DREAMING FROM VIRTUAL REALITY REHABILITATION TECHNOLOGY IN THE FUTURE: VIRTUAL REALITY, ROBOTICS AND TELEREHABILITATION

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The application of robotics to disability and rehabilitation research is growing rapidly. The National Library of Medicine's MEDLINE reports an increase of robotics citations. Data from the National Institute on Disability and Rehabilitation Research (NIDRR) also show an exponential increase of funding for rehabilitation robotics. The research domains appears to be moving from a paradigm of building robotic arms with which persons with disabilities can perform activities of daily living to a paradigm of developing robotic devices that assist with therapy in the hope of achieving longer-term achievement gains. (Robert Jaeger-2006).

"Biomechatronics" is more and more used as a therapy with interaction between technology and users in order to support movement and posture, and can be considered as therapy machines assisting the impaired motor system (P. Veltink-2001). Different technology devices are used in neurorehabilitation (cerebrovascular accidents, spinal cord lesions, brain injuries) like functional electrical stimulation (FES) and neuroprostheses , robot -assisted therapy and treatments based on virtual reality and virtual environment.

NEUROPROSTHESES

A neuroprosthesis is a device or system that provides FES and is used to substitute an impaired motor function. It functions as an artificial nerve system to control some body functions. Neuromuscular electrical stimulation (NMES) refers to electrical stimulation of an intact lower motor neuron to activate paralyzed or paretic muscles in precise sequence and magnitude to accomplish functional tasks. (L. Sheffler-2007). Today, these tasks include upper-limb performance of activities of daily living, standing or ambulatory activities and control of respiration and bladder function. Surface and implanted NEMS is used for functional and therapeutic applications in patients with spinal cord injury or stroke.

Upper-limb neuroprostheses are applied in C5C6 spinal cord lesions in order to provide grasp and release function. The prosthesis consists of a stimulator that activates the muscles in the arm, an input transducer, and a control unit. Gross hand grasp opening and closing is activated by the ability to retract and protract the shoulder. The NESS handmaster system (a hybrid brace –transcutaneous neuroprosthesis) is less invasive than the implant systems and can be used in C5C6 tetraplegia. More invasive is the implantable hand prosthesis, providing lateral and palmar grasp in response to activation of a shoulder-position transducer.

Lower-limb applications include transcutaneous multichannel electrical stimulation to produce standing and stepping for persons with complete spinal cord injury, but only for home and short community distances. The system can also be implemented in incomplete lesions to achieve functional ambulation, but the neurological variety of incomplete spinal cord lesions calls for caution, especially in the presence of moderate spasticity and a decreased range of motion. FES can enhance gait, muscle strength and cardiorespiratory fitness in a spinal cord injury population, but these benefits are dependent on the nature of the injury and further research is required to generalize these results. Today, the implanted multichannel lower-limb neuroprosthesis system for paraplegia is used in clinical trials and is under investigation. Combinations with reciprocating gait orthoses are possible. The metabolic energy required to walk is too high for this system to replace wheelchair mobility. In this domain the expectations for the immediate future are low.

FES is used in stroke patients to treat ankle dorsiflexion weakness during the swing phase of gait with increase in walking speed. The Odstock Dropped- Foot Stimulator, the NESS L300 and the WalkAide are transcutaneous peroneal nerve stimulators that may improve hemiplegic gait, but problems exist with exact electrode placement. Implantable systems may resolve these problems but other technical limitations arise, such as poor reliability of the heel-switch and foot-floor contact transmitter and difficulties in balancing inversion and eversion. New systems are being studied, such as the STIMuStep, an implantable two-channel peroneal nerve stimulator allowing individual stimulation of the deep and superficial branches for eversion-inversion balance.

Other indications of neuroprostheses are bladder stimulation and phrenic nerve stimulation for respiratory problems. An implanted bladder neuroprosthesis with electrical stimulation of the sacral parasympathetic nerves restores micturition with better bladder emptying and less incontinence. Phrenic nerve pacing provides a artificial ventilatory support in patients with respiratory failure secondary to a cervical spinal cord injury. However, all patients need a back-up mechanical ventilator system in case of pacemaker failure.

WHEELCHAIR CONTROL

Neural interfacing in wheelchair control is becoming more and more realistic. Control to steer the wheelchair can be provided through stimulation by eye movement or by muscle activity in the facial area. Brain activity (brain-computer interfaces) or a chip (implant) in the brain (braingate-trial) can also used for this purpose. Brain Gate is a brain implant system developed in 2003 by the biotech company Cyberkinetics in conjunction with the Department of Neuroscience at Brown University. The device is designed to help those who have lost control of their limbs or other bodily functions, such as patients with amyotrophic lateral sclerosis (ALS) or spinal cord injury. The computer chip, which is implanted into the brain, monitors the patient's brain activity and converts the intention of the user into computer commands. Currently, the chip uses 96 hair-thin electrodes that sense the electromagnetic signature of neurons firing in specific areas of the brain, e.g., the area that controls arm movement. The activity is translated into electrically charged signals, which are sent and decoded using a program, that can move a robotic arm, a computer cursor, or even a wheelchair. Also with this chip comes the ability to reactivated paralysed muscles.

ROBOTICS

Biomedical, rehabilitation, biomedical engineering and behavioral sciences continuously add to our understanding of how robotics can be used in rehabilitation. Robots and exoskeletons (wearable robotics) have used since 1990 to support training. Therapeutic systems are used for training in a clinical environment while home- based systems are designed to support the patient with activities in daily living. Therapeutic robots are used in neurorehabilitation, and may be classified into active, semi-active and passive robots.

The benefits are modest and mostly limited to a reduction of impairment.

Regaining full functional use of the upper limb is more difficult to realize. Some devices, such as the Armeo (Hocoma company), are already being used for intensive task-oriented therapy to improve the arm function of individuals who have suffered a stroke, traumatic brain injury or other neurological diseases and injuries. In this system an augmented feedback is added to the movement and allows functional therapy exercises in a virtual reality environment.

This therapeutic approach allows to improve the performance of a severely weakened arm by means of engaging functional arm training.

Supporting gait can start with specific devices such as Erigo (Hocoma) which is an innovative tilt table with integrated robotic stepping functions. It provides the opportunity to initiate intensive movement therapy and physiological loading of the lower limbs at an early stage combined with the possibility of simultaneous uprighting of stroke, brain-injured or spinal-cord injured patients. Erigo® -based therapy supports and facilitates patient mobilization in combination with sensory stimulation .and activates the cardiovascular system .The system intensifies afferent sensory stimulation while repetitive physical motion reduces spasticity in some patients. It may reduce the risk of secondary immobility-related complications, improve alertness in vegetative- state patients and relieve physical strain on therapists. It is also easy to use.

The MotionMaker (Swortec) or "cyberorthosis" is a stationary device for active mobilization of the lower limbs. Its main functions are investigation, diagnosis, training and rehabilitation of muscular strength and endurance, as well as articular mobility and movement coordination. The machine consists of an electrically adjustable table with two motorized orthoses, a system for neuromuscular electrical stimulation and a central control system, which regulates and coordinates the electrical stimulation of the muscles and the motors of the orthosis. Patients with spinal cord injury, stroke, traumatic brain injury, cerebral palsy or multiple sclerosis can benefit from an important increase in muscular strength, improvement of limb perception and balance, reprogramming and better control of voluntary movements and reduction of spasticity.

In the further evolution more driven gait orthoses can be used in spinal cord and brain injuries .Robot-aided treadmill training can be performed with use of the Lokomat equipment (Hocoma). Locomotion therapy supported by an automated gait orthosis on a treadmill has established itself as an effective intervention for improving over-ground walking function impaired by neurological diseases and injuries. Compared to manual treadmill training the robotic gait orthosis, which guides the patient's legs on a treadmill, offers a wide range of training possibilities and a faster progress through longer and more intensive training sessions. The physical strain on therapists is relieved. The patient's walking activity is easily monitored and assessed. Motivation is improved through visualized performance feedback. The gait pattern and guidance force are individually adjustable to the patient's needs.

Robot- supported gait allows the duration and number of sessions and the treatment is less time-consuming. Feedback from the therapist is necessary in the evolution and evaluation.

Possible advantages of robotics are an increased intensity of treatment and more self-treatment by the patient, possibly at home. Further treatment in the home-situation is possible. However, most of the current devices are not sufficiently adapted to patient's strength and passive mobility.

In conclusion, robots will be used in conjunction with conventional treatment. Robotic therapy is still an emerging technology, but its limitations should be acknowledged. The best treatment for an individual patient is most likely the combination of robotic therapy and other approaches.

VIRTUAL REALITY AND VIRTUAL ENVIRONMENT.

In virtual reality the patient is part of a virtual environment in which specific functions are trained. The manipulation of environment is realized by "haptic interfaces", which are interactions between user and virtual environment. Low-tech (television or computer monitor to create interaction with a video game) or high-tech (large video screens and head-mounted displays)applications can be used.

TELEREHABILITATION

According to the WHO, by 2050, the number of persons over 65 years will have increased by 73% in the industrialized world. Over 700,000 Americans and 920,000 Europeans have a stroke (CVA) each year, of whom more than 50% survive. The prevalence of CVA in the US is 1400/100,000 and in Japan 2880/100,000.The need for services is likely to increase for other age-related diseases, e.g., osteoarthritis.

Telerehabilitation robotic systems are used in a unilateral or bilateral way. In the unilateral way the patient only interfaces with the robot in the unilateral system, while in the bilateral configuration both patient and therapist use robots. (Carignan and Krebs-2006).

Most current systems use the unilateral configuration. The patient manipulates and receives force feedback from a robot while viewing a graphic of the task on a computer display. Different systems are already used such as the Rutgers Master II, to increase hand strength in stroke patients. Exoskeletons support the system. A virtual driving environment can be created with which the patient can interact through various kinesthetic interface devices in order to steer a wheel in gaming applications. In bilateral telerehabilitation, both patient and therapist interact with each other over the internet through a shared virtual environment with forced feedback. Many technical challenges remain before bilateral telerehabilitation can be fully implemented, such as large-scale haptics, interactive control, internet time delay and patient safety.

In interactive rehabilitation is both patient and therapist interact with each other in a graphical virtual environment but have no direct force-feedback interaction with each other. Today, this system is used in many computer games. Games more directed at therapeutic interventions can significantly influence movement kinematics in persons with CVA.

Cooperative telerehabilitation describes the situation in which patient and therapist interact directly with each other over the internet, both visually and kinesthetically. Bilateral rehabilitation has been fully implemented, e.g. InMotion2 at Georgetown University).

Future trends include multidimensional wearable exoskeletons, such as the MGA skeleton for assessing arm strength, speed and range of motion.

Care will move from the inpatient setting to the outpatient and home setting. There will be a need for specific robot-assisted interactive rehabilitation and telerehabilitation. Home-based telerehabilitation will be a part of the continuum of care from bedside in the acute ward to the rehabilitation hospitals and outpatient clinics, and to the home.

NEUROETHICS

The boundery between therapy and better human "performance" is fading. More personalized health care will be developed with the need of "interactive decision making" based on multiple criteria in the rehabilitation procedure. One should consider the cost-effectiveness and neuroeconomics in the future.

CONCLUSION

All these systems have been predominantly been developed by the industry alone and invented by engineers, not by the users. More interaction between rehab specialists, companies and patients is mandatory. Furthermore, the question arises whether all these therapies are evidence- based. More research and more rigorous trials are needed in this new field of treatment technology to provide definitive evidence for clinical guidelines.

While no machine can ever substitute for the "human touch" of an experienced therapist, we look forward to the future development of this exciting new field of rehabilitation.

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