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STANDING-UP OF A HEALTHY SUBJECT AND A PARAPLEGIC PATIENT*

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Abstract – The joint torques in hip, knee and ankle were measured during the standing-up of a healthy subject. Force plate and stroboscopic photography were used in the experiment. It has been observed that the time courses of particular joint torques depend on the kind of standing-up. On the basis of these results a standing-up procedure for paraplegic patients was proposed. With the use of electrical stimulation to both paralyzed knee extensors and through use of the arm support, a completely paraplegic patient was able to rise independently from the wheel-chair. The same dual-channel stimulation also provides knee locking during standing of spinal cord injured patients.

INTRODUCTION

Human locomotion consists mainly of walking under different circumstances and of motions occurring before and after gait, such as standing-up, gait initiation and sitting-down. Though many researchers and kinesiologic laboratories devote their studies to the problems of gait analysis, few are interested in other phenomena of bipedal locomotion. It is not difficult to realize that a potential ambulator is not completely rehabilitated if he cannot stand-up without the help of another person.

Functional electrical stimulation (FES) of paralyzed skeletal muscles has proven to be an efficient means of correction of locomotive disabilities in stroke patients (McNeal and Reswick, 1976). At present FES is also being introduced into the rehabilitation program of spinal cord injured patients with upper motor neuron lesions. It is used to strengthen disused atrophied muscles of complete and incomplete paraplegics and quadriplegics; it prevents further muscle atrophy; it provides better blood flow within the stimulated extremity; and it can prevent contractures (Kralj *et al.*, 1980b). A two-channel electrical stimulator has been built which is intended to enable standing in complete paraplegic patients (Bajd *et al.*, 1981). More than one hour of secure standing can be achieved by locking knee joints through the electrical stimulation of both knee extensors. Standing of the paraplegic patient has been started to prevent pressure sores and to improve the functioning of internal organs. FES was also found to be important from a psychological point of view since it makes paralyzed muscles of the lower extremities useful again.

If standing is to be a useful functional activity (e.g. to reach an object placed high) a person must be able to rise from sitting to the standing position independently. It has already been shown (Kralj and Grobelnik, 1973) that standing-up of a complete paraplegic patient can be achieved by stimulation of the hip and knee extensors and ankle plantar flexors of both lower limbs. However, present six-channel stimulators are not convenient for every-day patient use. The aim of the present study is therefore to develop a standing-up procedure in which only the knee extensor muscle groups will need to be stimulated. In this way the same two-channel stimulator can be applied for both prolonged standing and standing-up. The patient will assist the FES by lifting himself with his arms.

MEASUREMENT OF STANDING-UP IN HEALTHY SUBJECT

The aim of the measurement of standing-up of a healthy subject was to determine the torques in the hip, knee and ankle joints. If these torques can be compensated for by electrically stimulating paralyzed muscles, successful rising from sitting to standing can be achieved in paraplegic patients. The information needed for calculation of joint moments in the sagittal plane was provided by stroboscopic photography and force plate measurements. Figure 1a shows the motion of hip, knee and ankle during standing-up. White strips of flexible material were attached along the leg. Centers of joint rotations were marked with round markers. The motion of arms was recorded as well. The two arrows in Fig. 1a represent the edge of the force plate and the bench from which the subject stood up. Frequency of stroboscopic flashing was 10 Hz. From the stroboscopic photograph the levers of

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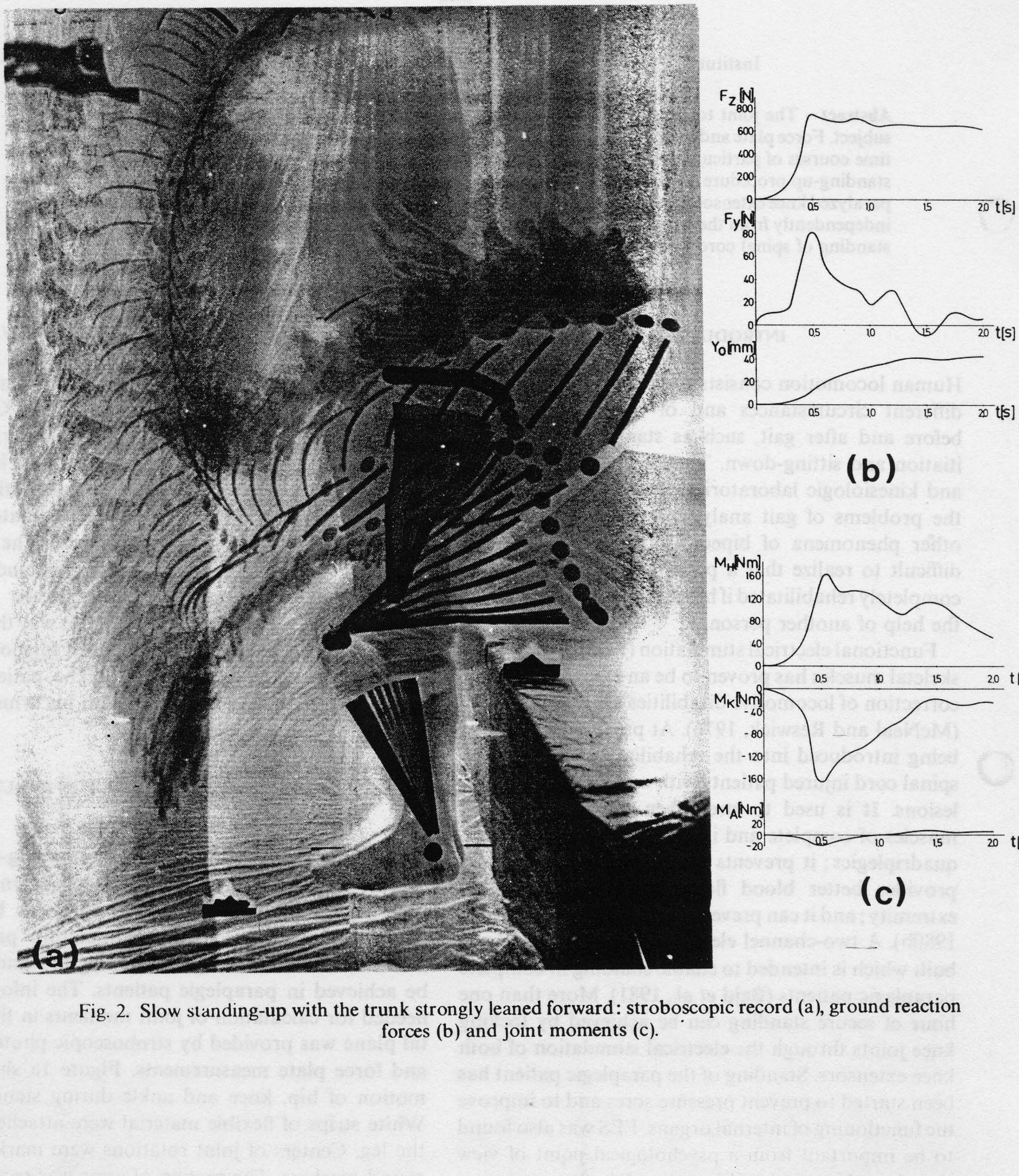

Fig. 2. Slow standing-up with the trunk strongly leaned forward: stroboscopic record (a), ground reaction forces (b) and joint moments (c).

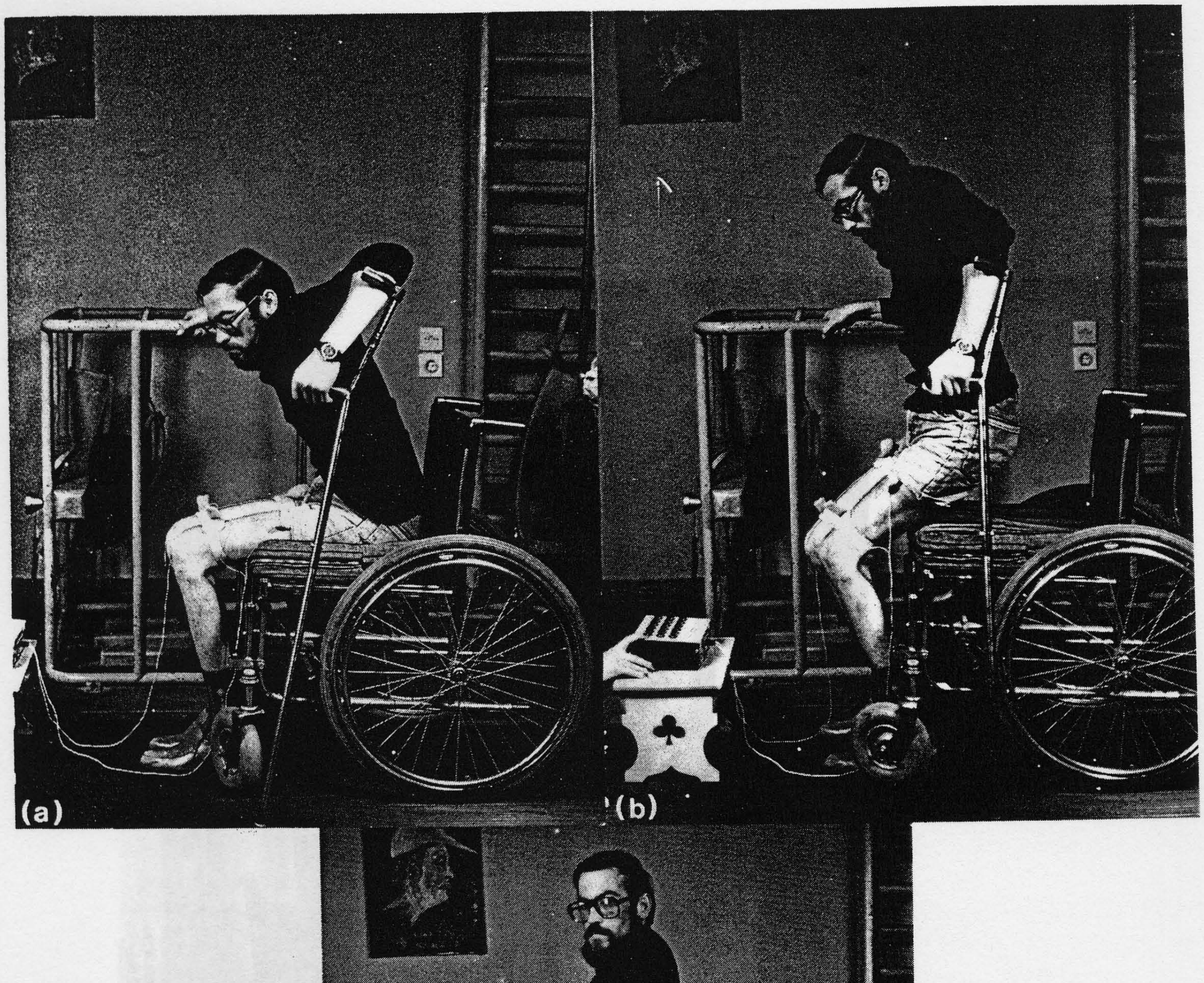

Fig. 4. T-5 complete paraplegic patient rising from the wheel-chair with the help of electrical stimulation of knee extensors.

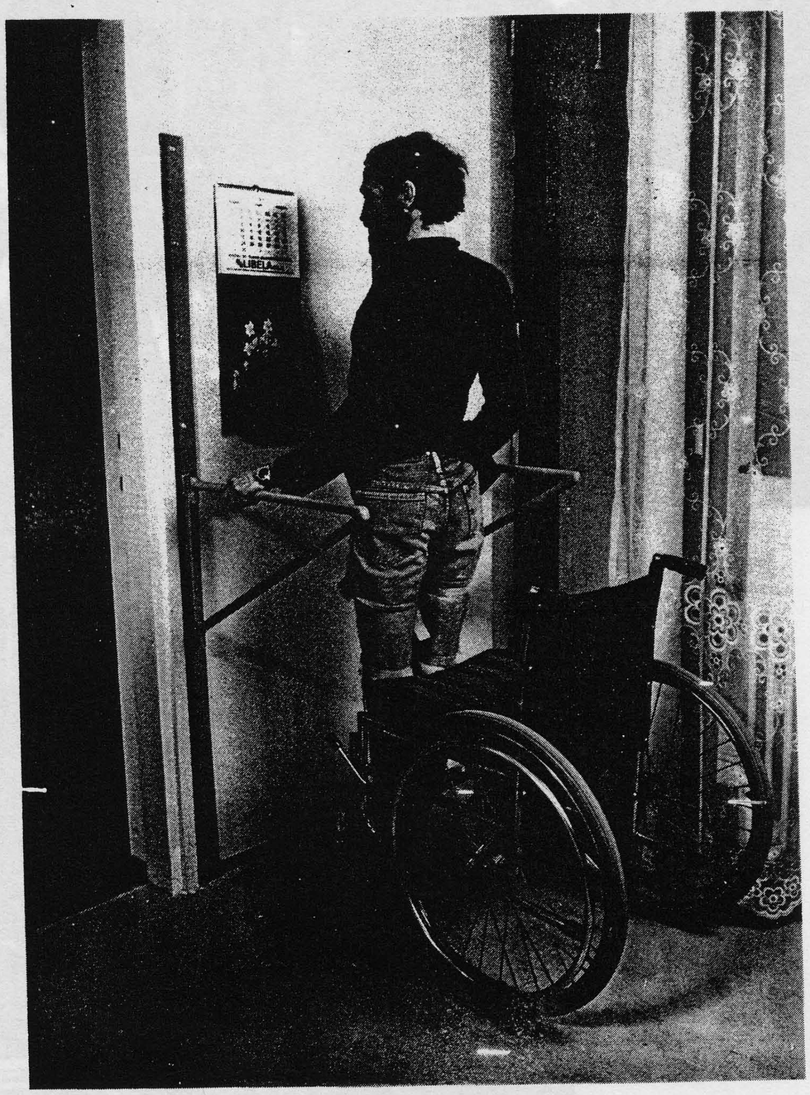

Fig. 5. Paraplegic patient standing with the help of electrical stimulator at his home.

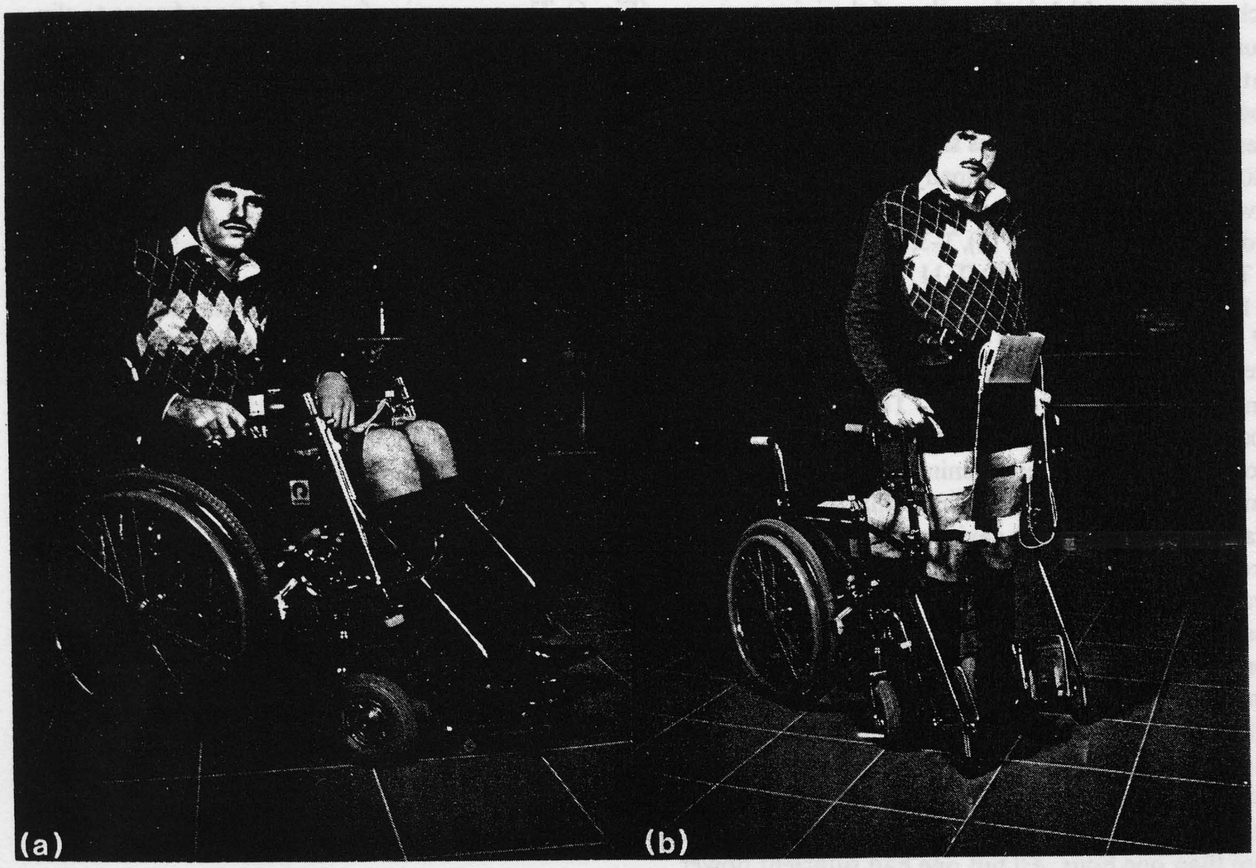

Fig. 6. Wheel-chair attached supporting frame while collapsed (a), and complete paraplegic patient while standing with its help and the help of the two-channel electrical stimulator (b).

amplitude of stimulation voltage. They were obtained in isometric measurements with a special measuring brace transforming joint moment into voltage with the help of strain-gauges. Stimulated muscle characteristics presented in Fig. 3a belong to a T-5 complete paraplegic patient. The lower curve was measured at the patient's arrival in the rehabilitation center several months after the injury. His disused atrophied muscles were then strengthened using cyclical electrical stimulation (4 sec of stimulation and 8 sec of pause). The frequency of rectangular unipolar stimulation pulses was 20 Hz, while a pulse duration of 0.3 msec was chosen. FES sessions lasted from half an hour at the beginning of the program to three hours at the end of the treatment. The upper curve in Fig. 3a was measured after one and a half months of FES exercising. At high stimulation amplitudes the patient almost reaches 40 Nm, which is the value of the joint torque required for rising from sitting. Figure 3b shows knee joint moments measured in 19 paraplegic patients with upper motor neuron lesions. They had different levels of lesions and different times since injury (Kralj *et al.*, 1980a). The numbers accompanying the knee torque curves belong to the patients with the following spinal cord lesions: T-10 (1), T-9 (2), T-3, 7 (3), T-5, 6 (4), T-12 (5), T-8 (6), T-4, 5 (7), T-8 (8), T-11, 12 (9), T-5, 7 (10), T-8 (11), T-12 (12), T-12 (13), T-4 (14), T-12 (15), T-4 (16), C-7 (17), T-5 (18) and T-6 (19). Half of them can develop almost 20 Nm of joint torque under the stimulation of knee extensors. This was also the maximal moment obtained with the patient P.K. (T-5), who completed the strengthening program of cyclical stimulation (Fig. 3a). This means that they are candidates for FES orthotic devices, as their muscles can be restrengthened to the required value. Nine complete paraplegic patients have up to now completed the FES muscle training process which lasts from two to three months. The two-channel FES unit was given for home use to all of them, although four paraplegic patients were able to stand for a few minutes only. The fatigue of electrically stimulated muscles was in these patients noticeable in spite of low stimulation frequency. The other five patients were able to stand for more than one hour. All but one had sufficient power and skill to stand up with the help of FES and arm support only. FES might be therefore considered as a strong adjunct to mechanical biasing.

For rising from the wheel-chair (Fig. 4) the complete T-5 paraplegic patient needed a solid support for one arm. Such solid support can be provided by a piece of furniture at his home. With the other hand he was holding a crutch. A six-channel experimental stimulator was used for standing-up. Only two channels were used, stimulating both knee extensors through water-soaked surface electrodes. The stimulator was switched on by a physiotherapist. In the two-channel stimulator (Bajd *et al.*, 1981) intended for the patient's home use a delay was provided between switch on and beginning of stimulation. In this way the patient can first turn on the stimulator and then grasp the support. As it was expected from the measurements of standing-up of the healthy subject, and from the measurements of joint torques produced by electrical stimulation of paralyzed muscles, the patient (much thinner than the measured healthy subject) was able to rise with the help of knee extensors stimulation only (Fig. 4). A special supporting frame was built for the patient's daily standing exercise at home (Fig. 5). The two-channel stimulator is attached to the patient's belt. During 30–60 min of standing the patient can look through the window (on his right), talk with visitors or read a book on a special holder which can be attached to the wall. A delay between turning off the stimulator and the end of stimulation permits secure sitting-down.

Standing at any location is provided by a special wheel-chair attached collapsible supporting frame (Fig. 6). The supporting frame is designed so as to slip into the holders for the arm supports. The height of the supporting frame can be adjusted according to the patient's needs. When it is collapsed it does not disturb the normal use of the wheel-chair. The wheel-chair together with the supporting frame can easily be stored in a car.

CONCLUSION

Functional electrical stimulation has the potential to become an effective orthotic tool in the rehabilitation process of complete and incomplete spinal cord injured patients. Compared to the long leg mechanical braces (calipers) ordinarily used, it has several important advantages. Stimulating electrodes can be mounted on an extremity much more easily and faster than mechanical orthoses. The stimulator is about the same price or even less expensive than calipers as its production does not depend on the size of the patient's extremity. Probably the most important fact is that FES uses the patient's own muscles which are with other rehabilitation methods completely useless. It can therefore be expected that the FES approach will improve the locomotion abilities of spinal cord injured patients in the near future. Standing-up will represent an integral part of this rehabilitation method.

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NOMENCLATURE

F_y horizontal ground reaction force component (N)

F_z vertical ground reaction force component (N)

M_A ankle joint moment (Nm)

M_H hip joint moment (Nm)

M_K knee joint moment (Nm)

y_o time course of the point of resultant force applicatio (mm).