

Multichannel functional electrical stimulation— facts and expectations¹

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Functional Electrical Stimulation (FES) was started with the simple and ingenious idea of Liberson *et al.* (1961) of lifting the drop-foot of a hemiplegic patient with a portable electronic stimulator. For the past ten years rather intensive research has been conducted in this area to test further possible applications of functional electrical stimulation. It was obvious that technological and cosmetic improvements of the single-channel peroneal brace could not be the ultimate goal of functional stimulation. Therefore we tried to visualize some possible long-range goals of FES from the beginning of our research.

Thus, we have always felt that the potential of FES lay in complex multichannel-systems which could provide much more than simple dorsiflexion of the foot. In this paper we attempt to show some results of these investigations.

Expectations of Multichannel FES

When our group started systematic work in this area about ten years ago, we had well-

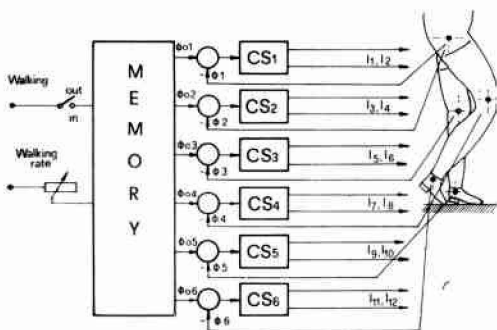


Fig. 1. Multichannel stimulation of paretic legs as visualized in 1965.

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defined, long-range goals in the field. In spite of the fact that our initial expectations were rather high and sometimes naive, it is interesting to note that our goals were realistic. Thus, for example, in 1965, the senior author visualized multichannel stimulation of lower limbs with closed-loop control of each joint (Fig. 1) at a conference in Brighton (Vodovnik, 1966). At about the same time, we published (Vodovnik and McLeod, 1965) our "science fiction" expectations regarding multichannel stimulation of the upper limbs (Fig. 2). In this instance we

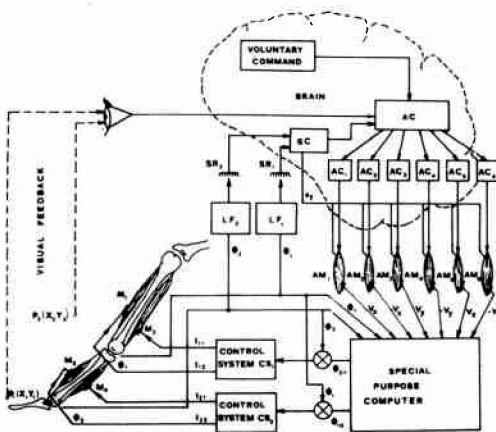


Fig. 2. Multichannel stimulation of paretic arms as visualized in 1965.

expected that the patient would control only the end-point velocity vector of the arm, and the special-purpose computer would find the optimal reference angles for all joints and produce adequate stimulation sequences for the muscles involved. For improved control we suggested local feed-back loops through the

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skin to improve the precision of the control signals.

It is a sobering thought that neither of these two proposals have been realized completely after ten years. The reasons lie both in engineering and in medicine. Our technology is still not advanced enough to enable well co-ordinated control with miniaturized implanted stimulators using radio-frequency operation. There do not exist as yet adequate position, force, or pressure transducers which can be attached easily and cosmetically to the body to send information to the electronic processors. The influence of electrical stimulation on the remaining reflex mechanisms in patients is still not well understood. These problems, however, should not completely cloud with pessimism, the picture of multichannel stimulation. In the next paragraphs we shall show some rather advanced and exciting, though not ideal, results in this field.

Present Status in Multichannel Stimulation

In 1971 Kralj and his associates developed the first three-channel stimulator which was intended for the control of the swing phase in hemiplegic patients (Fig. 3). A stimulation sequence of three muscle groups on the leg could be pre-set and triggered by a signal from a heel switch. With the use of this stimulator the gait of patients was markedly improved and to date about 50 hemiplegics in Ljubljana have been using it quite successfully. The system, however, is still too large and complicated for the patient to use at home. Therefore, walking with this stimulator was performed only at the Rehabilitation Institute under the supervision of the physiotherapist. Several modifications of this stimulator have been designed or suggested by Kralj *et al.* (1971), Kralj (1975), Kralj and Vodovnik (1977), Jeglič (1973), Stanič *et al.* (1974) and Acimović *et al.* (1976).

Another outgrowth of three-channel stimulation for the lower limbs is a project to make a paraplegic stand or perhaps ultimately walk by FES. Kralj and Grobelnik (1973) introduced a multichannel stimulation programme to train the atrophied muscles of paraplegic patients. After several weeks the muscle power improved to such an extent that the first attempt to make a paraplegic stand up by electrical stimulation was successful (Fig. 4). We are still far away from making a paraplegic walk, in spite of some preliminary attempts at Rancho Los Amigos



Fig. 3. Three-channel stimulation of a hemiplegic patient during the swing phase.

Hospital and at the University of Virginia but there exists reasonable hope that within the next few years paraplegic patients also might have some chances for locomotion. These chances are even increased if some success is achieved in the development of hybrid actuators combining electrical stimulation and external power.

Regarding the hand or arm, the facts are even farther away from the expectations shown in Figure 2. Until now we have not succeeded in much more than obtaining relatively crude two-

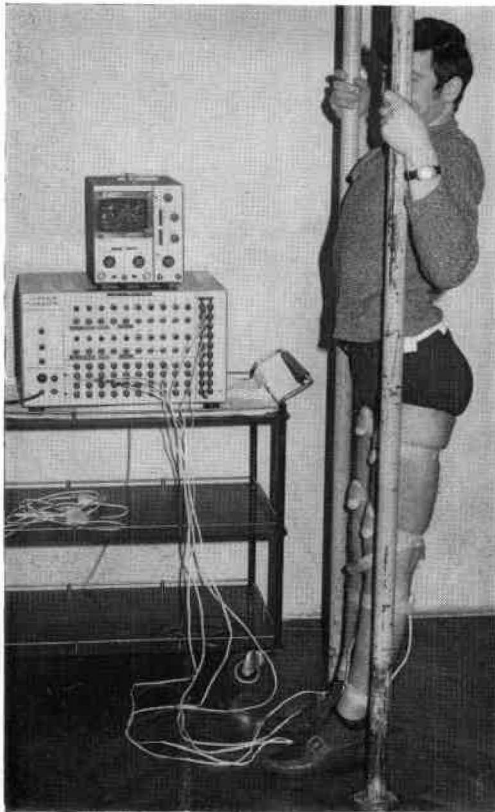


Fig. 4. Multichannel stimulation of a paraplegic patient in order to make him stand up.

channel stimulation of the hand. Merletti *et al.* developed a two-channel stimulator for the arm of hemiplegic patients. The most important muscle groups to be stimulated were the finger extensors and the *m. triceps* (sometimes combined with *m. deltoideus*). With two independent position transducers controlled by both shoulders the patient could perform manual tasks (such as picking up and transferring a bottle) which otherwise would be impossible (Fig. 5). The major problems with stimulation of the upper limb are the control sites. Except for minor "subroutines", not much can be programmed for movements of the upper limb. Therefore each paralysed muscle group has to be under voluntary control through one control site and for more than two channels the learning problems for the patient become almost insurmountable. One of the major efforts in future research for upper limb multichannel stimulation will be directed towards the development of training procedures, including biofeedback,



Fig. 5. Two-channel stimulation of a hemiplegic patient to improve hand function.

and finding adequate control sites to ensure the patient independent control of several muscle groups.

Conclusion

Clinically applied multichannel stimulation was visualized in the very beginnings of FES. A short survey of existing multichannel systems was taken and compared to initial expectations. While much still remains to be done to get multichannel stimulation out of the research environment and into the clinical routine, the results obtained so far are encouraging enough to continue work in this area with increased effort.

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