al., 2003) or the WalkTrainer (Stauffer et al, 2009).

#### **2.4. Conclusion: implication on the development of the WalkTrainer**

The foundations for the development of the WalkTrainer reeducation device have been given in this section. As a summary these are:

- Active muscular participation of the subject: coherent muscular activity, muscle build up, high afferent feedback.
- Robotic mobilization: correct motion and longer training sessions.
- Verticalized posture: coherent feet loading, control of balance.
- Overground deambulation: correct visual feedback, natural walking.

### **3. Robotic design and realization**

The development of the WalkTrainer was done with the idea of optimizing the feedback to the subject. The following sections will briefly highlight the key features of the five main components of the WalkTrainer.

#### **3.1 Mobile frame or deambulator**

"Should we go for a walk? Yes, sure." The mobile frame was developed with that

perspective (Figure 4a). Most rehabilitation devices are treadmill based; up to day the WalkTrainer is the only rehabilitation device that is rolling over ground with leg and pelvis orthoses. The deambulator is equipped with four wheels. Two castor wheels at the front for stabilization and two motorized wheels mounted in differential at the back. The WalkTrainer can thus roll along straight or curved paths at velocities up to 1.6 m/s. The training can take place indoor, in large corridors or outside on training tracks. This kind of real walking is not only more motivating for the subject. But visual information (i.e. moving scenery) is naturally provided to the user.

In addition the mobile frame serves as support to the other orthotic devices. As well as for the on board PC (control and wireless communication) and the 2 kWh LiPo battery (2 hours autonomy)

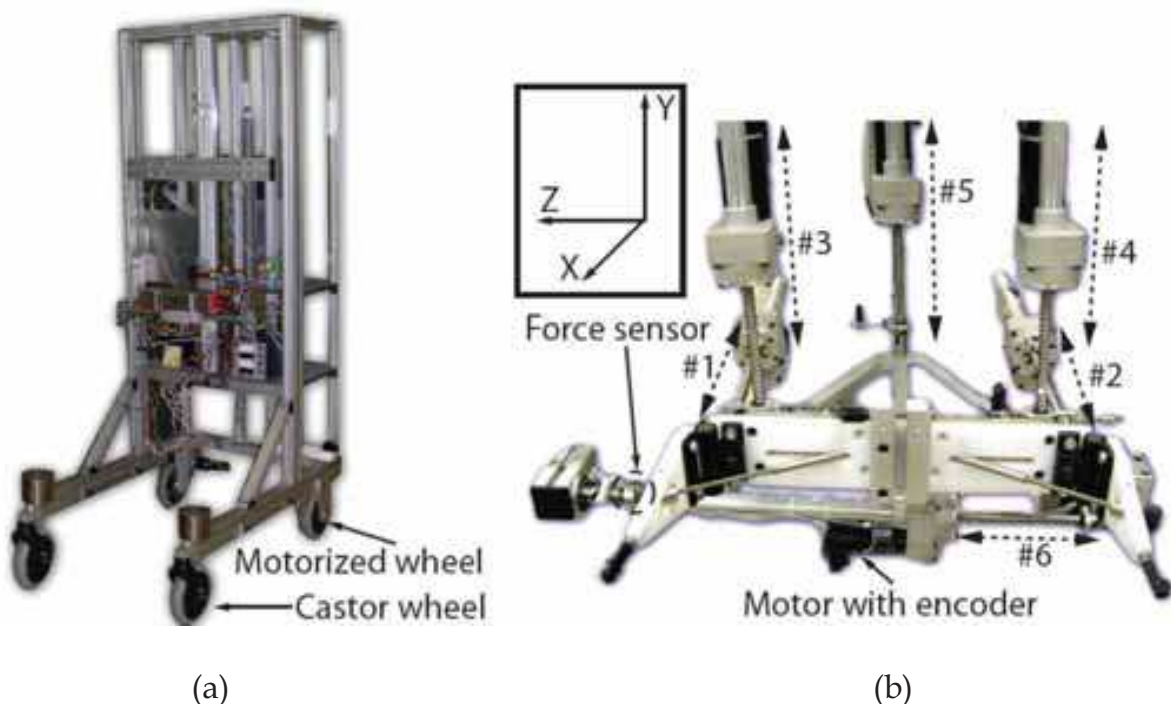


Fig. 4. (a) Mobile frame. (b) Pelvic orthosis. The motorized axes are numbered.

### 3.2. Pelvic orthosis (PO)

Trying to walk without getting the pelvis to move is almost impossible. During natural walking motions along the six degrees of freedom (DOF) occur. The combination of these motions allows the overall reduction of motion of the center of gravity of the body, which leads to a more energy efficient walking. In addition stability is also taken care of by pelvic motions. For instance when only one foot is in contact with the ground (stance phase) the center of gravity is shifted laterally (Z axis (Figure 4b)) towards that leg.

Naturally during reeducation therapists try to mobilize the pelvis in order to facilitate the walking process (Trueblood, 1989). Of course the WalkTrainer is expected to be able to do the same. For that reason a six DOF pelvis orthosis was developed (Figure 4b). Each motorized axis is composed of a backdriveable ball screw transmission with a redundant position measurement (absolute and incremental). In addition force sensors allow to precisely quantify what force the orthosis is applying to the subject, that information can be used for diagnostic or security issues (Stauffer et al., 2007).

### 3.3. Leg orthosis (LO)

As for the pelvis, the legs are mobilized and interactions monitored by using force sensors in series with every actuator (Allemand et al., 2009) (Figure 5a-b). Motorized mobilization is provided for the three main articulations (hip, knee and ankle) in the sagittal plane. Motorization is provided by backdriveable ball screw transmissions. As for the pelvic orthosis redundant position measurement is performed. The leg orthosis is also equipped with force sensors. Those are used mainly for the control of the closed loop electrical muscle stimulation. Using the force sensors for monitoring or diagnostic purposes is also feasible.

The kinematics of the leg orthosis allow a high lateral stiffness at the ankle (i.e. prevents the scissoring of the legs) and allows at the same time the hip to move in all directions. As a consequence the upper part of the leg orthosis is "following" the motions of the pelvic orthosis. In addition the actuation and linkages are located at the rear of the user. Which not only allows the arms of the subject to swing freely, but also reduces the apparent size of the device.

The motorized orthosis is connected to a lightweight exoskeleton that is to be put on the user first. Doing so allows to have a greater surface area to apply the force. Which of course reduces the applied pressure and prevents the apparition of skin problems. The hip actuation is provided by a linkage at the thigh. The knee motorization is connected to the shank and custom built shoes are used to transmit the actuation to the ankle articulation. In addition there is a link between the leg and pelvic orthosis (Figure 5c). That serves to distribute the unloading force (vertical) between the pelvic and leg orthosis.



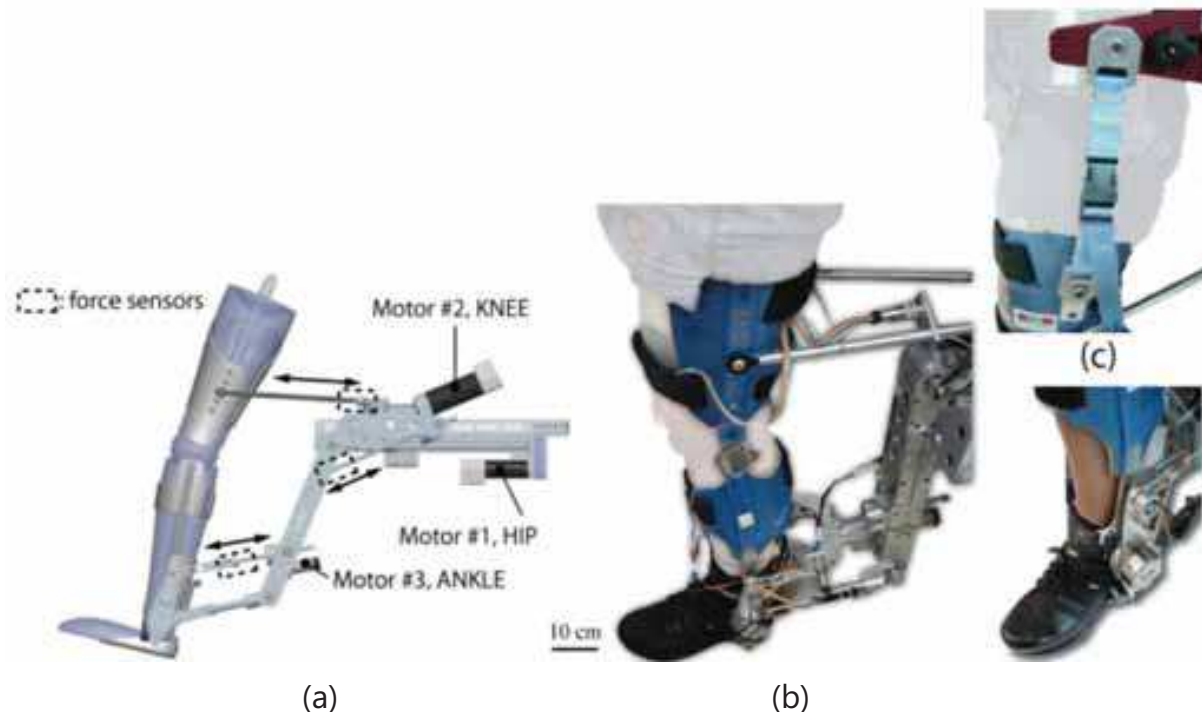


Fig. 5. (a) Leg orthosis schematic. Hybrid kinematics (combination of series and parallel kinematics). (b) Leg orthosis realization. (c) Link between leg and pelvic orthosis.

### 3.4 Active body weight support (BWS)

The weak muscular condition of paraplegic subjects restrains them from bearing all their weight on the legs. For that reason a certain amount of unloading is required. Furthermore in the case of high lesions, control of abdominal or trunk muscle can also be lost. The stability of the patient must then be guaranteed by the assistive device. These two conditions could be fulfilled with a simple unloading mechanism (a spring for instance). But it has been shown that the correctness of the weight bearing pattern felt under the foot is also important during training. For these reasons a more subtle motorization of the system is preferred.

In order to be energy efficient a spring in series with a motor allows to unload the subject by a fixed percentage of his body weight. A second motor (also in series) is then employed for the regulation of the unloading as a function of the gait cycle (i.e. during training). Again both motors are equipped with incremental and absolute position sensors. A force sensor mounted on the system also allows to control precisely the unloading.

The interface with the user consists of a specially developed harness (Figure 6b) that is fixed at two locations: at the pelvis (behind the user, Figure 6c) and above the subject's head. The second fixation point is a passive 3 DOF mechanism (translation, rotation, rotation), prevents the user from feeling like a pendulum (Figure 6a).

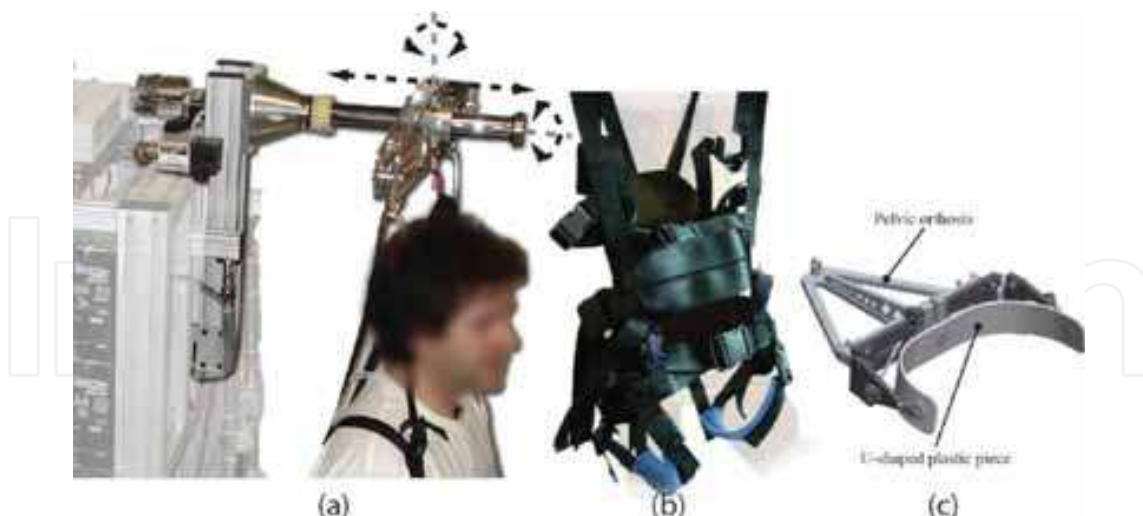


Fig. 6. (a) Active body weight support. The DOF of the upper fixation point are highlighted (b) Developed harness. (c) Fixation between the pelvic orthosis and the harness. Only the plastic piece that is fixed to the harness is shown.

### 3.5 Electrical muscle stimulator (StimMaker)

In order to replace the lacking voluntary muscle control, electrical muscle stimulation is provided in real-time. We developed a 20 channel stimulator that is to be used with standard surface electrodes (Figure 7a). On the WalkTrainer the following muscles are stimulated: gluteus maximus (GM), rectus femoris (RF), vastus medialis and lateralis (VM, VL), hamstrings (HA), tibialis anterior (TA) and gastrocnemius (GA). Each electrode pair (or channel) can be provided with currents up to 150 mA. By default the admissible stimulation intensity is lowered to values between 80 and 100 mA. The stimulator communicates with a PC by using a standard RS232 protocol.

Electrodes can either be individually connected to the device (frontal connection) or two times 10 channels connectors are provided at the back. The second solution is of course more practical for clinical applications. Especially since the WalkTrainer has been equipped with connectors that regroup the electrodes (one connector per thigh and one per shank (Figure 7b)).

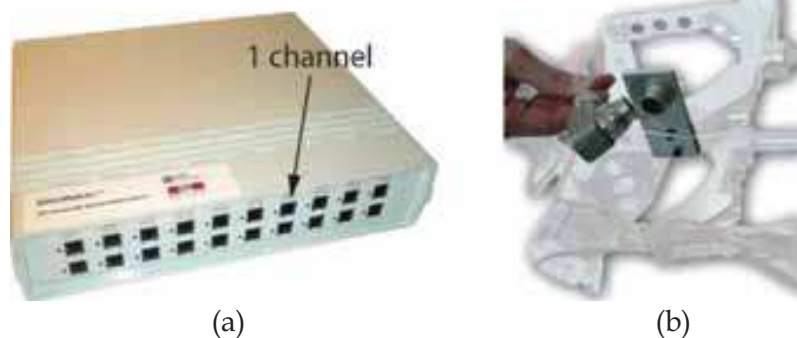


Fig. 7. (a) Electrical muscle stimulator (front view). (b) Regrouped electrode connection for the shank muscles (TA, GA) on the ankle part of the leg orthosis.

#### 4. Rehabilitation strategy on the WalkTrainer

As introduced in before rehabilitation with the WalkTrainer relies on the combination of robotic mobilization and muscle stimulation. This section describes how these were developed and implemented.

##### 4.1 Leg and pelvis mobilization

During manual reeducation physiotherapists aim at mobilizing the patients' legs and pelvis with the correct trajectory. The WalkTrainer is expected to do so, but during longer training sessions and with a greater accuracy. The therapists knows how to adapt to a tall, thin or elder subjects. The trajectory generator of the WalkTrainer is expected to be able to do the same.

For the pelvis a four step procedure was undertaken:

1. Motion measurement on valid subjects
  2. Motion model identification (offline)
  3. Implementation in the trajectory generator of the WalkTrainer
  4. Validation on valid and paraplegic subjects
- 
1. A measurement campaign was undertaken on twenty healthy subjects. Each person was requested to walk at four different speeds, every time the 6 DOF of the pelvis were saved for later analysis (Stauffer et al., 2008).
  2. The average curve of the twenty subject was then computed. Several models (linear with/without parameters) were then proposed to compute the peak to peak amplitude of each DOF as a function of various parameters (size, gender, walking speed, ...) (Figure 8a).
  3. One model was then selected and implemented in the trajectory generator of the WalkTrainer. Since the pelvic orthosis was employed alone, the phase and frequency synchronization for the motion control was provided by a footswitch placed under the subject's right heel (Stauffer et al., 2007).
  4. Finally the effect of using the model to adapt the reference pelvic trajectories was successfully assessed. As expected a reduction of the measured force applied by the pelvic orthosis is observed when the model is used to adapt the trajectory (Stauffer et al., 2007) (Figure 8b).

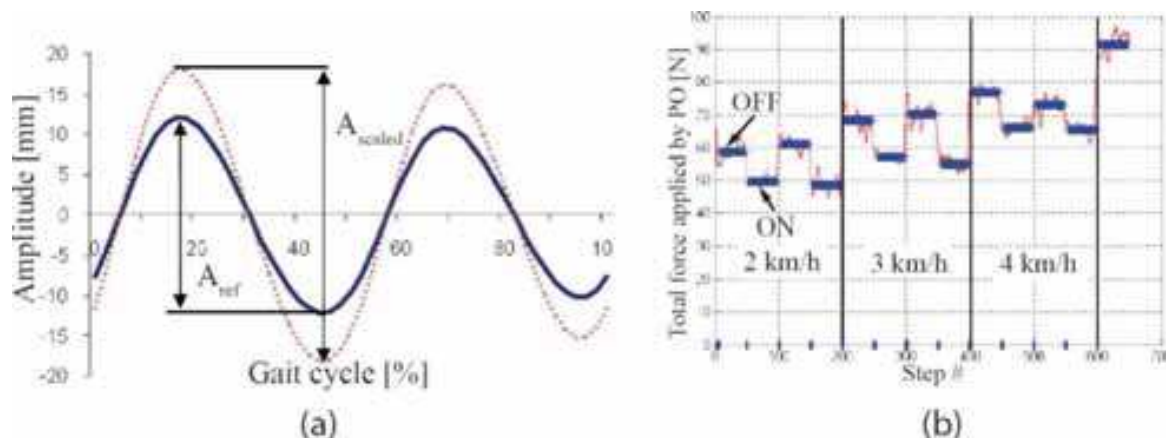


Fig. 8. (a) Reference trajectory ( $A_{ref}$ ) and scaled trajectory by using the developed model ( $A_{scaled}$ ). (b) Total force measured by the pelvic orthosis as a function of the step number at different walking speeds. The model is switched from OFF to On every 50 steps.

Speed dependent leg trajectory measurements have also been undertaken but not implemented on the WalkTrainer yet. In addition preliminary pelvic motion measurements along curved paths have also been performed.

As a conclusion, the motorized orthoses are providing precise mobilization and the force sensors serve as input to the muscle stimulation.

#### 4.2 Electrical muscle stimulation

An off line EMG based stimulation scheme was implemented. Indeed EMG represent well muscular activity and also muscular force (to a certain extent). For every of the 7 muscles the main working point (as a function of the gait cycle) was found (Figure 9c). This working point then served as identification position of the force-stimulation intensity relation (force-intensity (Figs. 9a-b)). These EMG measurements are also used to create a so called enable windows, that allow the muscle to be stimulated only at certain periods of the gait cycle (in order to be coherent with the motion and antagonistic inhibition).

Then for every articulation a target torque has to be generated as a function of the gait cycle. One can chose either to exaggerate some features such as: push-off or foot clearance. Or use the force sensors of the orthosis in order to minimize the interactions between the leg orthosis and the subject's leg by tuning the muscle stimulation.

Finally the so obtained target torque (hip, knee and ankle) has to be converted into a muscular force. By using the identified force-intensity relation of each muscle on the 3 articulations, one can find a set of rules to transform articular torques into muscular force.

Finally all these elements are combined and a coherent muscle stimulation strategy is obtained (Stauffer, 2009) (Figure 10). The torque generator, generates target torques for the hip, knee and ankle articulations as a function of the gait cycle by using predefined algorithms. That can either increase the physiologically needed torque, apply a constant torque or minimize the interaction between the user and the exoskeleton. This articular torque is then transformed into a muscular target torque, this operation is critical since some muscles span over several joints and joints are crossed by more than one muscle. By using the muscle model the required stimulation intensity is then computed. The so obtained intensity is checked for coherence by comparison to the timing obtained by offline EMG

measurements. Finally the muscle stimulator performs its task by stimulating the muscles and the interactions between the user and exoskeleton are measured and sent back to the torque generator.

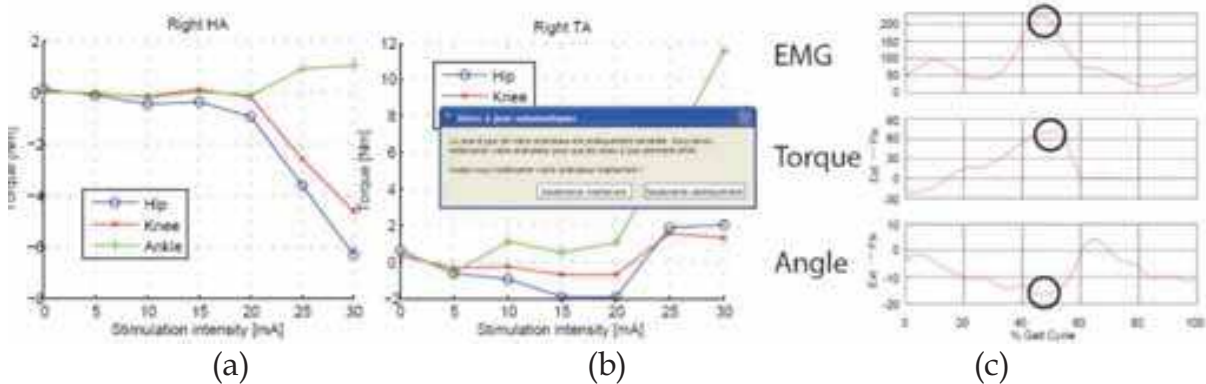


Fig. 9. (a) Hamstring muscle identification result (biarticular: hip and knee). (b) Tibialis anterior muscle identification result (monoarticular: ankle). (c) EMG activity of the triceps surae, ankle torque and ankle angle as a function of the gait cycle. Adapted from (Kirtley, 2006)

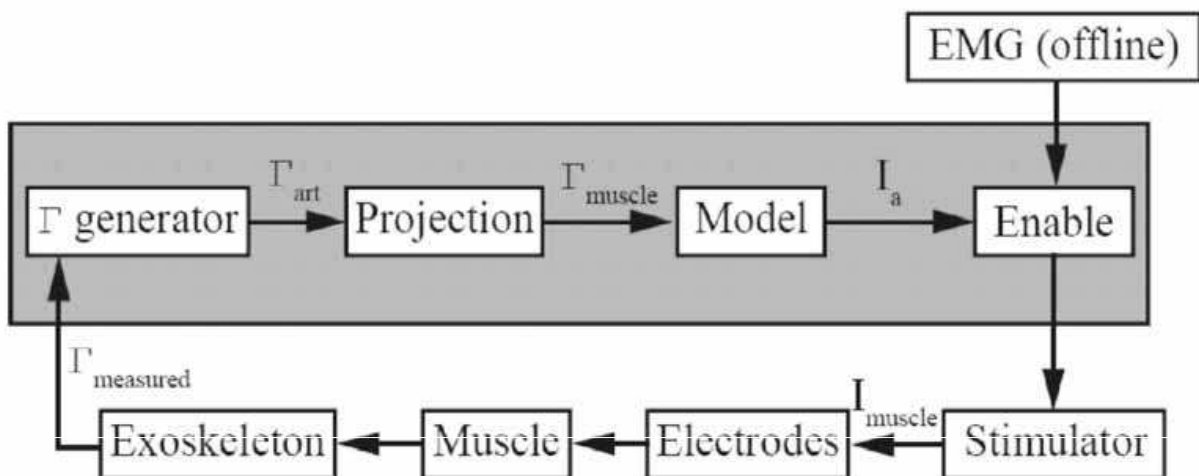


Fig. 10. Closed loop muscle stimulation strategy on the WalkTrainer.

**4.3 The complete rehabilitation strategy**

In addition to the orthotic mobilization and closed loop muscle stimulation the remaining components of the WalkTrainer are also utilized. The active body weight support motion is synchronized with the pelvic orthosis. This guarantees a coherent unloading and thus provides a good foot loading. At the same time the forward velocity of the mobile frame is matched with the walking speed programmed on the leg orthosis.

As a result coherent position information are provided to the legs and pelvis of the subject. The same is true for muscular loading, since it is either provided by the user himself (partial lesion) or by the FES only or by a mix of both. The joint work of the pelvic orthosis and body weight support creates a coherent loading of the users' feet. Finally the rolling of the

WalkTrainer provides natural visual feedback and further motivates the subject (Stauffer, 2009) (Figure 11a).

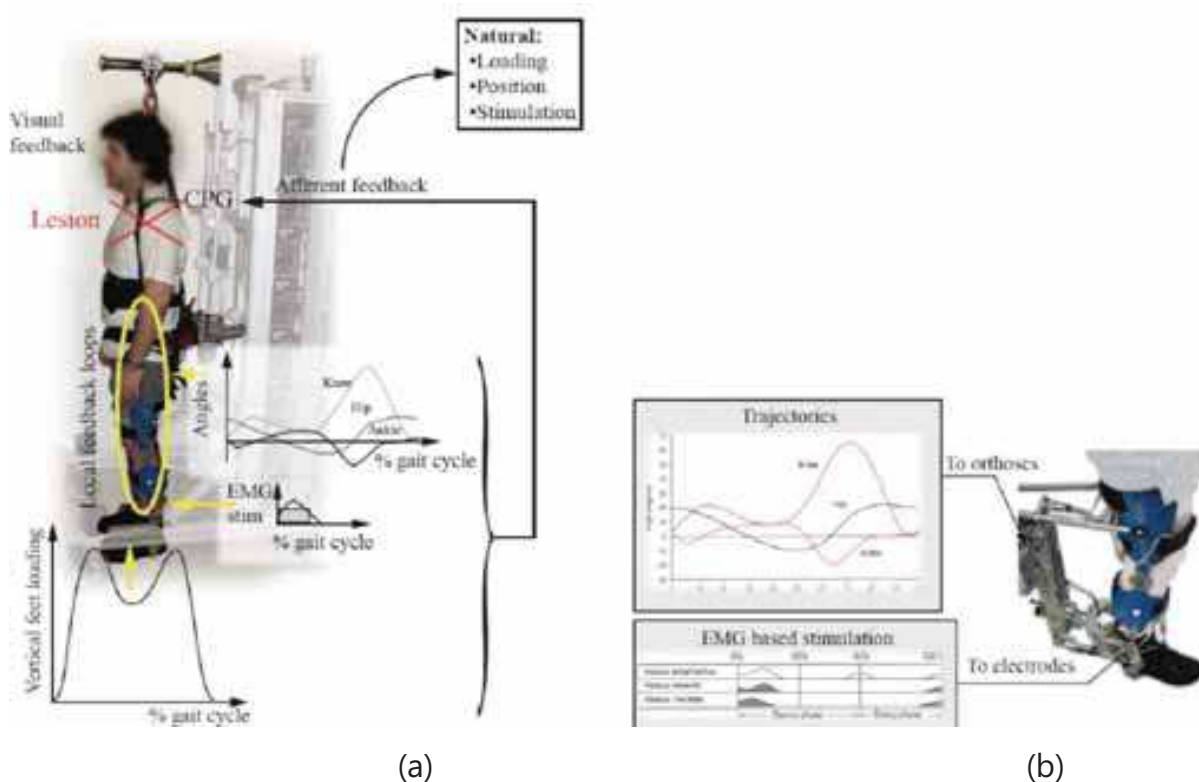


Fig. 11. (a) Main feedback pathways targeted by the rehabilitation strategy. (b) Integration of robotic mobilization and EMG based stimulation.

## 5. Clinical trials

At the beginning of 2008 a three month clinical trial was held at the Clinique romande de réadaptation (CRR). The objectives were of two kinds. First, practical questions had to be answered such as: how easily can paraplegic subjects be installed, do they have apprehension, do they appreciate the training. Second, therapeutic questions had also to be addressed. These were for instance: muscular increase, better coordination, reduction of spasticity (Allemand & Stauffer, 2009).

### 5.1 Phases and patients

In order not to provide the patient with too many new sensations at one time. And also to have a progressive testing of the device, a four phase clinical protocol was developed.

*Phase 1:* the WalkTrainer is mounted on a treadmill, no muscle stimulation is applied to the patient.

*Phase 2:* the WalkTrainer is mounted on a treadmill, muscle stimulation is applied to the patient.

*Phase 3:* the WalkTrainer is rolling over ground, no muscle stimulation is applied to the patient.

*Phase 4:* the WalkTrainer is rolling over ground, muscle stimulation is applied to the patient (Figure 12a-b).

Due to clinical constraints the patient population was quite heterogeneous (Table 1). Also

most of the patients couldn't stay during the whole trials, but merely 2 to 3 weeks. Which corresponds to their annual stay at the CRR.

Patient	Gender	Age	Lesion (motor/sensory)	# training Sessions	Phases
1	M	25	T12/T12	12	1-4
2	F	39	C7/C7	6	1-4
3	M	31	C4/C2	2	1
4	F	21	C8/C3	2	1
5	M	52	L2/L3	3	1-2
6	M	26	D5/D5	2	1,4

Table 1. Summary of the patients that participated to the clinical trial.

## 5.2 Results

The robotic mobilization performed as expected. The patients were successfully mobilized by the leg and pelvic orthoses. The electrical muscle stimulation algorithms also worked. For instance the stimulation intensities were higher on the more affected leg and the stimulation adapted to the remaining voluntary participation (i.e. decrease of stimulation) (Allemand & Stauffer, 2009).

From a therapeutic point of view a slight decrease of spasticity could also be observed (measured manually). Unfortunately no muscular force increase could be measured. This is not a surprise with a single weekly training session.

The WalkTrainer also turned out to be an effective diagnostic device. A comparison between the measured articular torques (with and without voluntary participation of the patient) confirmed the observations of the physiotherapists regarding the patient's remaining capabilities.

## 5.2 Conclusions for the clinical trials

The main objectives were reached. Transfer and installation of patients (even ASIA A) could easily be done with the adequate material, for instance a cigogne (Figure 12c). Also patients had absolutely no apprehension and even liked the training.

From a robotics point of view the WalkTrainer also succeeded his first trials, indeed no major incident or damage occurred to the device. From a control point of view everything turned out as expected. The motion generation as well as the muscle stimulation functioned perfectly.

The clinical outcomes are more contrasted, indeed some results have been obtained (reduction of spasticity, mobilization and stimulation, use of the WalkTrainer as a diagnostic device). However longer clinical trials with a higher training load should now be conducted.



Fig. 12. (a) Subject ready for training (front view), (b) side view. (c) Transfer using a cigogne.

## 6. Conclusion

The WalkTrainer is a novel reeducation device that combines optimal mobilization (personalized trajectories) by the means of a 6 DOF pelvic orthosis and a 2 times 3 DOF leg orthosis, coupled to closed loop electrical muscle stimulation. Its development was carried out at EPFL (LSRO) in collaboration with the FSC (Swiss Foundation for Cyberthosis) as a CTI project (7485.2 LSPP-LS) with SWORTEC SA as main industrial partner.

It is up to day the only reeducation device that combines leg and pelvis mobilization to electrical muscle stimulation, while walking over ground. In addition the control strategy is also new. First generation robots or stimulation strategies merely played back predefined patterns (motion or FES). Second generation robots or stimulation strategies adapted their effort (motion or FES) to the patient's participation. Third generation reeducation devices are the combination of second generation robotic control and second generation FES. The WalkTrainer can thus be viewed as the first third generation reeducation robot (Figure 13).

The clinical trials carried out at the Clinique romande de réadaptation (CRR) have proven that the WalkTrainer is functional and that its reeducation capabilities are real. The software and hardware have been tested thoroughly and are now ready for more intensive clinical trials.

Future development of the WalkTrainer will involve walking along curved paths. In order to do so a new leg orthosis will have to be designed. Indeed the current version cannot perform internal/external rotation. Then after a new set of clinical testing, the industrialization will begin.



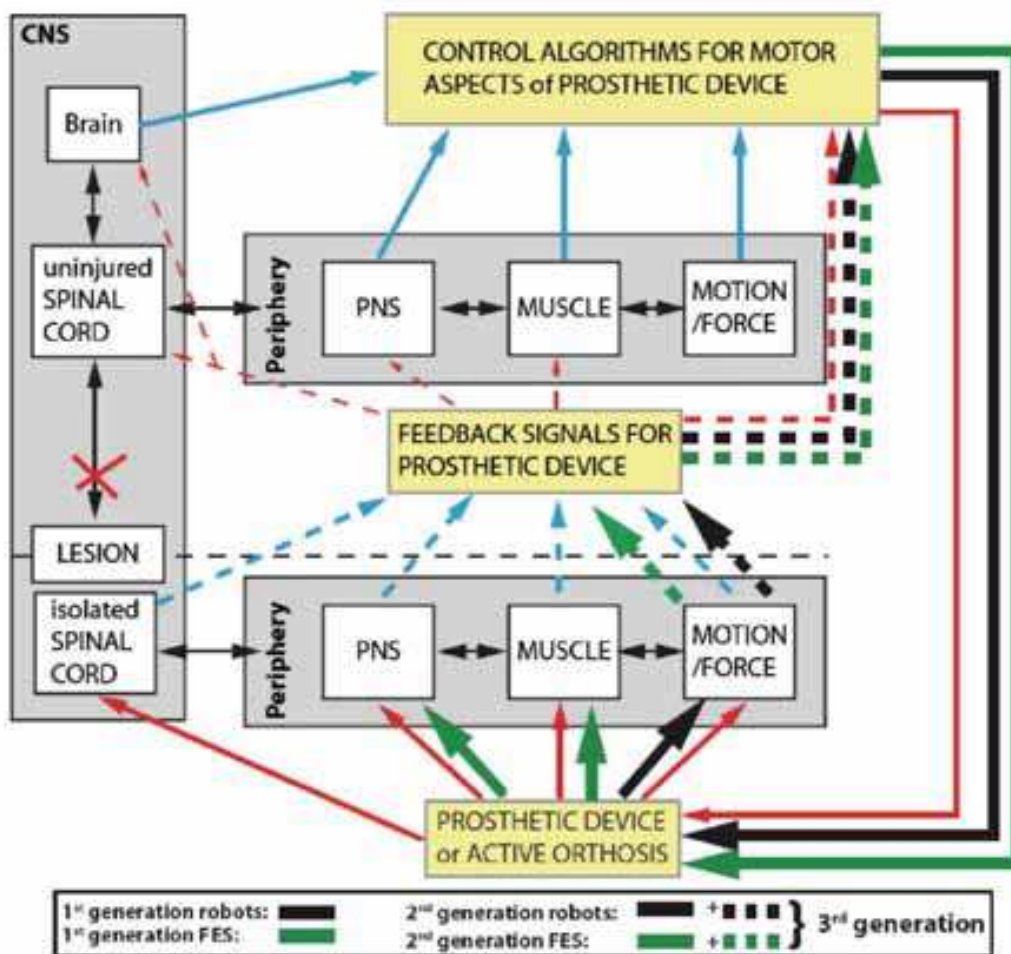


Fig. 13. First, second and third generation of reeducation devices (adapted from (Giszter, 2008)).

## 7. Acknowledgments

The Cyberthosis team would like to thank: the CTI/KTI (project: 7485.2 LSPP-LS) and the Loterie Romande for their financial support, as well as the Clinique romande de réadaptation (CRR) for the precious help before and during the clinical trials that took place in their facilities.

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## **Robotics 2010 Current and Future Challenges**

Edited by Houssem Abdellatif

ISBN 978-953-7619-78-7

Hard cover, 494 pages

**Publisher** InTech

**Published online** 01, February, 2010

**Published in print edition** February, 2010

Without a doubt, robotics has made an incredible progress over the last decades. The vision of developing, designing and creating technical systems that help humans to achieve hard and complex tasks, has intelligently led to an incredible variety of solutions. There are barely technical fields that could exhibit more interdisciplinary interconnections like robotics. This fact is generated by highly complex challenges imposed by robotic systems, especially the requirement on intelligent and autonomous operation. This book tries to give an insight into the evolutionary process that takes place in robotics. It provides articles covering a wide range of this exciting area. The progress of technical challenges and concepts may illuminate the relationship between developments that seem to be completely different at first sight. The robotics remains an exciting scientific and engineering field. The community looks optimistically ahead and also looks forward for the future challenges and new development.

### **How to reference**

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Stauffer Yves, Mohamed Bouri, Reymond Clavel, Yves Allemand and Roland Brodard2 (2010). A Novel Verticalized Reeducation Device for Spinal Cord Injuries: the WalkTrainer, from Design to Clinical Trials, Robotics 2010 Current and Future Challenges, Houssem Abdellatif (Ed.), ISBN: 978-953-7619-78-7, InTech, Available from: <http://www.intechopen.com/books/robotics-2010-current-and-future-challenges/a-novel-verticalized-reeducation-device-for-spinal-cord-injuries>

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