

Examples of motor prostheses

INTRODUCTION

The knowledge regarding biomechanics (chapters 3 and 7), physiological motor control, sensing and actuation (chapters 2, 4 and 5), artificial motor control, sensing and actuation (chapters 8, 9 and 10) can be used in the design of support systems for the impaired human motor control system (chapter 6).

This chapter will give an overview of motor support systems and how they interact with the impaired human motor control system (chapter 1, figure 11.1).

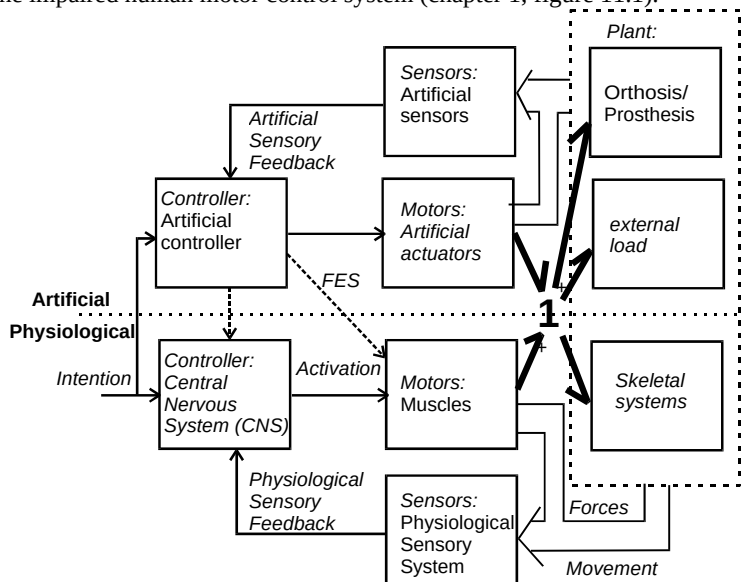


Figure 11.1 Orthotic and prosthetic systems that support the impaired motor control system consist of mechanical, sensory, actuation and control components that interact with the physiological system.

OBJECTIVES

This chapter

- gives an overview of prosthetic and orthotic systems which have been developed for the support of the impaired neuromuscular system. It should be noted that this is not a comprehensive overview.
- describes the interaction with the impaired neuromuscular system for the described systems.
- gives an indication of the user experiences and clinical effects of using these systems.
- provides references to papers and documentation regarding the described motor support systems. This gives the reader an entrance to further information regarding these systems and their use.

CONTENT

11.1 Introduction

The needs of the user with his/her impairments, disabilities and handicaps need to be the starting point in the design of prosthetic systems for the human motor system. This requires a close collaboration with medical doctors (rehabilitation, neurology, neurosurgery, orthopaedics) and physical therapists.

The design needs to satisfy several criteria, of which the following are of primary importance (see Cool et al.):

- *Cosmesis*: the prosthetic system needs to be in concert with the body image.
- *Comfort*: the system should be comfortable to the user. The comfort should include easy or no donning and doffing (putting on and off) and comfort during use (preferably not requiring any conscious effort and preferably forgettable to the user).
- *Control*: the system should be well controlled, performing the supporting the impaired motor function effectively, thus reducing handicap of the user.

A well designed prototype motor support system which satisfies the need of the user does not necessarily yield a commercially successful product. Companies need to be involved who re-engineer the prototypes such that they can be produced in quantities for acceptable prices and introduce the system on the market and give support (Van Leerdam 1999).

In this chapter, examples will be given of several support systems for the human motor system. The support systems are divided in:

- mechanical orthoses and prostheses (11.2)
- systems which involve electrical stimulation of muscles (section 11.3)
- hybrid systems involving mechanical support and electrical stimulation (section 11.4)
- systems which have as primary goal to modulate the central nervous system (section 11.5)
- systems which train the Central Nervous System (section 11.6)

For all presented systems, the relation to physiological and artificial human motor control as discussed in this course will be shortly discussed.

It should be noted that this chapter does not provide an exhaustive treatment of all motor support systems. It merely provides some representative examples. The overview includes successfully commercialized systems, unsuccessfully commercialized systems, systems which are in the process of being clinically introduced and commercialized and systems that have not yet been commercialized.

11.2 Mechanical orthoses and prostheses

Many mechanical orthoses and prostheses (fig. 11.2) have been developed for upper and lower extremities. Orthoses support part of the body in its mechanical function, prostheses replace part of the body. The prostheses can be passive or involve active component, with or without sensing and control.

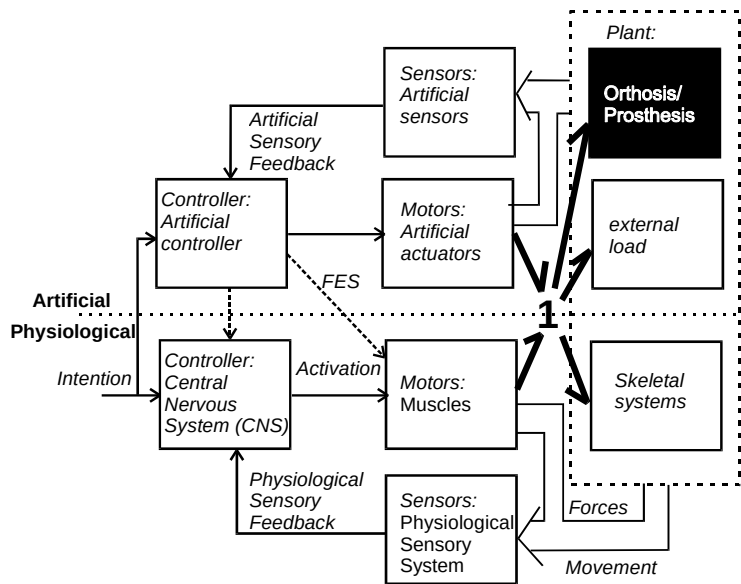


Figure 11.2 Orthosis and prostheses systems mechanically support the motor function of the body. These support systems can be passive or active, with or without sensing and control.

11.2.1 UTX passive knee orthosis

The UTX is a passive Knee Ankle Foot Orthosis (KAFO) developed at the University of Twente and re-engineered by the firm Kunst and van Leerdam (Van Leerdam 1993), (Van Leerdam 1999). The orthosis extends the knee during stance, while allowing free swing during swing phase of gait (figure 11.3).

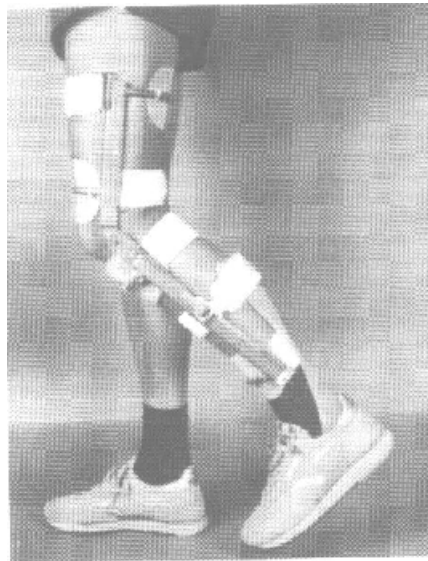


Figure 11.3 UTX-swing orthosis (from (Van Leerdam 1999))

INTENDED USER GROUP

People with weak knee extensors, requiring knee extension support during stance phase.

INTERACTION WITH IMPAIRED MOTOR SYSTEM

During the stance phase the knee is mechanically locked allowing safe weight bearing. During the swing phase the knee is unlocked, allowing efficient swinging of the leg with good foot clearance. The knee locking mechanism is controlled from the ankle joint. The knee is mechanically unlocked if the ankle is dorsiflexed (at end of stance phase) and no flexion moment is present at the knee.

USER EXPERIENCE / CLINICAL ACCEPTANCE

The orthosis is in production by firm Ambroise Holland bv and has been introduced in the clinic, where it progressively is gaining acceptance.

11.2.2 LSU and STEEPER Reciprocating Gait Orthosis (RGO)

The LSU (Louisiana State University orthosis) is a Hip Knee Ankle Foot orthosis (HKAFO) for complete paraplegic (Spinal Cord Injured persons with thoracic lesion) (Solomonow et al. 1989). The flexion-extension movements of both legs are coupled by a bowden cable connecting both hip joints (reciprocating gait orthosis: RGO). The STEEPER is an newer RGO, based on the same principles as the LSU (figure 11.4). An improved RGO has been developed by Baardman and IJzerman (Baardman et al. 1997a), allowing knee flexion during swing phase (see UTX, section 11.2.1) and can be divided in a below knee part and a part above for easy donning and doffing and compatibility with wheel chair use.

INTENDED USER GROUP

Complete Spinal Cord Injured (SCI) persons with thoracic lesion (paraplegics). These persons can stand and walk in the orthosis using crutches for balancing.

INTERACTION WITH IMPAIRED MOTOR SYSTEM

- Because of the bowden cable connecting both hip joints, the flexion-extension movements of both legs are coupled (Baardman et al. 1997b; IJzerman et al. 1997). Extension of one leg occurs simultaneously with flexion of the other leg. A step (flexion at one side) coincides with extension at the other leg. A backward trunk movement also assists in making a step. The propulsion comes from the healthy part of the body.
- Crutches or walking frames are used for balancing the body.

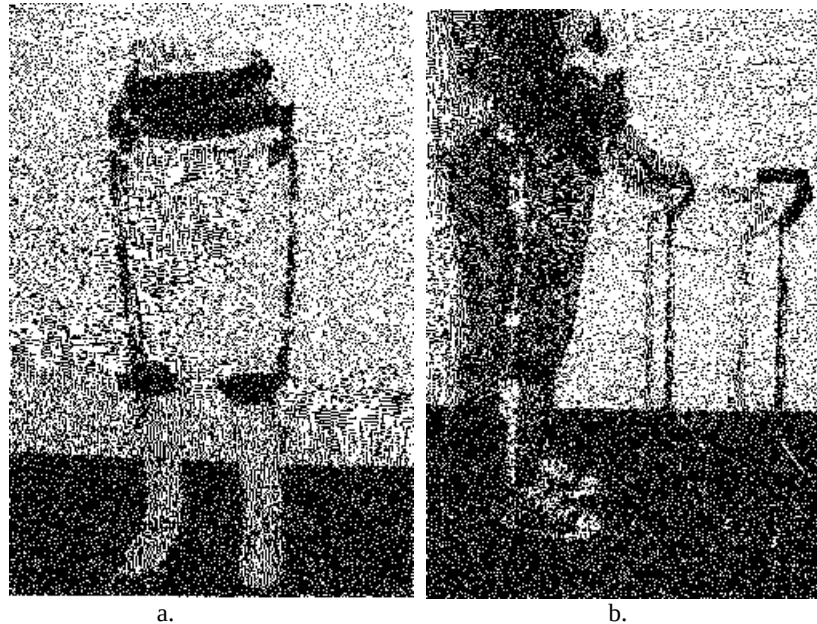


Figure 11.4 (a) A modified STEEPER Reciprocating HKAFO orthosis.
(b) modified STEEPER RGO in combination with electrical stimulation
(Baardman et al. 1997a).

USER EXPERIENCE / CLINICAL ACCEPTANCE

- LSU and STEEPER are both commercially available for many years (10-20 years) and are used at many, but not all rehabilitation institutions
- The RGO orthoses have limited functional meaning (large don/doff time, slow walking (Solomonow et al. 1989)), but important therapeutic effect have been reported (Solomonow et al. 1997): reduced spasticity, improved bone density, improved cardiovascular fitness, etc..
- The SEPERIX has not been commercialized yet. It is currently further developed in a cooperative project of UT, Roessingh and Kunst and van Leerdam

11.2.3 Controlled transfemoral prostheses

In recent years, microprocessor controlled knee joints for transfemoral prostheses have been introduced commercially by the firms Blatchford (Intelligent Prosthesis) and Otto Bock (C-leg) (figure 10.5). The C-leg of Otto Bock contains a hydraulic damper, which is continuously controlled by a microcontroller in the prosthesis. Several sensors are included in the prosthesis for feedback and user intention detection. The C-leg is based on pioneer research in Belgrade (Popovic et al. 1991), (Tomovic 1984) and further development in Edmonton (Popovic et al. 1995).



Figure 10.5 C-leg intelligent transfemoral prosthesis (Otto Bock).

INTENDED USER GROUP

Transfemoral amputees, especially young amputees who challenge the performance of an above knee prosthesis.

INTERACTION WITH IMPAIRED MOTOR SYSTEM

- In the C-leg the knee damping is continuously controlled. In the Blatchford knee, the damping is only controlled during the swing phase.
- Movement, force and moment sensors are incorporated in the prosthesis. These sensors provide feedback information and user intention detection for the control of the damper.
- Controlled knee joint with electrical motor has been investigated at MIT. This has not yielded commercial systems (Hunter 1981).

USER EXPERIENCE / CLINICAL ACCEPTANCE

- The Otto Bock C-leg and Blatchford knee are clinically used in limited numbers. No extensive and independent clinical outcome studies have been performed for these systems.
- Improved performance in comparison with passive prostheses has been reported: the Blatchford Intelligent Prostheses showed lower metabolic energy consumption by the user for speeds above 3.2 km/h (Taylor et al. 1996)

11.2.4 James Transfer Systems

The James is an active support for standing up developed by the firms 3T and Indes for Demcon (Van Alste et al. 1999) (figure 11.6).



Figure 11.6 James Transfer system (from (Van Alste et al. 1999)).

INTENDED USER GROUP

People who can not stand-up and sit-down independently.

INTERACTION WITH IMPAIRED MOTOR SYSTEM

The James transfer system follows a natural standing up trajectory (comparable to normal standing up) and stimulates active participation of the user in standing up by allowing faster standing up when the user participates.

USER EXPERIENCE / CLINICAL ACCEPTANCE

The system has been developed and is being commercialized. The controlled character of the system and the natural trajectory are specific features of this transfer system, which is not found in other transfer systems.

11.2.5 Passive below elbow prostheses

Passive below elbow prostheses are most commonly used, although many amputees prefer no prosthesis or only a nonfunctional cosmetic hand.

A very interesting principle to make a passive below elbow prosthesis controllable is Extended Physiological Proprioception (EPP) (see below).

INTENDED USER GROUP

People with below elbow amputation.

INTERACTION WITH IMPAIRED MOTOR SYSTEM

Extended Physiological Proprioception was first described by Simpson (Simpson 1974; Doubler et al. 1984): The controlled prosthesis hand joint is coupled to the contralateral shoulder. The hand opening can be controlled by the shoulder, while the grip force is directly felt at the shoulder.

USER EXPERIENCE / CLINICAL ACCEPTANCE

Passive below elbow prostheses are most commonly used, although many amputees prefer no prosthesis or only a nonfunctional cosmetic hand.

11.2.6 EMG controlled below elbow prostheses

EMG controlled (myoelectric) prosthetic systems have been developed since the 1960's (Parker et al. 1986). The best know application is the myoelectric controlled below elbow prosthesis (figure 11.7).

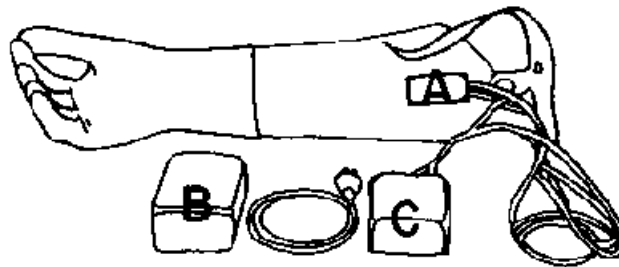


Figure 11.7 Myoelectric prosthesis developed in Moscow in 1965 (Parker et al. 1986)

INTENDED USER GROUP

People with below elbow amputation.

INTERACTION WITH IMPAIRED MOTOR SYSTEM

- EMG from synergistic muscles under voluntary control are used as control signals.
- no sensory feedback is available, which limits the controllability of the prosthesis. More recent research investigates the possibility to provide sensory feedback to prosthesis users by stimulating sensory nerves (Riso 1999)

USER EXPERIENCE / CLINICAL ACCEPTANCE

EMG controlled below elbow prostheses are in limited clinical use

11.3 Systems involving electrical muscle stimulation (neural prostheses)

Functional Electrical Stimulation (FES) involves the stimulation of muscles with the objective to support the motor function of the body (figure 11.8). Systems using FES are also often referred to as Neural Prostheses, although Neural Orthoses may be a better name, since the neural tissue is not replaced, but only the neural function is supported by supplying information.

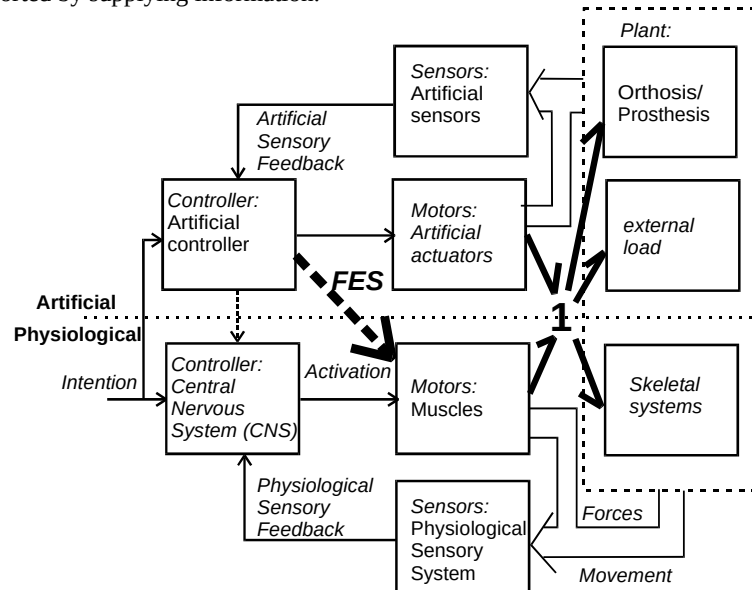


Figure 11.8 Functional Electrical Stimulation (FES) involves the stimulation of muscles with the objective to support motor functions of the body

11.3.1 Drop foot stimulator

Drop foot stimulators stimulate the dorsiflexor muscles to lift the foot during the swing phase of gait. This is useful for persons who cannot lift their feet voluntarily (drop foot), e.g. stroke patients. The drop foot stimulator was introduced already in 1961 by Liberson et al. (Liberson et al. 1961) (figure 11.9).

Recently, a two channel implant drop foot stimulator was developed by Bultstra et al. which allows for balanced stimulation of inversion and eversion of the foot, such that an optimal foot lift can be readjusted if required (figure 11.10).

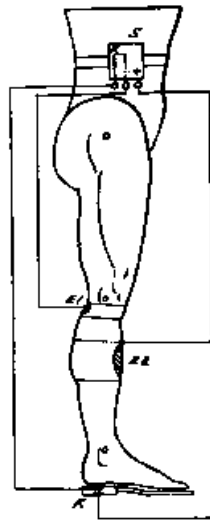


Figure 11.9 Concept of drop foot stimulator (copy of drawing from original paper of Liberson (Liberson et al. 1961)). The peroneal nerve is stimulated, activating the dorsiflexor muscles. A heel switch detects swing phase of gait.

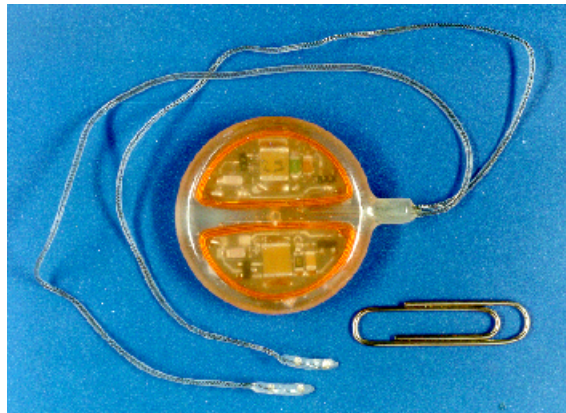


Figure 11.10 Two channel peroneal nerve stimulator for dropfoot applications. One channel stimulates the deep peroneal nerve, resulting in dorsiflexion and some inversion. The second channel stimulates the superficial peroneal nerve, at the ankle mainly resulting in eversion. A well balanced activation of both channels results in optimal foot lift during the swing phase of gait. The implant was a joint development of University of Twente, RRD and MST and is currently produced for clinical trials by the English firm Finetech.

INTENDED USER GROUP

Stroke (CVA) patients with drop foot.

INTERACTION WITH IMPAIRED MOTOR SYSTEM

- the peroneal nerve, innervating the dorsiflexor muscles, is stimulated either by electrodes on the surface of the skin (Liberson et al. 1961) or by implanted electrodes (Vodovnik et al. 1978; Holsheimer et al. 1993; Rozman et al. 1993)
- A heel switch is used for swing phase detection (Liberson et al. 1961)). This can alternatively be done by an accelerometer (Willemsen et al. 1990; Dai et al. 1996), which can be integrated with the stimulator or by measuring signals from skin sensory nerves carrying information from the skin sensors of the foot (Haugland et al. 1995).

USER EXPERIENCE / CLINICAL ACCEPTANCE

- Peroneal drop foot stimulators are clinically used in a limited number of Rehabilitation Institutions.
- Except immediate orthotic effect of dorsiflexion during swing phase, beneficial therapeutic effects have been reported, including reduced spasticity and improved voluntary control of dorsiflexor muscles have been found (Merletti et al. 1979).
- The use of drop foot stimulator increases walking velocity and reduces energy cost (Taylor et al. 1999a; Taylor et al. 1999b)

11.3.2 FES systems for marginal walkers

FES is expected to improve the mobility function in marginal walkers. Among this category are incomplete paraplegics, hemiplegics and multiple sclerosis patients. There is a large request for functional FES systems in the incomplete paraplegic community (Maxwell et al. 1999)

INTENDED USER GROUP

Marginal walkers among incomplete paraplegics, hemiplegics and multiple sclerosis patients.

INTERACTION WITH IMPAIRED MOTOR SYSTEM

- The neuromuscular impairments can be variable among individual users, including drop foot, weak knee extension, mostly unilateral, but sometimes bilateral. Therefore, the FES system (including stimulation sites, number of channels, sensing and control) needs to be individualized (Hermens et al. 2000)
- Most commonly, stimulation is applied for foot drop, for generating a step (stimulation of the flexion withdrawal reflex, which yields flexion in hip, knee and ankle) and for knee extension during stance (Hermens et al. 2000).

USER EXPERIENCE / CLINICAL ACCEPTANCE

- Clinically used in limited number of rehabilitation centres.
- In the EU CREST project from 23 treated incomplete paraplegic patients, 10 were given single channel stimulator (stimulation of flexion withdrawal reflex to generate stepping), 12 were given a 2-channel system (flexion withdrawal reflex + knee extension) and 1 was given a 3 channel system (Hermens et al. 2000).
- Ladouceur et al showed that training effect is as important as the immediate orthotic effect (Ladouceur et al. 2000b; Ladouceur et al. 2000a)

11.3.3 Parastep FES system for paraplegics

Graupe et al. developed the Parastep FES system for paraplegic ambulation. (Graupe et al. 1998). The system uses FES with surface electrodes and no orthosis. It is the only FES system for paraplegic ambulation which has obtained FDA approval (permission for clinical use in the USA) so far. The system is based on the earlier work of Kralj et al. (Kralj et al. 1980)

INTENDED USER GROUP

Complete/near-complete T4 to T12 paraplegics

INTERACTION WITH IMPAIRED MOTOR SYSTEM

- quadriceps muscles are stimulated for knee extension
- flexion withdrawal reflex is stimulated via de peroneal nerve to provide a stepping motion
- the user operates the stimulation with switches in the crutches

USER EXPERIENCE / CLINICAL ACCEPTANCE

- the only paraplegic FES system with US permission for clinical use (Approval from the Food and Drug Administration FDA).
- The systems has been clinically introduced, but the company could not make it.

11.3.4 Implantable stimulation systems for complete paraplegics

Several implantable systems for restoration of mobility in complete paraplegics have been developed. The first system was developed in Vienna (Stoehr et al. 1983; Thoma et al. 1983). Recently, such implantable systems have been developed and clinically tested by Davis, using a modified cochlear implant from the Australian firm Neopraxis (Davis et al. 1999a; Davis et al. 1999b), Rabischong (EU CREST and SUAW projects) and Donaldson (Donaldson et al. 1997a; Donaldson et al. 1997b; Rushton et al. 1997).

INTENDED USER GROUP

Complete paraplegics

INTERACTION WITH IMPAIRED MOTOR SYSTEM

- Muscles are stimulated using implanted electrodes around nerves or on the surface of the muscles (epimysial electrodes), or by electrodes on the ventral roots (Donaldson et al. 1997a; Donaldson et al. 1997b; Rushton et al. 1997). The last option has the advantage that all muscles can be reached from one central region, although selectivity is a problem.
- An external transmitter/controller is connected to the implanted receiver/stimulator. Energy and information is transmitted via coupled coils in transmitter and receiver.
- Sensors and control are external

USER EXPERIENCE / CLINICAL ACCEPTANCE

- Until now, implanted systems for complete paraplegics have not been functional in restoring mobility. The function restoration is not essentially improved with respect to external stimulation systems, because the control is still similarly coarse.

- The root stimulation system of Donaldson (Donaldson et al. 1997a; Donaldson et al. 1997b; Rushton et al. 1997) has the potential of being integrated with bladder stimulation, for which electrodes are also implanted at the spinal roots. This would yield a bladder stimulator with limited motor function, which could be functional in making transfers. Such a combination may be clinically acceptable, but this has not yet been evaluated. The combination of bladder stimulation and neuromodulation with motor function restoration is also possible with the system of neuropraxis (Davis et al. 1999a).

11.3.5 Freehand Upper Extremity FES system

The Freehand stimulation system aims at functional restoration of hand function in complete Spinal Cord Injured persons. The system features an implanted stimulator and electrodes (figure 11.11) (Kilgore et al. 1997; Hart et al. 1998), (Smith et al. 1998). This implanted stimulation system can be combined with tendon transfer surgery (Kilgore et al. 1997).

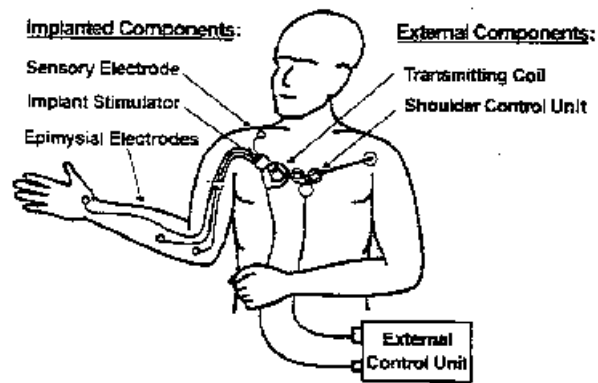


Figure 11.11 Free Hand implanted stimulation system for upper extremity function in Spinal Cord Injured persons (from (Kilgore et al. 1997).).

INTENDED USER GROUP

C5/6 complete paraplegics

INTERACTION WITH IMPAIRED MOTOR SYSTEM

- Stimulation of paralysed muscles.
- Sensory feedback of system state by electrocutaneous stimulation
- Shoulder command stick, enabling control of the system by contralateral shoulder.
- Possibilities to use feedback of skin sensory signals in the control of hand grasp with the Freehand system has been shown at Aalborg University (Sinkjaer 1999).
- The system was combined with stimulation of the elbow extensor (m. triceps), which resulted in an increased workspace for grasping in SCI subjects. An accelerometer was used to measure the orientation of the upper arm. From this, the required stimulation level of the triceps could be determined. (Crago et al. 1998), (Hollander et al. 1998)). The system has been tested in two SCI subjects.
- an implantable Hall effect joint angle sensor was developed to be incorporated in the system (Johnson et al. 1999) for command control (compare

with sensor in Bionic Glove: 11.5) and feedback control. This has not been tested in patients yet.

USER EXPERIENCE / CLINICAL ACCEPTANCE

- Grasp force increased, functional grasp patterns were restored, users improved independence (Kilgore et al. 1997). The systems are used at home.
- FDA and CE approval have been obtained. It is marketed by the firm NeuroControl, Cleveland.
- the Freehand system has been clinically introduced in several clinical centres world wide. The system is in the process of being clinically accepted.
- It should be noted that the system is only useable for a relatively small population of C5/6 complete paraplegics

11.3.6 Hand grip stimulation system: Bionic Glove

The Bionic Glove is a surface stimulation system for support of hand grasp in C5-7 (figure 11.10). Electrodes are mounted in a garment which can easily be put on ('donned') covering the lower arm and wrist. Muscles that generate opening or closing of the hand are stimulated depending on the wrist angle, which is measured with a sensor in the garment. This stimulation system supports the 'tenodesis grip'. This grip is passively used by quadriplegic patients when extending the wrist.

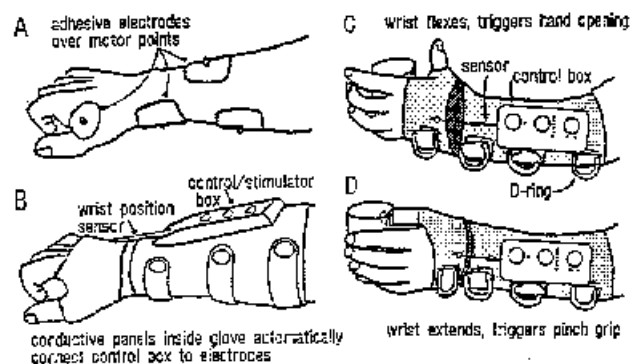


Figure 11.10 The Bionic Glove (from (Prochazka et al. 1997)).

INTENDED USER GROUP

Complete C5-7 Spinal Cord injured people having active wrist extension and flexion.

INTERACTION WITH IMPAIRED MOTOR SYSTEM

- Surface stimulation of muscles in lower arm, yielding hand opening and closing, supporting tenodesis grip.
- Controlled by wrist angle sensor incorporated in garment and stimulator.

USER EXPERIENCE / CLINICAL ACCEPTANCE

The Bionic Glove has been evaluated in 9 SCI patients in Edmonton (Prochazka et al. 1997) and in 12 SCI patients in Belgrade (Popovic et al. 1999). These studies report that the Bionic Glove improves the hand grip (higher grasp force) and results in better

hand function. This results in improved independence as judged by Functional Independence Measure and Quadriplegia Index of Function scores (Popovic et al. 1999).

The Bionic Glove has not been commercialized yet. A company in Edmonton was set up, but had to stop.

11.3.7 Bladder stimulator

A bladder stimulator supports controlled voiding of urine. An effective bladder stimulator has been developed several decades ago by the group of Prof. Brindley in London (produced by FineTech). It is the only commercial bladder stimulation system and is clinically used.

INTENDED USER GROUP

People with spinal cord injury having voiding problems.

INTERACTION WITH IMPAIRED MOTOR SYSTEM

- bladder and sfincter are simultaneously stimulated. This results in bladder pressure build up with closed sphincter. After the end of the stimulation burst the fast sphincter muscle relaxes faster than the slow bladder muscle, resulting in emptying of the bladder. This process is repeated several times intermittently until the bladder is empty
- In order to allow for sufficient bladder filling and preventing spastic contraction of the bladder, the dorsal sensory spinal roots coming from the bladder are often cut (dorsal rhizotomy). This also ends erection in male subjects.
- Improved methods for bladder stimulation have been developed (Rijkhoff et al. 1997; Rijkhoff et al. 1998; Haugland et al. 1999), applying selective stimulation of nerve fibers innervating the bladder and fibers innervating the sphincter. This allows for a more continuous voiding.
- Also methods have been developed to prevent reflexive contraction of the bladder without dorsal rhizotomy, by measuring and subsequent block afferent activity (Haugland et al. 1999). This can also yield a warning signal for the user that the bladder has filled and that it is time to go to the toilet.

USER EXPERIENCE / CLINICAL ACCEPTANCE

- The Finetech bladder stimulator has been used for 10-20 years in many patients world wide with good clinical results.
- The improved bladder stimulation methods have not yet been implemented in a commercial system.

11.4 Hybrid systems involving mechanical support and electrical stimulation

In several motor support systems, FES and orthoses are combined (figure 11.11). The orthosis ensures stabilization of the supported limb, while FES provides active movement.

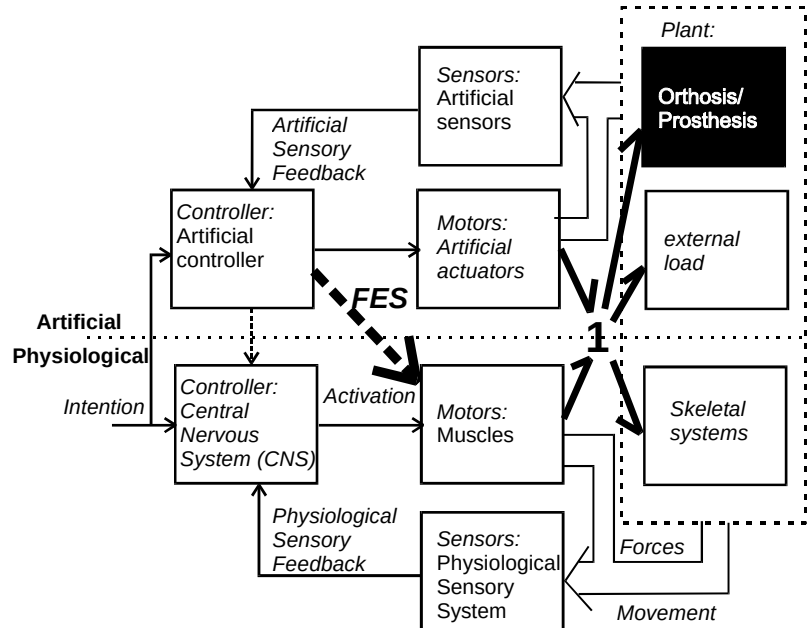


Figure 11.13 FES and orthoses can be combined to support motor function (hybrid systems). The orthosis supports and stabilizes the limb, while FES provides active movement

11.4.1 Hybrid gait orthosis

Hybrid gait systems have been developed using reciprocal gait orthoses (RGO) (section 11.2.2) and FES (Solomonow et al. 1989; Franken et al. 1994; Nene 1994; Baardman et al. 1997a)..

INTENDED USER GROUP

Complete Spinal Cord Injured (SCI) persons with thoracic lesion (paraplegics).

INTERACTION WITH IMPAIRED MOTOR SYSTEM

The RGO supports and stabilizes the body, FES provides propulsion

USER EXPERIENCE / CLINICAL ACCEPTANCE

Combination of electrical stimulation with RGO reduces energy consumption (Solomonow et al. 1989)), but is also not functional. FES as such also has therapeutic effects during and without gait (Solomonow et al. 1997).

11.4.2 The Handmaster: FES and orthosis system for support of hand function in C5 SCI and reduction of spasticity in stroke subjects

The Handmaster (NESS company, Israel) is a hybrid system combining FES of muscles for flexion and extension of the fingers (figure 11.14). It is designed for support of hand grasp, but also has important training effects, as reduction of spasm in stroke subjects, improved range of motion, increased muscle strength (Nathan 2000). The training effects even seem to be more important for the use of the device than the generation of functional by the device.

The stimulator has a functional mode for support of grasp and a training mode, which delivers cyclical extension and flexion stimulation.

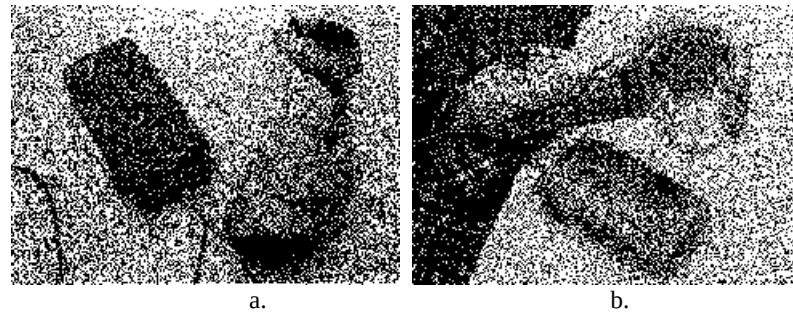


Figure 11.14 (a) The Handmaster FES-orthosis for support of hand grasp. (b) while being used by a tetraplegic patient picking up a glass of water (from (IJzerman et al. 1996))

INTENDED USER GROUP

- C5 Spinal cord injured with loss of wrist extension: grasp, key grip and hand open can be supported (IJzerman et al. 1996).
- Stroke subjects: the Handmaster helps in relearning motor control and can contribute in reducing spasm (IJzerman et al. 1996), (Weingarden et al. 1997), (Weingarden et al. 1998)
- Other patient groups: head injuries, cerebral palsy, multiple sclerosis, orthopaedic patients after hand trauma/surgery

INTERACTION WITH IMPAIRED MOTOR SYSTEM

Posture of the arm and hand is supported by an orthosis. Finger flexors and extensors are stimulated by surface electrodes.

The stimulator has an automatic training mode, in which finger extensors and flexors are alternately stimulated.

For functional support of grasp and hand opening the control box has control keys which can be pressed with the contralateral limb.

Posture

USER EXPERIENCE / CLINICAL ACCEPTANCE

- Therapeutic effects have been shown in stroke patients and seem to be the major reason for prescription. In stroke patients, spasticity was significantly reduced at fingers, wrist, elbow and shoulder joints (Weingarden et al. 1998). Also active range of motion was improved in 80% of patients (Nathan 2000).

- Upper limb function was regained in part of the quadriplegic subjects (Nathan 2000).

11.5 Systems that modulate the Central Nervous System

If the Central Nervous System, which is the controller of the physiological motor system, does not function properly, it can be influenced such that the function is improved (figure 11.15). This often involves continuous stimulation of the brain (see e.g. section 11.5.1) or the spinal cord (see e.g. section 11.5.2). Such systems are often referred to as Neuromodulation systems (Holsheimer 1998).

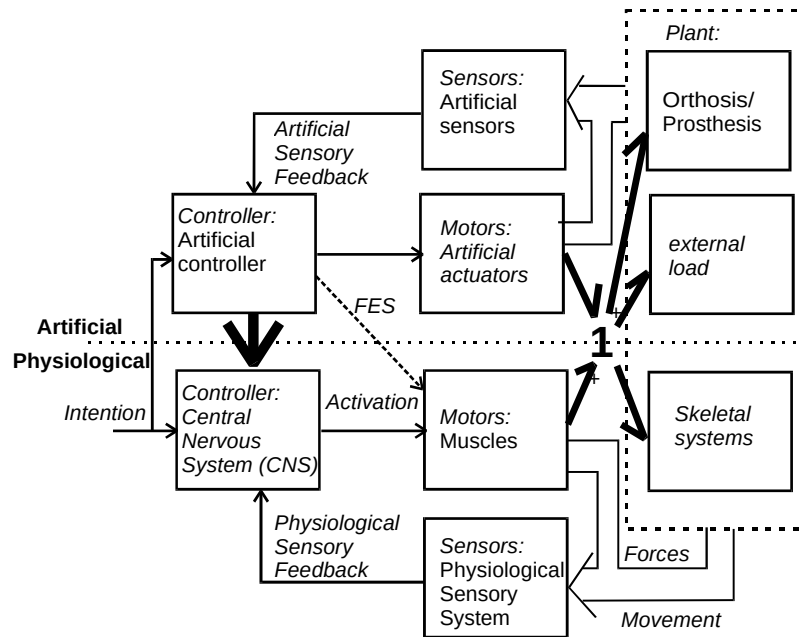


Figure 11.15 Neuromodulation systems influence the behaviour of the Central Nervous System by continuous activation

11.5.1 Spinal cord stimulation for reduction of pain and spasm

Spinal cord stimulation has been in clinically use for several decades, with variable results in reducing pain and spasm. It has been especially succesful in reducing chronic pain (Holsheimer 1997; Holsheimer 1998). In the last decade the mechanisms of spinal cord stimulation have been elucidated. On the basis of this knowledge improved stimulation electrode configurations have been designed (Holsheimer et al. 1997)

INTENDED USER GROUP

People with chronic pain

INTERACTION WITH IMPAIRED MOTOR SYSTEM

Certain paths of pain transmission are blocked at the level of the spinal cord

USER EXPERIENCE / CLINICAL ACCEPTANCE

Spinal cord stimulation has been especially successful in the reduction of chronic pain.

11.5.2 Deep brain stimulator

Parkinson patients have impaired motor control (tremor, stiffness, slow movements, less movement), which originate in certain centres in the brain. Continuous stimulation of the thalamus or pallidum centres using implanted electrodes can reduce these movement disorders, e.g. reducing tremor (Limousin et al. 1995; Lenders et al. 1999; Limousin-Dowsey et al. 1999).

INTENDED USER GROUP

Parkinson patients.

INTERACTION WITH IMPAIRED MOTOR SYSTEM

The stimulation of the thalamus or Pallidum brain centers change the behavior of the brain centers involved in motor control. This also affects the modulating inputs from the brain to the spinal cord, affecting the reflex system.

USER EXPERIENCE / CLINICAL ACCEPTANCE

Pallidum or thalamus stimulation is very effective in reducing tremor and other movement problems. It is only used if medication does not provide effective motor control improvement or provides unacceptable side effects, because it involves brain surgery with a certain level of risk.

11.6 Systems that train the Central Nervous System

After the occurrence of a neuromuscular impairment, the Central Nervous System can be retrained to improve its function as a controller. This can be done by physical and ergonomic therapy, but can also be supported by technical systems (figure 11.16). This paragraph will present some examples of systems that have been specifically designed to train the Central Nervous Systems. These systems support the movement of limb, taking partial control. The sensory feedback supplies patterned signals to the CNS, which is assumed to contribute to the motor control relearning. Many of the mechanical and FES systems for support of motor function (section 11.2-4) also have a secondary training effect (Ladouceur et al. 2000b; Ladouceur et al. 2000a).

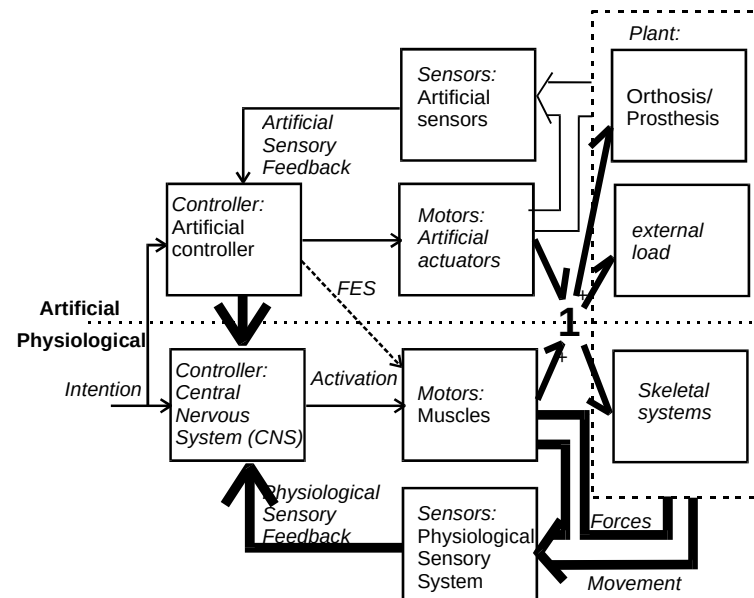


Figure 11.16 Systems for training the motor control performance of the Central Nervous System move the extremities in functional patterns. The resulting sensory feedback contributes to the training of the CNS

11.6.1 Mobility training system

Gait training on a treadmill with partial body weight support has been shown to improve voluntary motor control (Dietz et al. 1998; Schindl et al. 2000). This therapy requires therapists to move the legs of the subject, while walking over the treadmill. This is a physically demanding task for the therapists. Recently, a controlled gait trainer was developed (Hesse et al. 1999), which moves the legs of the subject in a gait-like manner, while suspending part of the body weight.

INTENDED USER GROUP

Stroke patients, incomplete paraplegics and Cerebral Palsy children.

INTERACTION WITH IMPAIRED MOTOR SYSTEM

Imposing the walking movements trains the central nervous system such that it improves the voluntary control of walking. The walking training results in the transmission of patterns sensory information to the central nervous system. It has been hypothesized that a central pattern generator is present in the spinal cord and this generator is trained by the provided patterned sensory information. The presence of a central pattern generator has been shown in animals, but its presence in humans is still debated (Duysens et al. 1998).

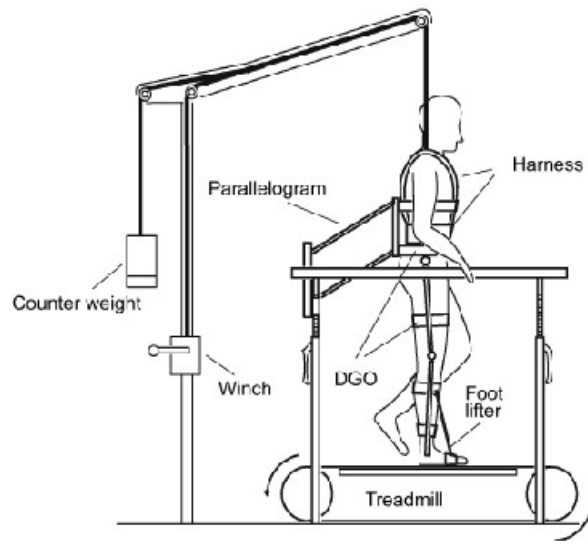


Figure 11.17 Mobility training system using a treadmill and partial weight support (ETH, Zurich, Switzerland)

USER EXPERIENCE / CLINICAL ACCEPTANCE

Walking training on a treadmill with partial weight suspension has been shown to improve voluntary motor control and mobility in stroke patients, incomplete paraplegics and Cerebral Palsy children (Dietz et al. 1998; Schindl et al. 2000). Even in complete paraplegics the generation of patterned muscle activation patterns by the central nervous system is improved, but this does not result in mobility improvements in this group.

11.6.2 Upper extremity training robot system

In stroke subjects, motor control in the upper extremities can be improved by moving the arm in a cyclical manner in regular training sessions (Krebs et al. 1999). At MIT a robot system was developed which imposes movements to the upper extremity.

INTENDED USER GROUP

Stroke patients having unilateral upper extremity motor control impairments.

INTERACTION WITH IMPAIRED MOTOR SYSTEM

An impedance control scheme ensures that the movement control is shared between the robot and the person being trained. At the start, the movements are imposed via a stiff control. If voluntary motor control improves, the robotic support is reduced by reducing the stiffness of the robot action via the stiffness control scheme (Krebs et al. 1998).

USER EXPERIENCE / CLINICAL ACCEPTANCE

- voluntary motor control is improved more than in patients who received standard rehabilitation treatment (Krebs et al. 1999).
- This improvement was sustained beyond three years (Krebs et al. 1999).

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