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Biomechanics of functional electrical stimulation

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Abstract

Patients with hemiplegia frequently have difficulty in walking due to lack of eversion and dorsiflexion capability of the foot. One method of treating these patients utilizes functional electrical stimulation (FES). The effect of FES on locomotion, co-ordination, proprioception and balance sense was assessed using instrumented gait analysis and a postural sway test. In general patients treated with FES showed either a marked improvement or very little change. Any improvement was reflected in postural sway and ankle control during locomotion. Changes in hip and knee control were insignificant.

Introduction

This paper describes the influence of functional electrical stimulation (FES) on locomotion and co-ordination/proprioception assessed by tests carried out on hemiplegic patients using the underknee peroneal stimulator (Malezic et al. 1978). Tests included gait analysis and measurement of the displacement of the centre of pressure while standing still on both feet. During the locomotion test kinetic and kinematic data were collected using a Kistler force platform and television cameras interfaced to a digital computer. Forces and moments transmitted at the ankle, knee and hip levels were calculated and used for comparative assessment together with hip/knee angle variation and postural sway test results.

Method and apparatus

The underknee peroneal stimulator (FESE–L2) which was developed in Yugoslavia,* assists the swing phase of the gait by correcting the spastic equinovarus of a hemiplegic patient.

Fig. 1. The underknee peroneal stimulator (FESE–L2).

The FESE–L2 consists of a small compact stimulator unit attached to an elastic knee support and is powered by a 1·5 volt battery; the external electrodes are fixed in the elastic knee support and are placed over the tibialis communis and peroneal nerve points, in the popliteal fossa and behind the fibular head respectively. The stimulator is controlled by a heelswitch placed in the shoe which is switched on automatically on lifting the heel from the ground and stays on until "heelstrike" occurs or for a duration of 3 seconds whichever is less. The stimulator has a fixed delay time and provision for a variable delay time to simulate a more physiological walking pattern. The first delay, adjustable up to 350 ms, occurs at the start of the stimulus trigger allowing the plantarflexors to continue to be active until the instant of "toe off". If spasticity in the inverters and plantarflexors persists strongly and inhibits forward pivoting in the ankle joint, in late stance, this delay of stimulus trigger can be omitted and thus the eversion and dorsiflexion action can inhibit the spasticity in the

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antagonistic muscles. The second delay is non-adjustable at 100 ms and occurs at the end of the stimulus trigger allowing the dorsiflexors to be active from "heelstrike" until "foot flat". The introduction of these two delays and the location of the device close to the point of application is a great improvement over the earlier developed devices.

Two main tests were used to assess the patients: instrumented gait analysis and postural sway measurements.

Gait analysis

Kinetic and kinematic data were collected during both the swing and stance phases.

The patient was fitted with retro-reflective markers on the shank and spinae anterior iliacus and at the top part of the sacrum. These markers were illuminated by a light source fitted underneath the television cameras, whereby displacement data in the frontal and lateral planes were acquired using an interface and transmitted to the PDP 11 computer; corresponding measurements were taken from the Kistler force platform including the three ground reaction forces and their moments about the reference axes of the platform (X being antero-posterior, Y being vertical and Z being medio-lateral). After parallax correction of the displacement data the joint axes, ankle, knee and hip on the affected side were identified and moments about these axes were calculated considering external loading; gravity and inertia loading effects were included in the calculations for the knee and hip. For this particular test the main features during stance were knee angles and ankle moments while during the swing phase special attention was paid to hip and knee angles.

Postural sway measurements

Standing upright is a dynamic process and is maintained by input from visual, proprioceptive and vestibular systems. Measurements of sway were first attempted in the last century. In 1853 Romberg directed attention to the diagnostic significance of increased postural sway while standing still or while performing different tasks, in subjects with posterior column disorders. In 1886 Mitchell and Lewis estimated sway by observing the movements of the subject's head against a scale placed behind him.

Since then various methods have been developed to assess postural sway in "normal subjects" and in patients with neurological disorders.

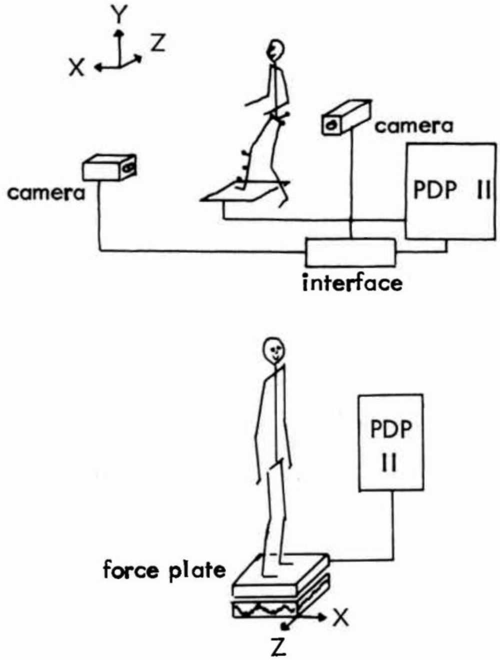

Fig. 2. Setup for instrumented gait analysis (top) and postural sway measurements (bottom).

Although measurement of the displacement of the centre of pressure between ground and feet is not a direct measure of the magnitude of body movement it is closely related to balance sense, co-ordination/proprioception and the ability of the body to correct. The patient or "normal" subject was placed with both feet on a single Kistler force platform without any external support.

Measurements were made of the vertical force, shear forces and their moments, while the subject stood still with eyes open and then closed. Duration of the measurement was 40 seconds and the data was sampled at a frequency of 20 Hz. From these, the displacement of the centre of pressure between ground and feet was derived in the antero-posterior (XO) and medio-lateral (ZO) direction. From the displacement of XO and ZO the length of the trajectory traced by the centre of pressure in the given time was calculated.

Data analysis

Hip and knee angles were calculated from the TV data in the gait analysis and are presented as

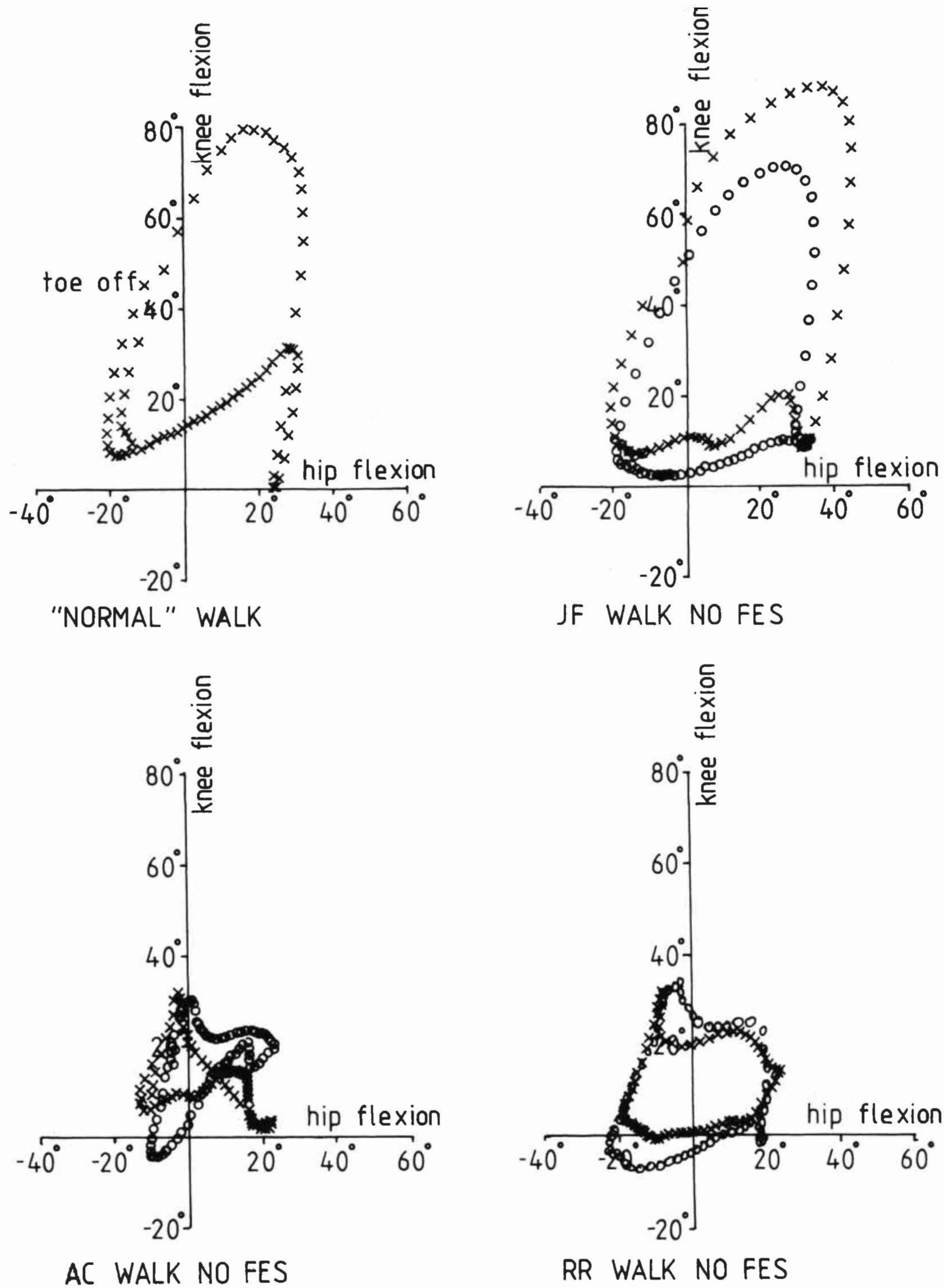

Fig. 3. Hip and knee angles—see text.

characteristic angle/angle diagrams of the hip and knee (Grieve, 1968), in Figure 3. Although the changes in hip and knee angles are small for the individual patient, when the curves for several patients are compared a marked difference in the shape of the diagrams is apparent.

A patient with a dropfoot and only slight spasticity shows a diagram approaching the "normal" (Fig. 3, top left and right); a patient with a dense hemiplegia with little hip and knee control shows a sharp triangular shape (Fig. 3, bottom left) and a patient with marked spasticity and reduced knee action during swing shows a rectangular shaped diagram (Fig. 3, bottom right).

The characterization of this type of patient is variability in performance from step to step and also from one occasion to another.

As mentioned earlier, the length of the trajectory traced by the displacement of the centre of pressure was calculated. In Figure 4 the length of this trajectory is represented for all of the patients reviewed and for each occasion of review the points corresponding to each patient are connected by a full line and these are presented to a base of time according to the scale indicated.

The three subjects (C1; C2 and C3) are patients who did not receive FES treatment, but conventional physiotherapy, they show some small changes. The subjects F1 to F11 are patients who during the course of this investigation received FES treatment. All patients were "stabilized" having received the normal course of physiotherapy treatment before the commencement of the trial. During the test period the controls and the patients treated with FES received normal physiotherapy. Figure 4 shows that the patients treated with FES showed a great variety of changes.

These changes correspond greatly with subjective clinical observations. For example subject F11 had an ischaemic transient attack during the period of treatment; his second assessment just after this attack showed large deterioration; the third assessment shows that

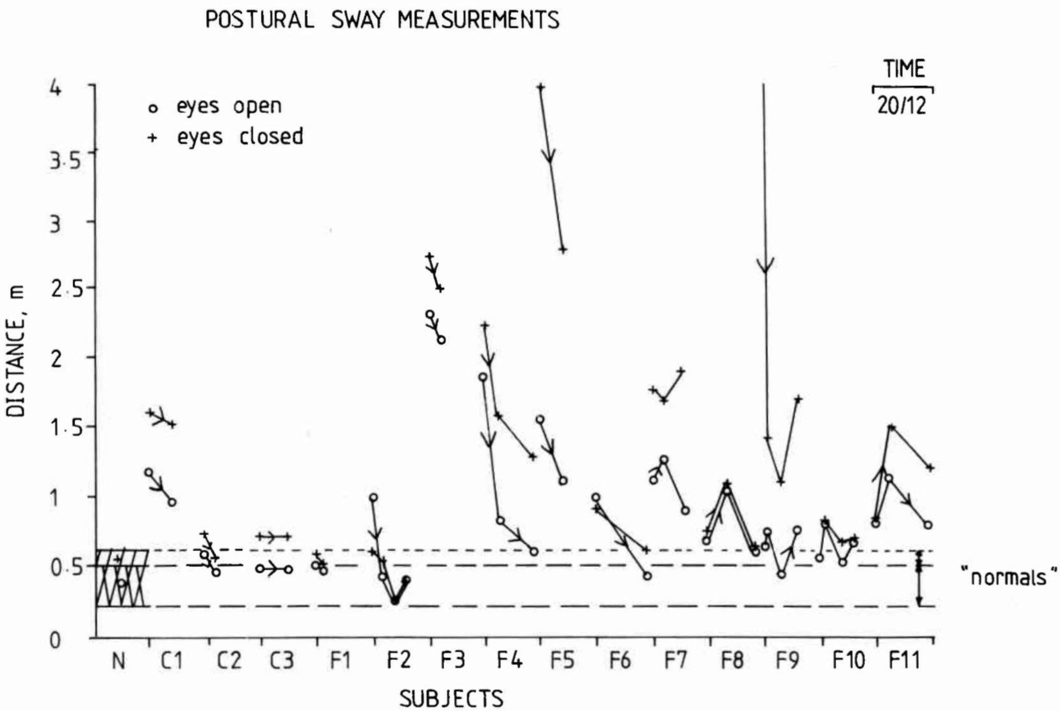

Fig. 4. Postural sway measurements for all patients reviewed.

with the eyes open he had recovered to the same level as before, but with his eyes closed he had improved but not to the level of his first test. Clinically this patient showed after this intermediate attack some difficulties in concentration but his walking ability had hardly changed.

These transient strokes are not always remarked upon but do hold the patient's progress back. This is also one of the drawbacks when stroke patients are compared with each other, either as a control group or for assessment of one patient over any length of time.

Conclusions

In general, patients treated with FES show either marked improvement or barely assessable improvement. Since patients in this trial were all "old", well established hemiplegic patients, who were considered to have reached the optimum point in their rehabilitation programme, the improvement may be considered to be due to the influence of FES, and it may be concluded that for some patients FES offers the chance of considerable improvement. It is not clear, however, how such patients may be identified.

The underknee peroneal brace is an improvement over the earlier developed devices; nevertheless it still needs further improvement in durability. A hemiplegic patient is inevitably a clumsy patient and cannot always be as careful as he would like to be. Nevertheless, patients were very quick to learn how to apply and use this device. Generally patients' aptitude in fitting the brace was satisfactory, as judged by an assessment by the researcher the first day after primary fitting.

During this trial it was remarked upon that the postural sway measurements may reflect the progress of the patient more accurately than the instrumented gait analysis which may exhibit the great variability in performance from step to step.

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