QUANTITATIVE ASSESSMENT OF THE INFLUENCE OF FES USING THE UNDERKNEE PERONEAL STIMULATOR

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Introduction

Although Functional Electrical Stimulation(FES) has been used for many years, there is little quantitative information about patient performance.

Earlier clinical trials indicate a variable amount of improvement in the patient's gait, motor function/co-ordination and muscle power, but most of these parameters were assessed, in a subjective manner, by standard clinical tests (Graccnin, 1972; Merletti et al, 1978; van Griethuysen et al, 1978).

This paper approaches in an objective way the influence of FES on locomotion and co-ordination/proprioception. For this purpose hemiplegic patients were selected according to a protocol based on earlier experiences(Murdoch et al, 1978) and were randomly assigned to be treated by FES or by conventional physiotherapy only, the latter forming a control group.

The same tests were carried out on both groups of patients and on some "normal subjects" and include gait analysis, stepping up a negotiable height and measuring of the displacement of the centre of pressure while standing still on both feet. During the tests kinetic and kinematic data were collected using the "Strathclyde" 3-dimensional gait analysis system comprising Kistler force platform and multiple camera television filming linked directly to a digital computer.

All the tests were carried out in the biomechanics laboratory of the Bioengineering Unit of Strathclyde University.

Patients in the FES group used the Underknee Peroneal Stimulator and once fitted were treated at their homes only.

Method and Apparatus

The Underknee Peroneal Stimulator (FESE - L2) was developed in Yugoslavia by the J.Stefan Institute and Faculty for Electrical Engineering, University of Ljubljana (Malezic et al, 1978) and is produced by Gorenje, Yugoslavia.

The FESE - L2 consists of a small stimulator unit attached to an elastic knee support and is powered by a 1.5 volt battery; the external electrodes are fixed in the same 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 activated by a heelswitch placed in the shoe and is switched on automatically by lifting the heel from the ground the signal continues until heel strike occurs or fo a duration of 3 s, whichever is less.

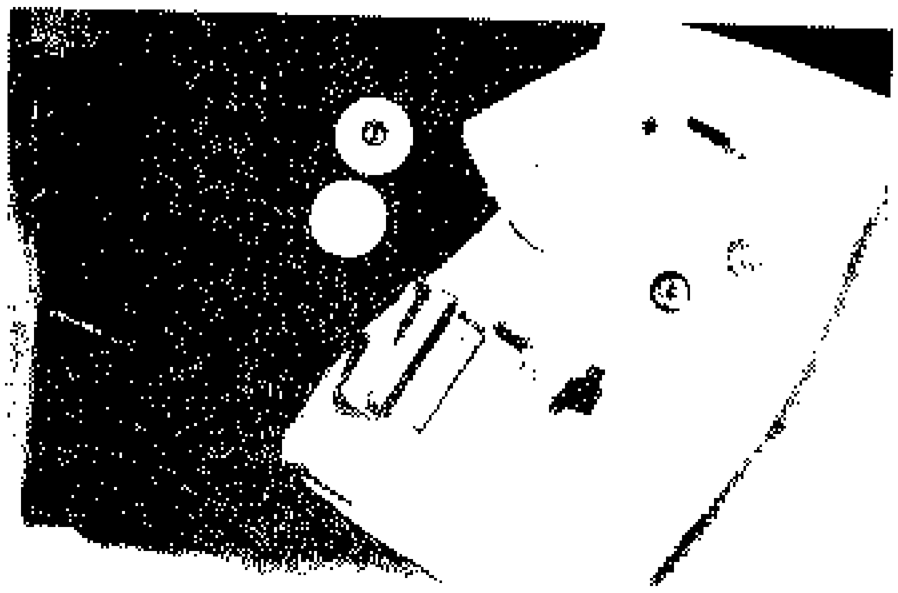


Fig. 1a
Underknee Peroneal Stimulator

Fig. 1b

This particular Peroneal Stimulator shows several advantages over earlier developed devices. It is compact and fitted close to its point of application avoiding tension on the connecting leads to the electrodes. The stimulation has both a variable and a fixed delay time to simulate a more physiological walking pattern.

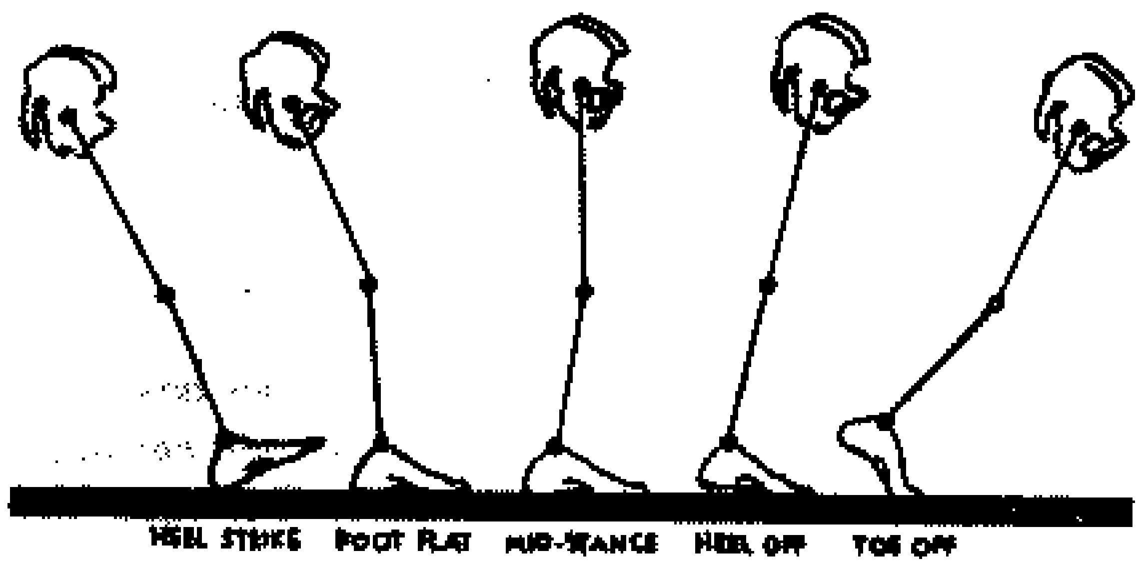


fig.2 stance phase of a "normal gait cycle".

The first delay, adjustable up to 350ms,occurs at the start of the stimulus trigger at the instant of 'heel off', allowing for "passive push-off function". But if spasticity in the inverters and plantar flexors persists strongly during late stance and inhibits forward pivoting in the ankle joint, this delay of the stimulus trigger can be omitted and thus the everting and dorsiflexing action can inhibit the spasticity in the antagonistic muscles.

The second delay is non-adjustable at 100 ms and occurs at the end of the stimulus trigger at the moment of 'heelstrike' allowing the dorsiflexors to be active until 'foot flat' and this helps to reduce the 'foot slap'.

Gait analysis

Although the Underknee Peroneal Stimulator is working only during the swing phase and switches off in early stance, it still influences the position of the foot during the stance phase. Kinematic and kinetic data were therefore collected during both the swing and stance phases. During the swing phase special attention is paid to the hip and knee action; while during stance, knee angles and ankle moments are the main features.

The patient is fitted with retro-reflective markers on the shank and spinae anterior iliacus and at the top part of the sacrum. These markers are illuminated by a light source fitted just underneath each tv-camera, whereby data in the frontal and lateral plane is acquired by the interface and transmitted to the PDP 12 computer; corresponding measurements are 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).

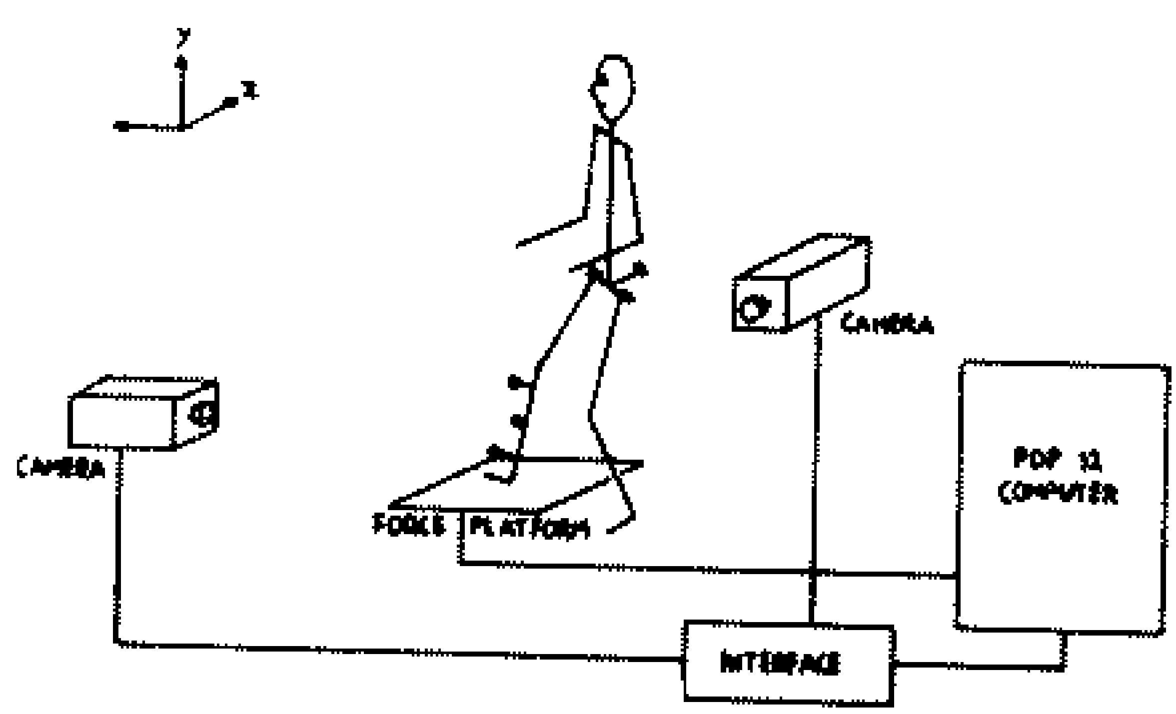


fig. 3 3- dimensional gait analysis system comprising Kistler force platform and multiple television filming linked via the interface to the digital computer.

After parallax correction the joint axes, ankle, knee and hip are indentified and moments about these axes are calculated considering only external loading on the affected foot.

These same principles are used for the stepping up test.

An adjustable step comprising a number of 30 x 30 x 1 cm chipboard squares is built up to a negotiable height for the patient and is placed on top of one force platform, another step of the same height is placed beside the force platform for the sound leg. The patient steps up, either leading first with the sound leg followed by the affected leg, or the other way round, corresponding to the capability of the patient. During this step function special attention is paid to hip and knee angles and the amount of weight the patient transfers to the affected leg.

The same established height for each individual patient is maintained throughout all the tests.

Again retro-reflective markers are used in the same position as during the gait analysis and the side and front tracing co-ordinates are transferred through the interface to the PDP 12 computer together with the corresponding force platform data.

The patients in the FES group were asked not to wear the Peroneal Stimulator just before testing and only to fit the brace for the second part when the same tests were performed again while wearing the stimulator.

Postural sway measurement

Standing upright is a complex neuromuscular activity, dependent upon the integrity of the myotatic reflex (Sherrington, 1924) and much affected by the influence upon the final path of impulses descending over the extra-pyramidal tracts (Magnus, 1926).

In 1893 Romberg directed attention to the diagnostic significance of increased postural sway in subjects with posterior column disease by closing the eyes and narrowing of the base support.

Since then various methods have been developed to assess postural sway in "normal subjects" and in patients with neurological disorders, while standing still or while performing different tasks.

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 force platform without any external support.

Measurements were made of the vertical force, shear forces and their moments while standing still with eyes open and then closed. Duration of the measurement was 40 seconds and the data was sampled at a frequency of 20 Hertz.

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.

Data Analysis

From the gait analysis the most characteristic diagram is the angle/angle diagram of the hip and knee (Grieve, 1968).

Hip and knee angles are calculated from the TV data and not as in most studies from goniometer measurements (Öberg, et all, 1978)

If therefore the "normal" diagrams from Öberg (fig. 4a) and from this series (fig. 4b) are compared a rather sharp peak at heel contact in the left top corner of fig. 4b may be noticed, probably corresponding to the difference between hip flexion angle and the inclination of thigh to the vertical.

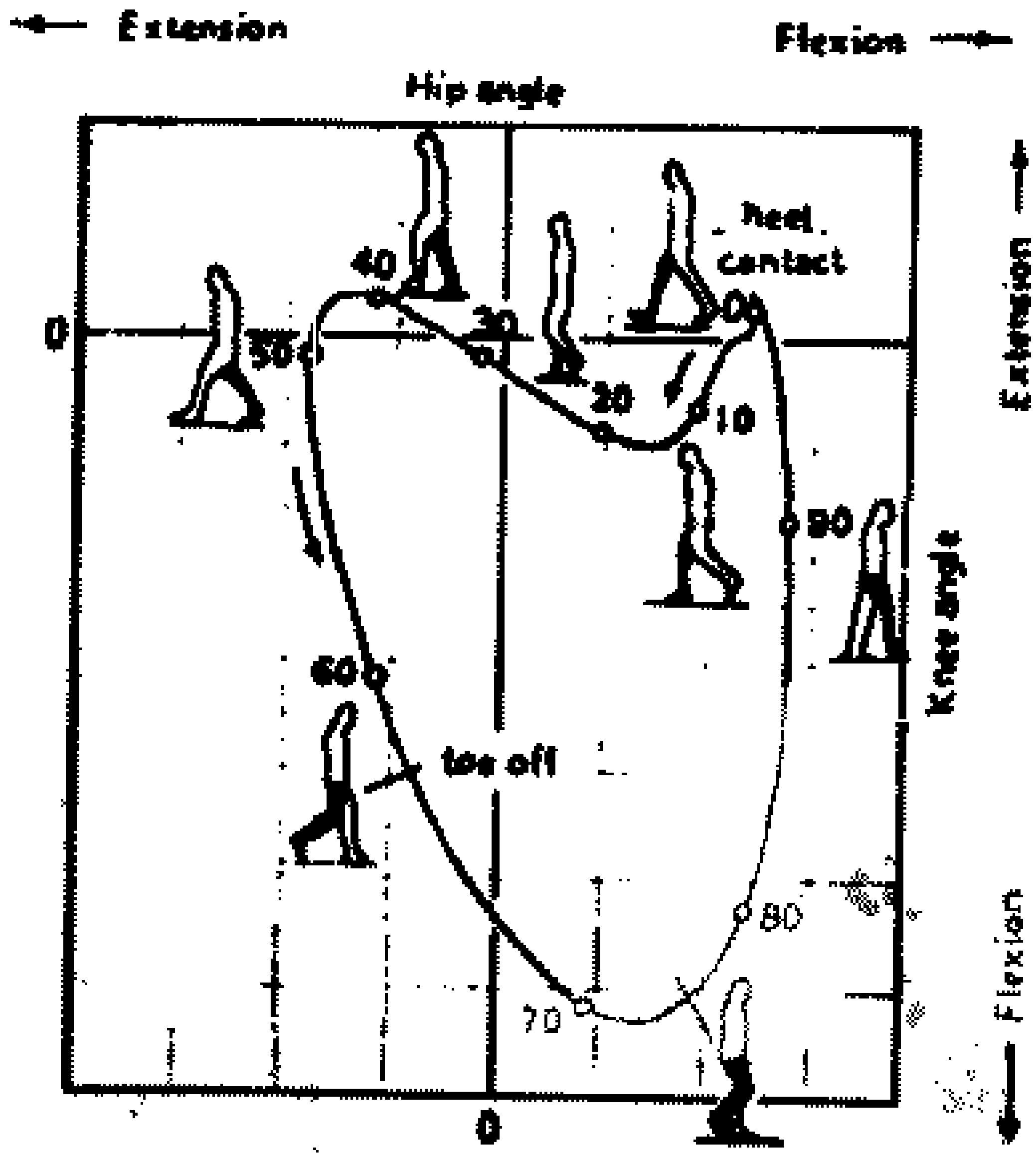


fig. 4a
" normal " diagram from Oberg
hip/knee angles derived from
goniometer measurements.

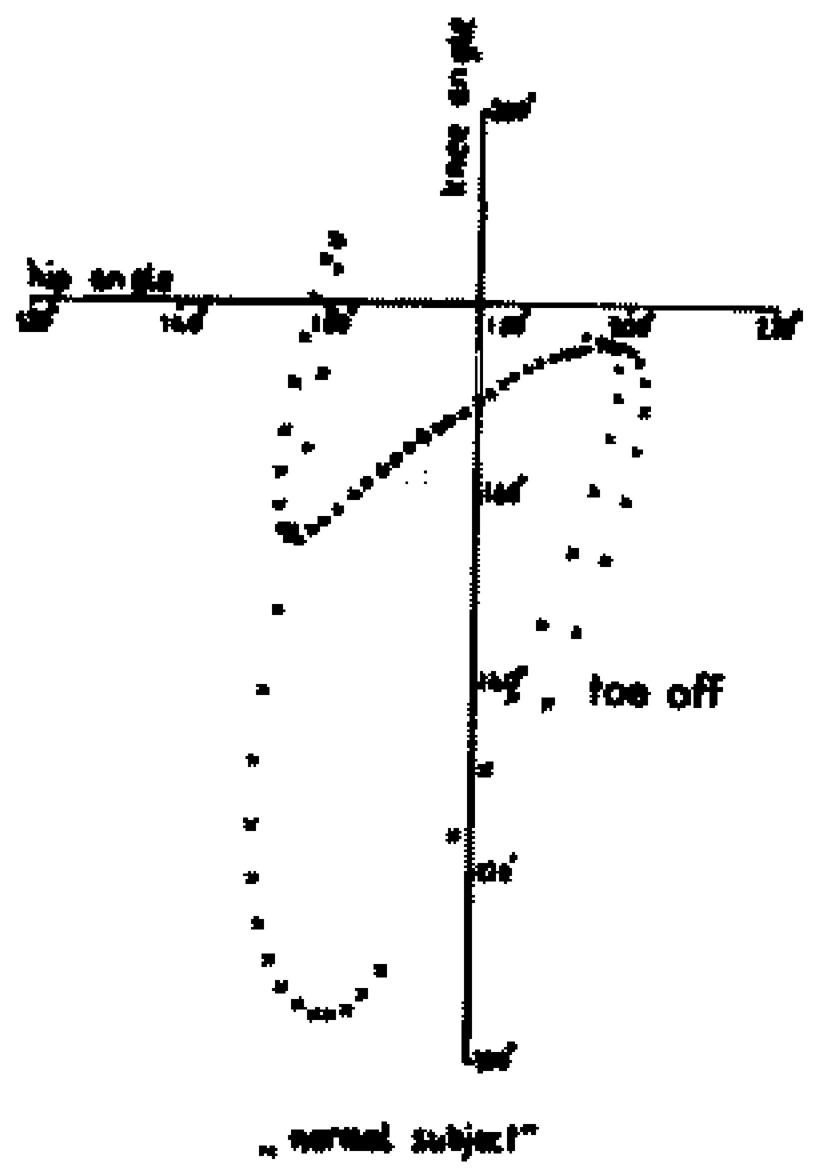


fig. 4b
"normal" diagram from this serie
hip/knee angles derived from
TV data measurements.

Patients who have a walking problem related only to ankle joint function show diagrams approximately similar to the "normal subject (fig 5)
On the contrary a patient with a rather dense hemiparesis, but only slight spasticity shows a pointed triangular diagram (fig 6)
Patients with moderate spasticity, which inhibits knee action during the swing phase, show a rectangular diagram (fig 7)

Although these diagrams show differences between them; there are no striking differences between the diagrams (fig. 8a and 8b) of one patient wearing the stimulator and not wearing it. This might be expected since the stimulator directly influences the ankle only.

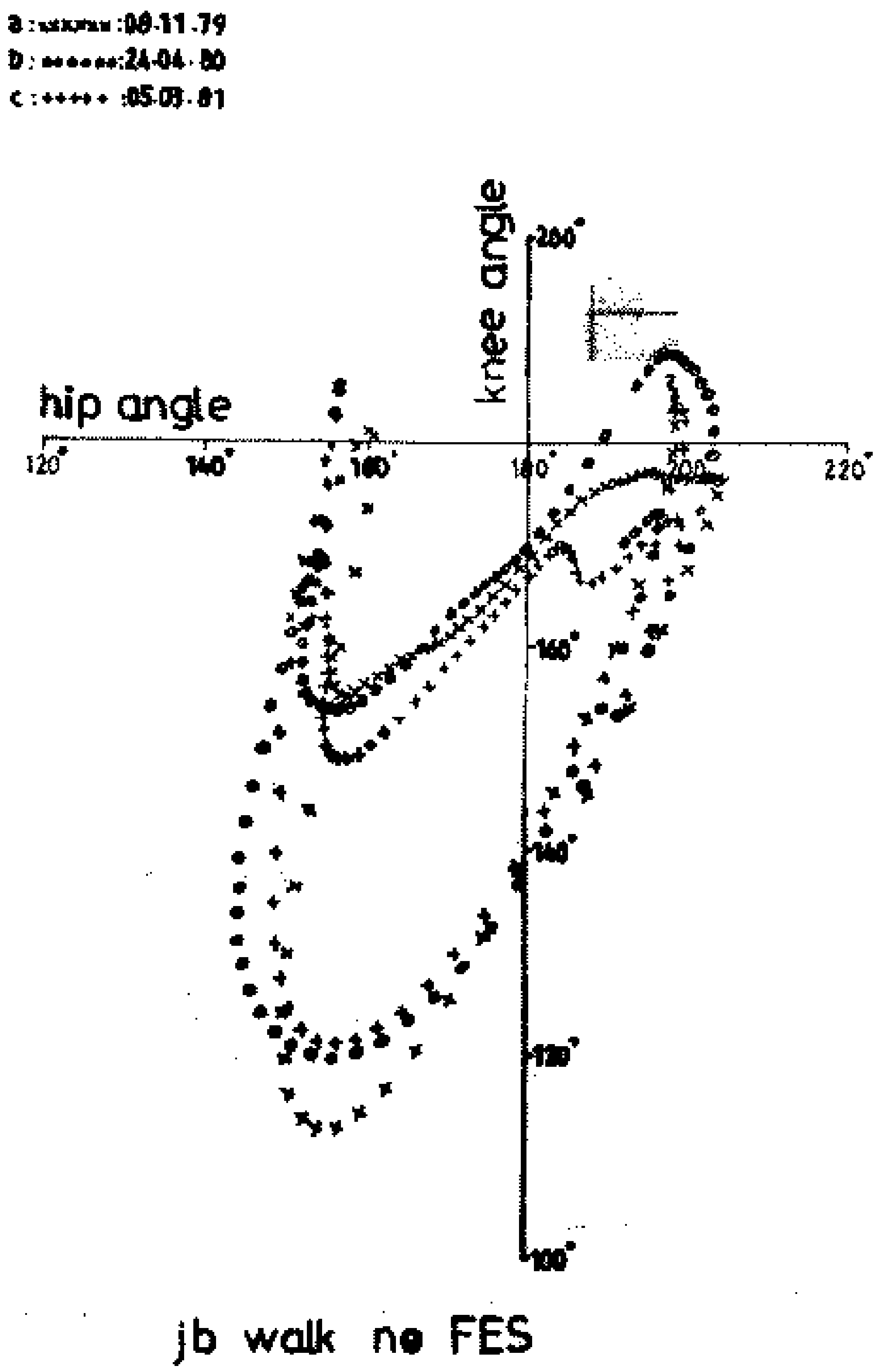
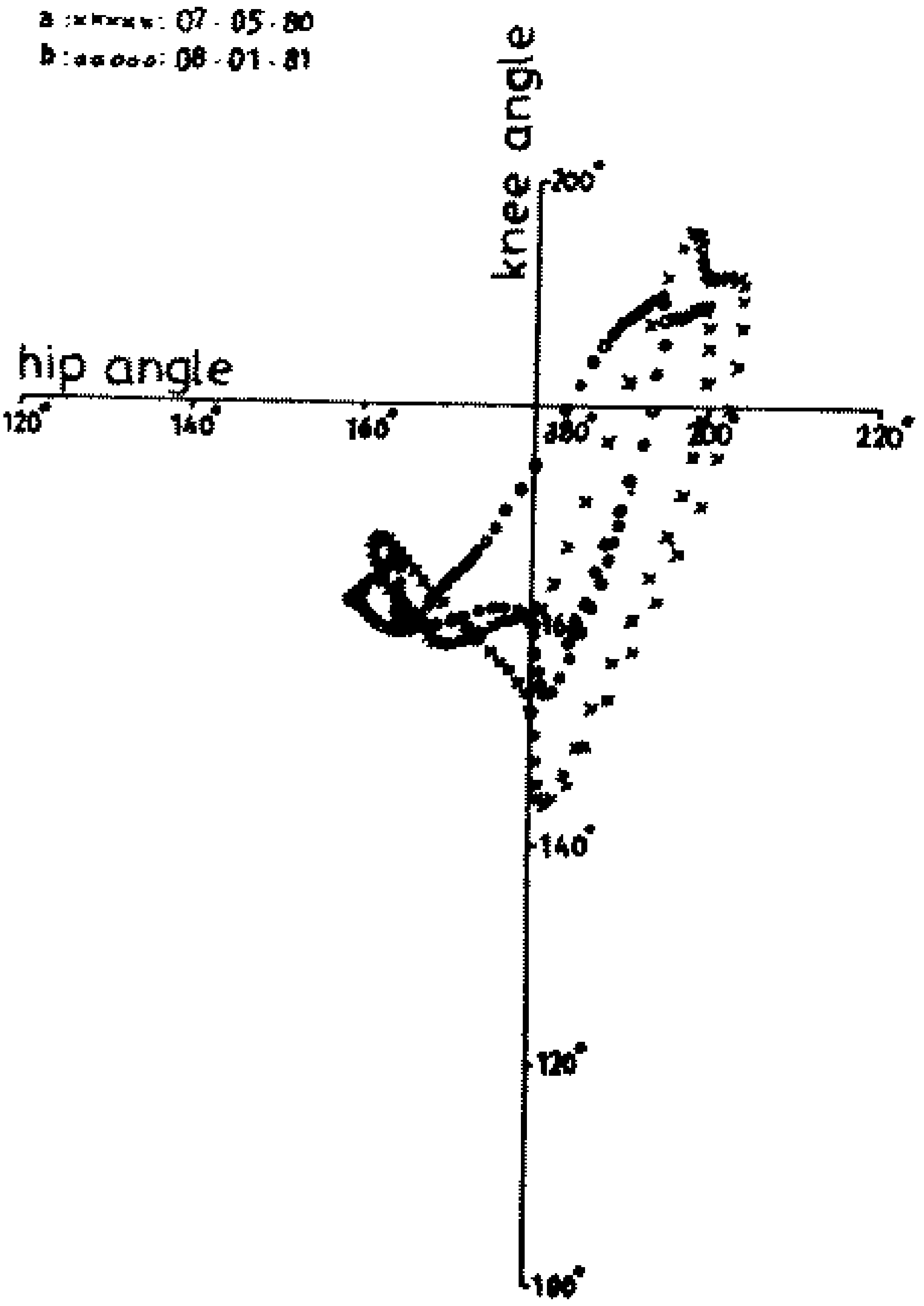


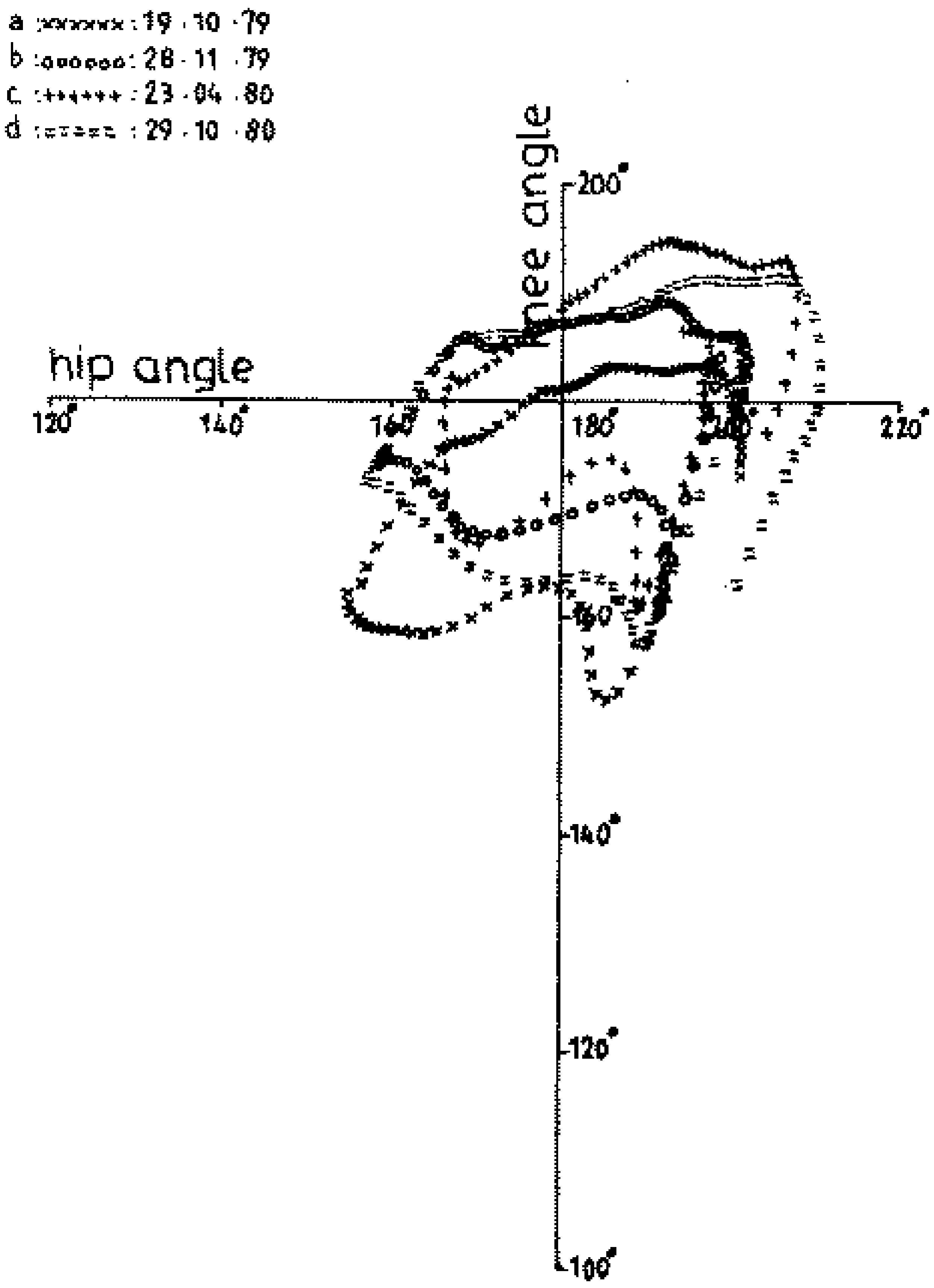
fig. 5

hip/knee diagram of a patient with a walking problem related mainly to the ankle joint function



ac walk, no FES

fig. 6
patient with a dense hemiparesis, but only slight spasticity
little hip and knee action during walking.



rr walk no FES

fig 7
hip/knee diagram of a patient with moderate spasticity which interferes with his walking pattern.

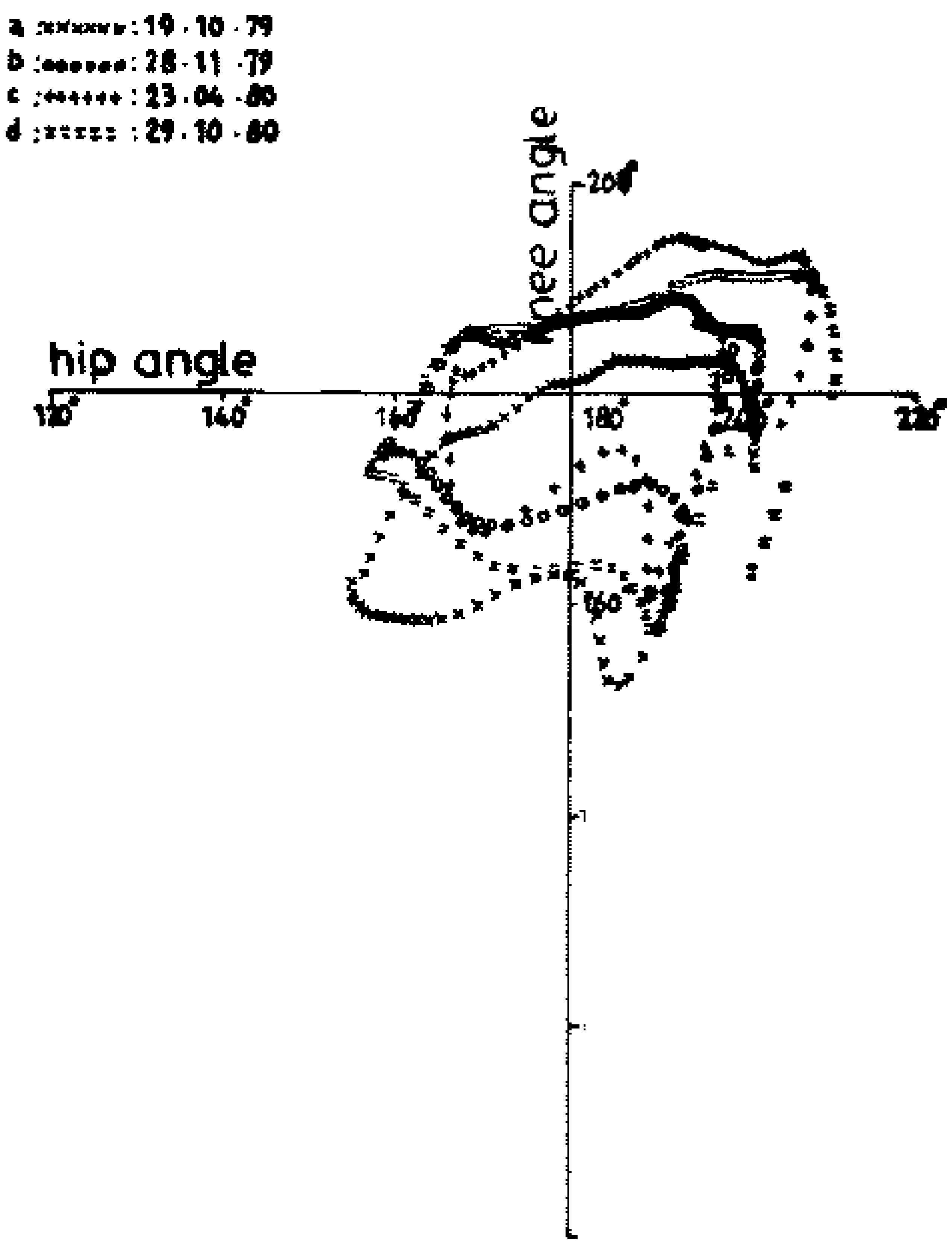


fig. 8a
rr walk,

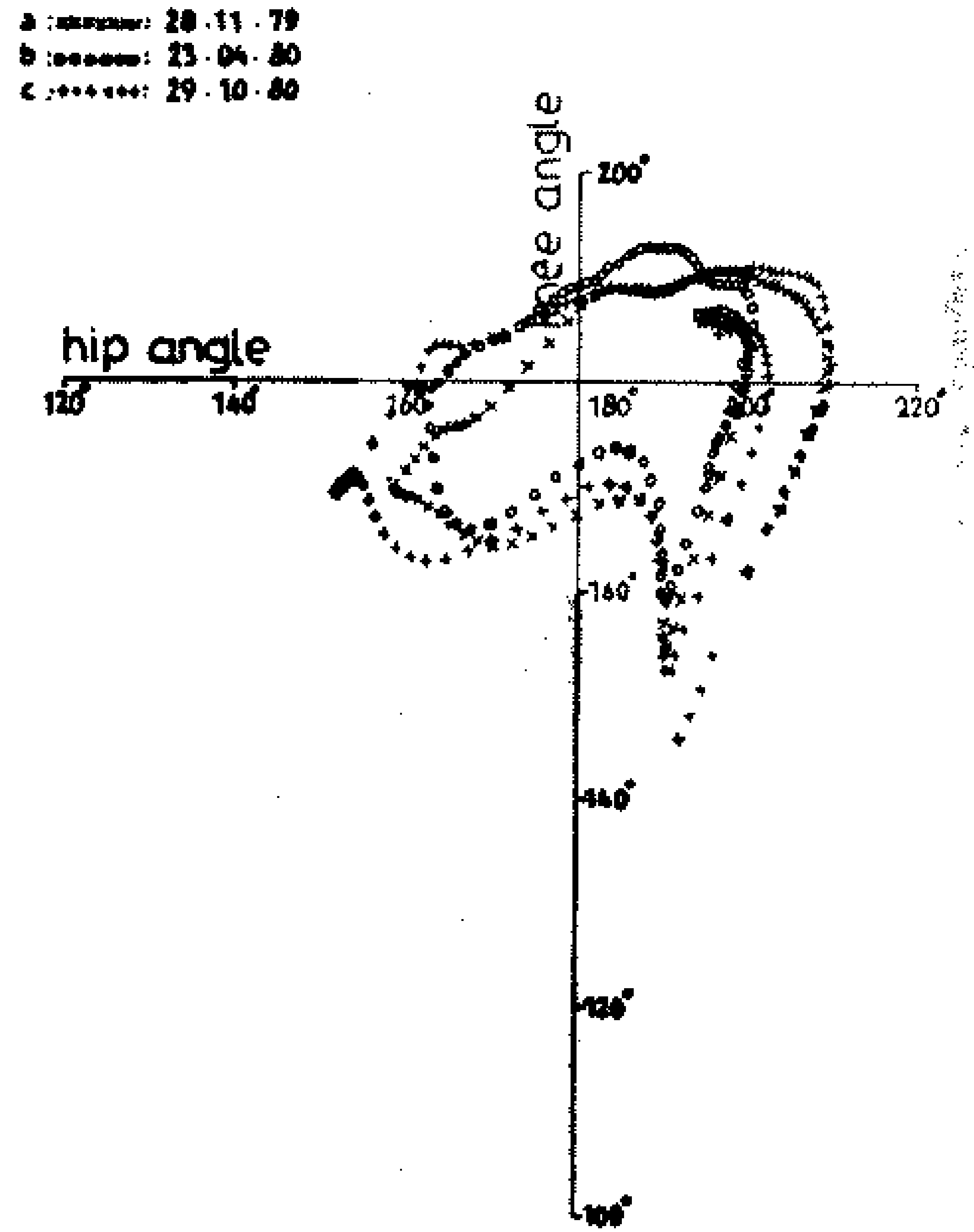


fig. 8b
rr walk with FES

If one one patient in particular is followed up, the following changes may be observed.
Background history of the patient was as follows:
Left parasagittal meningioma removed in 1975 and intensive physiotherapy (conventional) administered until 1979.
When clinically tested at the start of FES treatment, it was found that the tibialis anterior muscle showed a barely detectable contraction and the peroneal muscles allowed slight eversion (about power 2 , according to the Oxford scale, contraction possible but not overcoming gravity).
The balance was very poor, the patient was ambulant with the aid of a stick and was wearing a bilateral metal calliper with a T-strap.

After c. 17 months of FES treatment, it was established subjectively that the tibialis anterior muscle had gained strength, (up to power 3 to 4, overcoming gravity) and the peroneal muscle showed only slight improvement, (power 3, just overcoming gravity). The balance of the patient had improved greatly, the patient now used only a stick when walking over the beach or through a field, while wearing the peroneal brace.

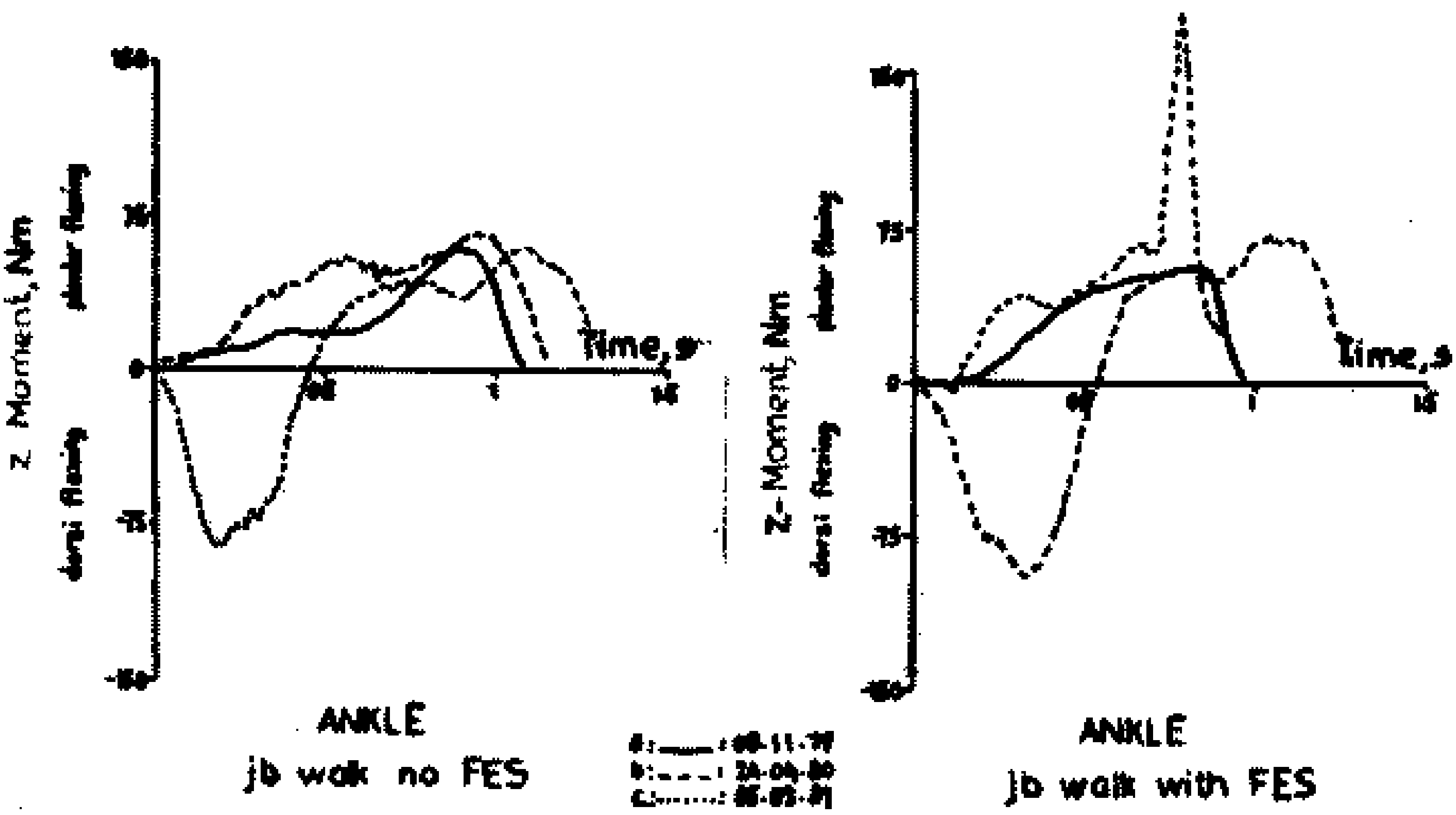
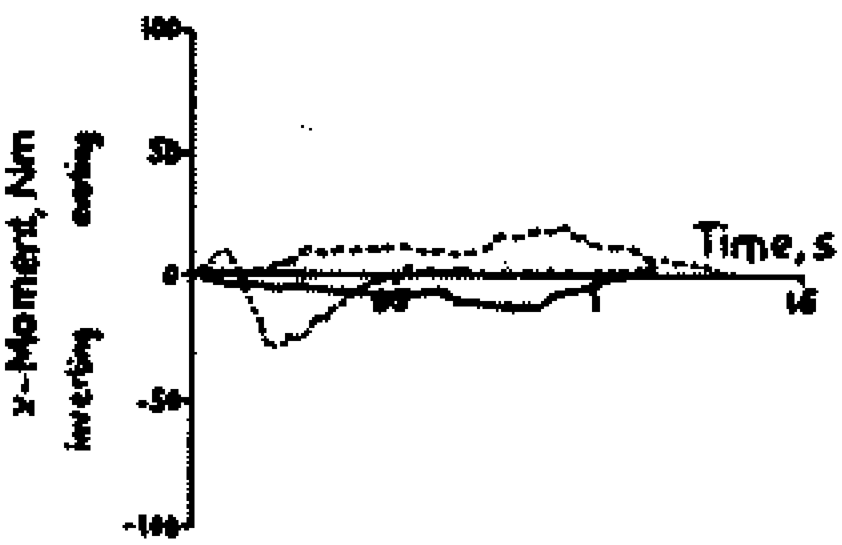
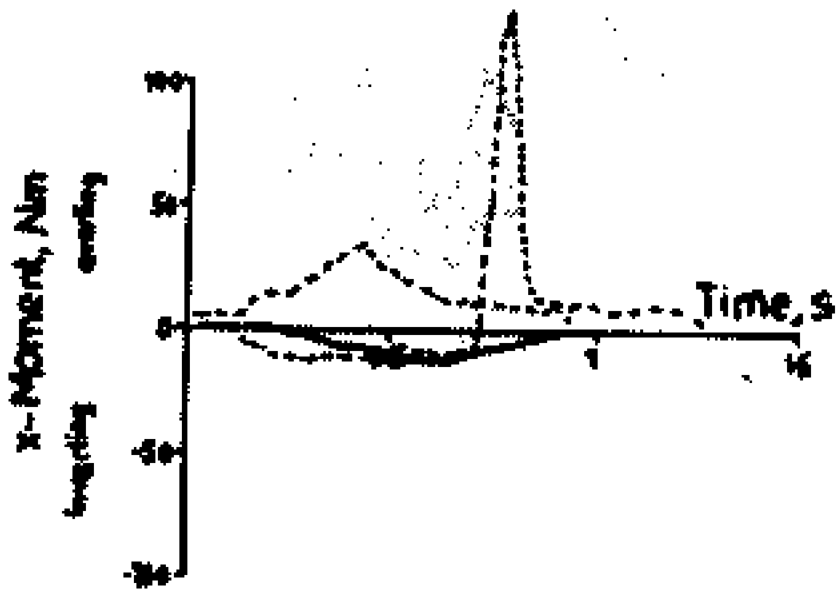


fig 9a
patient not wearing the peroneal brace

fig 9b
patient wearing the peroneal brace.

In fig. 9a, the dotted line, corresponding to the patient not using FES and tested after 17 months, shows a dorsiflexing moment in early stance. When tested after 17 months , while wearing the stimulator in fig 9b there is a sharp burst of activity in late stance which is also reflected in the lateral moment as shown in the dotted line of fig. 10b





ANKLE
jb walk no FES

a: ___: 08.11.79
b: — — : [illegible]
c: ..... : [illegible]

ANKLE
jb walk with FES

fig. 10a
not wearing the peroneal brace

fig. 10b
wearing the peroneal brace

This sharp burst may indicate overactivity, i.e. too strong correction of the everters by the peroneal brace as compared to normal subjects.
Bresler and Frankel,(1950) give a value for the everting moment of ca 14 Nm and one of the normal subjects in this series shows an inverting moment of ca 25 Nm.

Fig. 11 a, c, e show changes in the patient's balance as reflected by the displacement of centre of pressure in antero-posterior direction (xo) over a time period of 17 months. There is a marked improvement in patient's performance with eyes open (fig. 11 a, c, e) but a little less when the eyes are closed (fig. 11 b, d, f). The same can be observed in the transverse (zo) direction (fig 12 a, c, e, and b, d, f) In particular a diminution is shown of the higher frequency sway superimposed on the slow sway. The higher frequency sway corresponds to a tremor (Whitney, 1962). After 17 months the sway approaches the normal as compared to fig. 11 d and 12 d; this is shown even clearer in fig 13 a - h, where xo is plotted against zo.

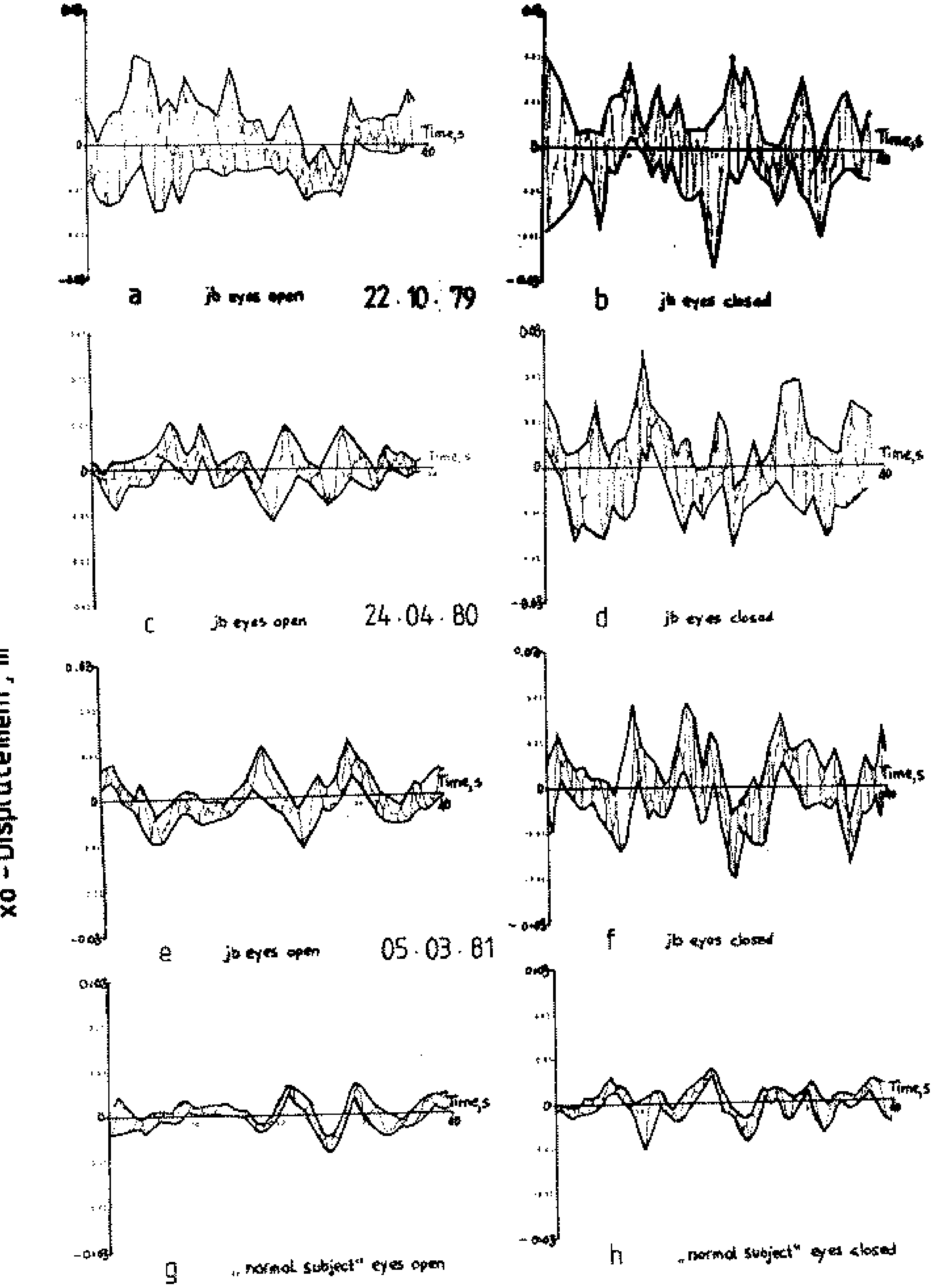


fig 11

Centre of pressure displacement in antero-posterior direction, on the left with eyes open and on the right with eyes closed.

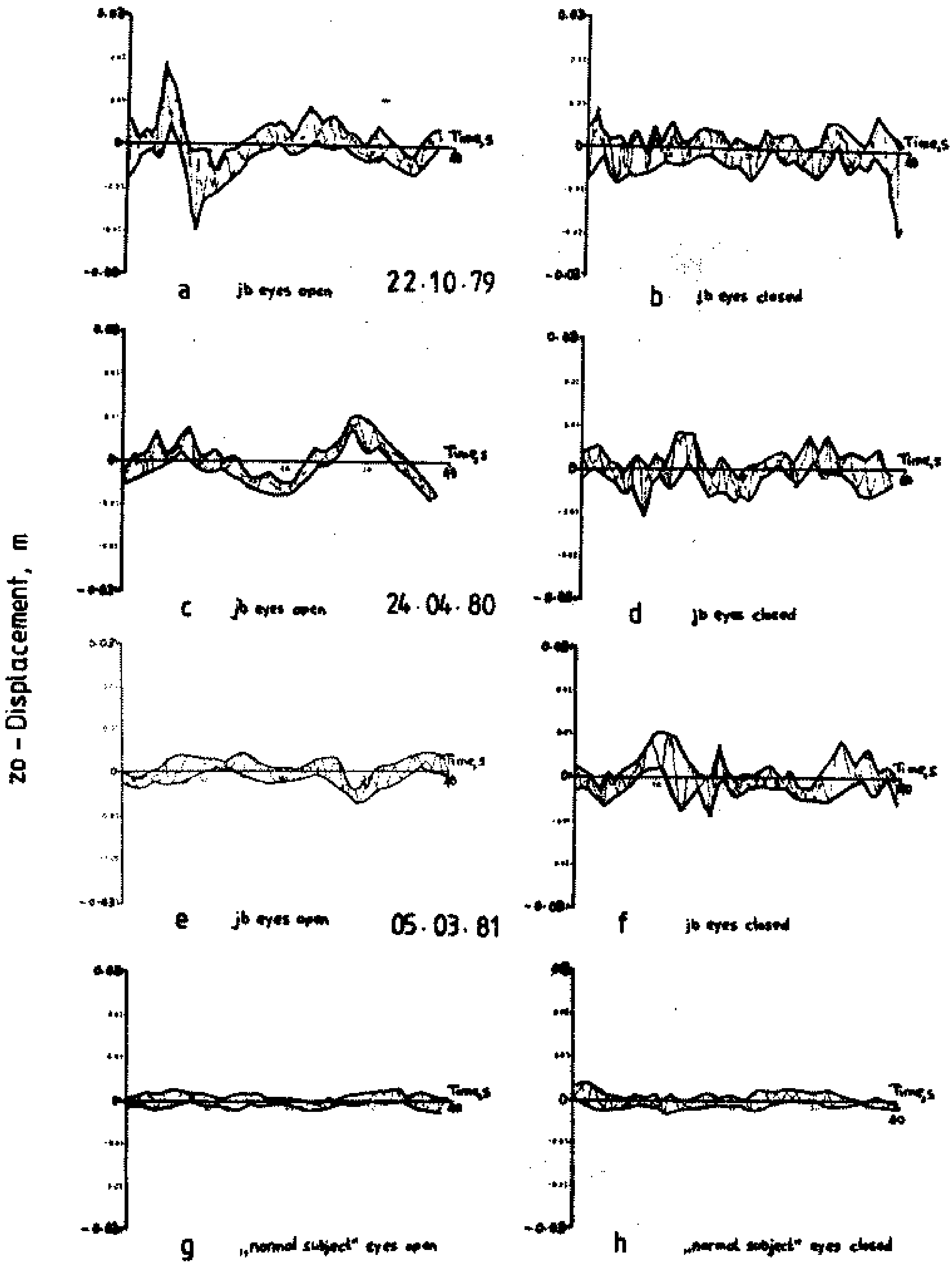


fig 12

Centre of pressure displacement in the medio-lateral direction, on the left with eyes open and on the right with eyes closed.

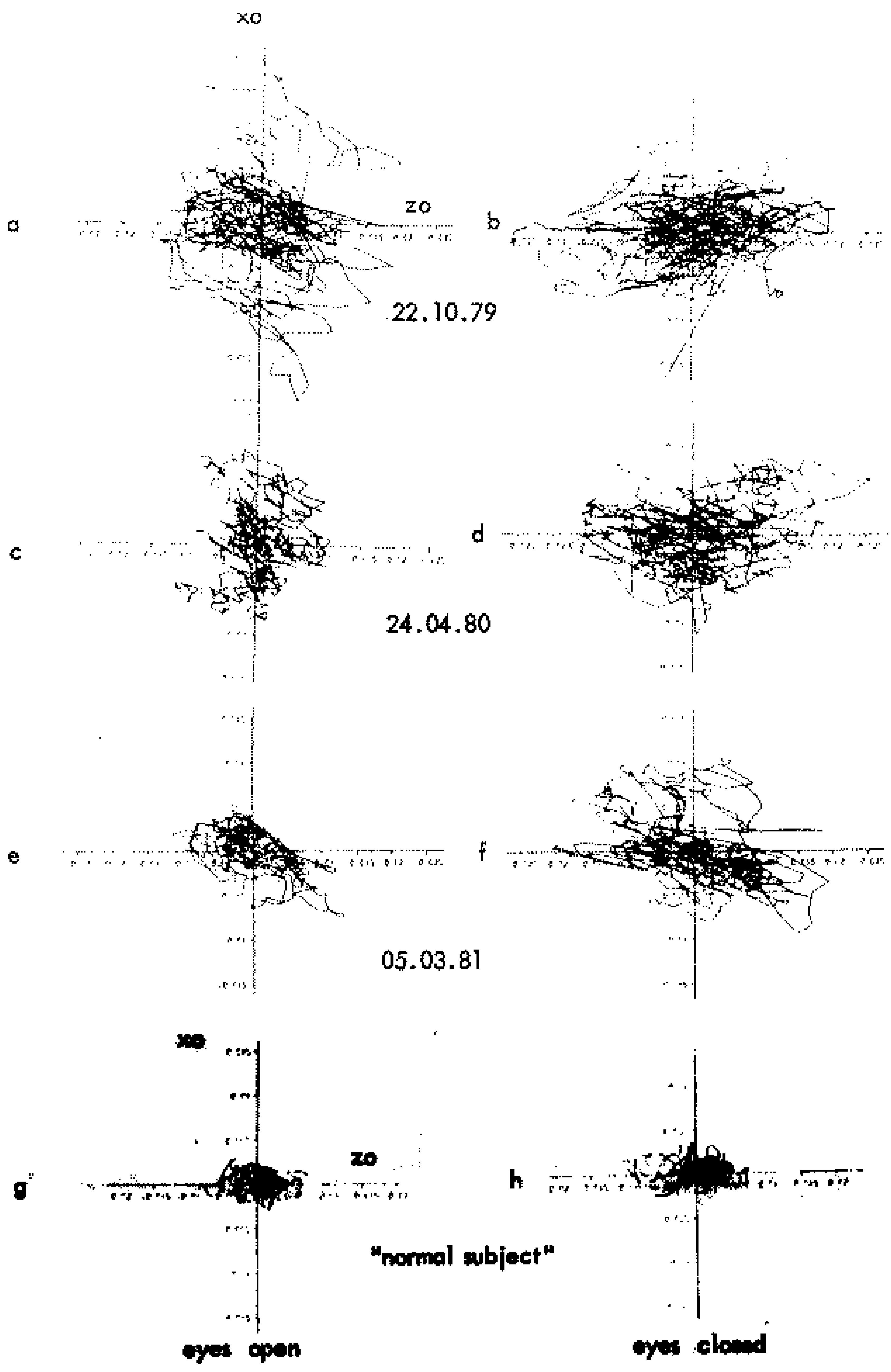


fig 13
Centre of pressure displacement, antero-posterior plotted against medio-lateral direction

Experiences with the Underknee Peroneal Stimulator

In general there were no great difficulties encountered with this particular brace. The stimulator unit does need some further improvement regarding durability of the casing; the battery cover comes loose very readily and requires fixation either by tape or by an elastic band.

The connection of the leads to the stimulator unit gave no problems, but the connectionof the leads to the electrodes should be accessible so that it is possible to solder the leads back on when breakage occurs.

The regulation of the stimulus intensity was not fine enough. In the region of a detectable contraction a movement of one millimeter gave either full power or nothing.

The heelswitch needs to be made of more durable material since it is worn out by an active patient within a fortnight.

Conclusions

In general patients treated with FES either show marked improvement or barely assessable improvement.

The graphs shown corresponds to a patient in the group having marked improvement. The postural sway test reflects improvement in patients who had balance disturbances at the start of treatment.

Since patients in this trial were all "old", well established hemiplegic patients, who were considered to have reached their optimum point in their rehabilitation programme, the improvement may be considered to be due to the influence of FES.

The underknee Peroneal Brace is an improvement on the earlier developed devices; nevertheless it still needs further improvement in durability. A hemiplegic patient is inevitable a clumsy patient and can not 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.

There were less breakages of leads in comparison with the FEPA 10; but the weak spot is still the connection of the leads to the electrodes and this is dependent on the manipulative skill of the patient.

A suggested design improvement to the casing and heelswitch is to make these components waterproof, since patients suitable for the peroneal brace are active and have outdoor activities.

Cosmetically it is an improvement since it is inconspicuous for men and for ladies it can be hidden under a medium length skirt. Comparison with an Ankle-Foot-Orthosis, patients prefer generally the peroneal brace.

Acknowledgements

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References

Bresler,B and Frankel,J.P. (1950). The forces and moments in the leg during level walking. Transactions of the ASME, Jan. 1950, pp 27 - 36

Gracanin, F. (1972). Final report. Use of functional stimulation in rehabilitation of hemiplegic patients. Ljubljana

van Griethuysen, C.M., Condie, D.N., Murdoch, G. (1978). Evaluation of the Ljubljana Functional Electronic Peroneal Brace. "Disability" proceedings of a seminar on Rehabilitation of the disabled. ed. by R.M. Kenedi, J.P. Paul, J. Hughes. pp 485 - 492

Grieve, D.W. (1968). Gait patterns and the speed of walking. Biomed. Eng., 3(3), pp 119 - 122

Magnus, R. (1926). Some results of studies in the physiology of posture. Lancet 11 pp 531 - 585

Malezic, M., Trnkoczy, A., Rebersek, S., Acimovic, R., Gros, N., Strojnik, P., Stanic, U. (1978). Advanced cutaneous electrical stimulators for paretic patients personal use. Advances in External Control of Human Extremities, Belgrade.

Merletti, R. Zelashi, F., Latella, D., Galli, M., Angele, S., and Bellucci Sessa, M. (1978). A control study of muscle force recovery in hemiparetic patients during treatment with Functional Electrical Stimulation. Scand. J. Rehab. Med. 10: pp 147 - 154

Murdoch, G., Condie, D.N., van Griethuysen, C.M. (1978). Evaluation of the Ljubljana Functional Electronic Peroneal Brace. Report to the Scottish Home and Health Department.

Öberg, K and Lamoreux, L.W. (1978). Gait assessment of total joint replacement patients by means of step parameters and hip - knee angle diagrams. "Disability" Proceedings of a seminar on Rehabilitation of the disabled. ed. by R.M. Kenedi, J.P. Paul, J. Hughes. 274-284

Romberg, M.H. (1893). A manual of the nervous diseases of man. London.

Sherrington, Sir Charles (1924). Problems of muscular receptivity. Nature CXIII pp 892 - 929

Whitney, R.J. (1962). The stability provided by the feet during manoeuvres whilst standing. J. Anat. 96 pp 103 - 111