# FUNCTIONAL ELECTRICAL STIMULATION AND KINEMATICS OF WALKING

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## Summary

*At present we can observe larger interest for surface than implanted functional electrical stimulation (FES) of extremities. Surface FES can be considered as an efficient training approach in clinical environment. FES training can be upgraded by the use of sensors, communicating the information not only to the FES system but also to the patient and therapist. FES training can become an efficient exercise when combined with virtual environment. The influence of FES on movements of paralyzed extremities is demonstrated through kinematic measurements.*

## Key words:
*electrical stimulation of extremities, kinematics of walking, gait training, virtual environments*

## INTRODUCTION

Functional electrical stimulation (FES) of extremities is a rehabilitation approach which is known already for more than a century and will very likely stay in clinical practice for another hundred years. The area of FES is characterized by frequent ups and downs. Some twenty years ago there was increased interest of international rehabilitation medical and engineering community for FES. The reason was simple: FES assisted walking of completely paralyzed paraplegic subjects (6). As FES gait did not become a functional way of mobility in every day life, the interest was soon lessened. In particular, this is true for complex implanted systems for extremities which were not favorably accepted by the patients. We can claim that within today's medical and engineering knowledge, surface FES has better expectations than implanted FES. Surface FES rehabilitative devices are less appropriate for daily use in the sense of an electronic orthosis. We envisage them as therapeutic tools in clinical environments used with the patients soon after the damage to the central nervous system. Such systems would increase the quality of training of paralyzed extremities and as a consequence shorten the duration of treatment in rehabilitation center. Because of low price (specially when compared to robotic systems) they can be applied also to the patients at their homes immediately after leaving the rehabilitation program. In the paper we shall limit ourselves to FES of lower extremities. Surface FES is more appropriate for rather large leg muscle groups. More noticeable improvements were observed in swing than in stance phase of walking, therefore, our attention will be focused to kinematics of movements of lower extremities excited by surface FES.

## FES GAIT TRAINING WITH SENSORY CLOSED LOOP

The aim of the FES gait re-education system for incomplete special cord injuoy (SCI) subjects was to estimate the quality of the swing phase of walking (1,2). In order to accomplish the swing phase of walking, the peroneal stimulation has been considered. A multisensor system was developed employing single-axial gyroscope, and two pairs of single-axial accelerometers. The accelerometers were measuring the tangential and radial acceleration components of the swinging movement (4). The gyroscope was used to measure the angular velocity of the shank. Data assessed from accelerometers and gyroscope were used to determine the numerical value, which represented a comparison with the desired reference swing. The reference swing movement was captured from the less affected lower extremity of the incomplete SCI patient. The numerical value, representing swing quality, was provided to the patient as auditory feedback at three different levels. The levels were presented as three different frequencies. The low frequency indicated a poor swing, the middle frequency indicated a sufficient swing and the high frequency represented a well performed swing phase. The feedback was simple enough to be understood during walking and enabled the patient voluntarily to improve the swing of his/her affected leg. The swing quality value was in the same time used also to control the stimulation amplitude. The stimulation amplitude was first pre-set by the physiotherapist at the beginning of the session. During treadmill walking the stimulation of amplitude was adjusted based on the quality of the swing phase. A succession of pre-set number of good swings meant that the patient has managed to walk adequately; therefore the level of FES augmentation was decreased. Conversely, in the case of a number of successive poor swings, the level of FES motor augmentation was not sufficient and the stimulation amplitude was increased. The system developed was tested in a patient with incomplete spinal cord injury whilst walking on treadmill (Fig. 1). The incomplete SCI patient was concentrated on the audio feedback signal and was able to achieve symmetrical gait pattern. The walking subject was active participant in the gait re-education process what resulted in reducing of the level of FES augmentation initially preset by the therapist.

***Figure 1:*** *Gait training by use of FES and sensory closed loop.*

***Figure 2:*** *Use of virtual mirror during stepping-in-place training.*

## FES TRAINING IN VIRTUAL ENVIRONMENT

A virtual mirror was designed – a large screen which showed a simplified human figure in virtual environment (Fig. 2), displaying the patient's lower extremity movements in real time (7). An optical system with active markers was used to assess the movements of a training subject. Another figure – a virtual instructor, also included in the display, showed the reference movements to be tracked by the patient as accurately as possible. This approach included patient's visual feedback interactively in the training process. The system was first evaluated in a group of healthy persons. Afterwards, we investigated training abilities of an incomplete tetraplegic patient, undergoing a rehabilitation process, two years after an accident. He was instructed to track the virtual instructor's stepping-in-place movements as performed by a healthy person. In the second part of the investigation, functional electrical stimulation triggering flexion reflex in the less able of the lower extremities was included. The virtual mirror provided a tight temporal coordination between the patient and the experienced therapist who triggered the stimulation, delivering better results of the patient's reference tracking performance, compared to non-stimulated execution of the same task.

## CONCLUSIONS

We anticipate that surface FES will be predominantly used for therapeutic purposes. In therapeutic applications, the goal is to produce a functional benefit that lasts beyond the application of the stimulation itself. The question is arising, how FES can produce a "carryover" effect. FES, particularly when applied through surface electrodes, activates both motor and sensory nerve fibers. Repetitive movement therapy mediated by FES has the potential to facilitate motor relearning via spinal and/or cortical mechanisms. Regardless of spinal or cortical mechanisms, the experimental and theoretical considerations suggest that the necessary prerequisites for FES mediated relearning include repetition, novelty of activity, concurrent volitional effort, and high functional content (8). Biofeedback mediated FES training, requiring greater cognitive investment, may result in greater therapeutic benefits. Here, it is of interest to mention also the training modality combining FES and sports. Such examples are FES cycling (5) and FES rowing (3). FES sport activities improve the cardiopulmonary abilities of a training subjects to a larger extent than FES assisted walking, are safer, and represent fun and relaxation.

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