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ELECTROMYOGRAPHY OF MUSCLES OF POSTURE: LEG MUSCLES IN MALES

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This investigation was begun in the first place in order to obtain information about the muscles which maintain the upright position in man, using standard postures, standard positions for the electrodes and larger numbers of subjects than had been studied by previous workers. Since Hellebrandt & Braun (1939) have pointed out that there are some differences in the erect posture due to age and sex (children tending to be restless, adults to be stiff and girls to be steadier than boys) it seemed advisable to investigate subjects in different groups, and this paper deals with a first group of subjects.

Furthermore, it has recently been suggested that the muscles which maintain the upright posture in man show minimal or no electrical activity while performing this function. Floyd & Silver (1951) have demonstrated this in case of the sacrospinalis (erectores spinae) and Weddell, Feinstein & Pattle (1944) in the thigh and calf muscles, while Seyffarth (1942) claimed that 'action potentials cannot, in general, be recorded from tibialis anterior, gastrocnemius and soleus'. Hoeffer (1941) obtained different results in men and women when he investigated the action of the calf muscles in standing at ease. He found that in three women there was no activity in the gastrocnemius but the tibialis anterior showed potentials, while in four men the calf muscles were active and the tibialis anterior was not. All these authors suggest that the upright posture is largely maintained not by active contraction of the muscles involved but by their 'inherent elasticity'. However, Hellebrandt, Tepper, Braun & Elliott (1938) have shown that the line of gravity in the 'normal upright position' passes about 5 cm in front of the lateral malleolus of the ankle joint both in males and females, i.e. it usually bisects the antero-posterior line of the base on which we stand, namely the line joining the heel and the heads of the metatarsals. Hellebrandt (1938) has also shown that although there is a body sway from side to side and backwards and forwards the line of gravity does not shift to any appreciable extent away from its relation to the base on which we stand. Thus one can calculate the approximate force exerted on the tendo calcaneum (Achillis) in the 'standing at ease' position in a subject weighing 64 kg and 178 cm in height. The base on which he stands is approximately 24 cm from the heel to the ball of the foot, the ankle joint 6 cm above the base and 8 cm in front of the heel, the centre of gravity 55% of his height above the ground (Hellebrandt *et al.* 1938), i.e. 98 cm, the line of weight bisects the base, and the length of the calf muscles is 50 cm (see Fig. 1). The force which the calf muscles *ZW* have to exert to

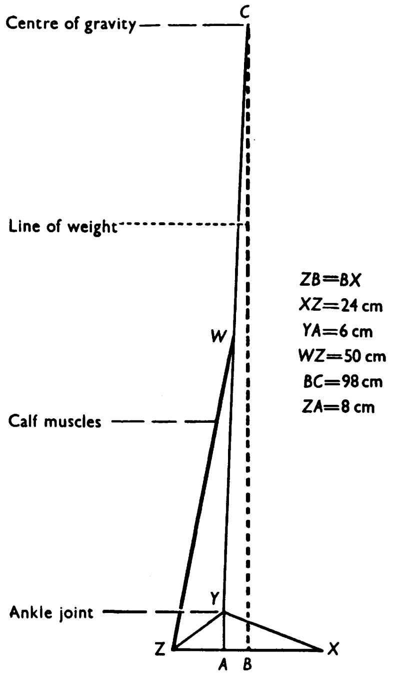

Fig. 1. Diagram to illustrate the basis for calculating the force exerted by the calf muscles in the standing at ease position. Height of subject, 178 cm; weight, 64 kg.

maintain the upright position is obtained by finding the ratio between the perpendicular from *Y* to the line of weight *BC* and the perpendicular from *Y* to the calf muscles *ZW*. This is approximately 1 : 2. Since the weight is assumed to be equally distributed down both limbs, the force required is approximately one-quarter of the body weight, i.e. 16 kg. It therefore seemed unlikely that the muscles of the calf could maintain the upright position without some active contraction.

MATERIAL AND METHOD

In this preliminary investigation twelve males aged 18–28 years acted as subjects. It is important to define as exactly as possible the postures used in this type of problem. Most people neither stand still nor fail to avail themselves of every opportunity to lean or partially sit on whatever presents itself. If, however, they do stand still and have no opportunity to lean or sit on something, they will usually stand so that the weight is mainly borne alternately on one or other limb. Sometimes they stand with their weight distributed equally through both limbs, but that is unusual. In this experiment three standard postures were used:

(1) *Standing at ease.* The subject stands with his feet about 18–24 in. apart and turned out about 30–45°, weight is distributed equally through both lower limbs, the body as a whole is held comfortably erect, the eyes look forward and the upper limbs are held so that one hand lightly clasps the other wrist behind the back.

(2) *Standing with weight mainly on left lower limb.*

(3) *Standing with weight mainly on right lower limb.*

In (2) and (3) the subject was often given a paper to read in order to persuade him to stand 'naturally'. Usually it was fairly easy to obtain postures in which the subject paid little or no attention to what was going on.

The subject's age, occupation (past and present), height, weight, size of shoe and any relevant history (e.g. history of injury to lower limbs, difficulty with shoes, family history of lower limb abnormalities, particularly of the feet) were noted. The length of the leg between the proximal end of the tibial tuberosity and distal end of the lateral malleolus was measured and noted. Paired electrodes were used. One pair was attached to the right leg one-third of the distance down from the tibial tuberosity 2 cm lateral to the anterior border of the tibia and another pair 1 cm behind its posteromedial border. The electrodes were moved about slightly to obtain a better recording if necessary. In these positions the muscles lying immediately deep to the electrodes are respectively tibialis anterior in front and soleus posteromedially. Recordings were also made with a pair of electrodes over the lateral belly of the gastrocnemius at the same level as for the other two muscles. For comparison, recordings of active contractions of the soleus and gastrocnemius were taken.

The electrodes were smeared with Cambridge Jelly, and placed on the skin which had been rubbed with the jelly until a slight erythema was produced. They were held in place by elastic bands. The electrodes used were silvered brass disks covered with gauze moistened with saline. They were 1 cm in diameter and were fixed in Perspex holders so that the distance between the centres of the two disks was 2 cm.

The amplifier input circuit employed a screened switch which enabled the operator to connect the amplifier to either of the two pairs of electrodes placed as described above over the front and back muscles of the leg of the right lower limb. An additional single electrode was strapped to the right wrist of the subject and earthed. The leads from the two electrodes were taken to the grids of a balanced pair of valves which constituted the first stage of a battery-operated amplifier. The second stage was a 'compressor' stage converting the originally balanced signal into an unbalanced one. When the 'balance' control of the first two stages was correctly adjusted, a rejection ratio of 3000 : 1 was achieved against interfering potentials picked up from the mains at the input of the amplifier. Two further stages of amplification followed. The amplifier was capacity-coupled and had constant gain between 30 and 400 c/s, the gain being reduced to one-half at 10 c/s and 1200 c/s. Outputs were taken to two cathode-ray oscilloscopes and a loud speaker. One single-beam oscilloscope was used for observation with its time base running. The second, a double-beam tube, was used without a time base for photographic recording in conjunction with a continuous recording camera, the signal being taken to one beam and a time marker to the other. A calibration signal of 700 μV peak to peak at 300 c/s could be switched to the input of the amplifier when required.

The following observations and recordings were made:

(1) 700 μV peak to peak, 300 c/s.

(2) Noise level of amplifier with input grids earthed.

(3) Noise level recording from relaxed right soleus (i.e. the subject was sitting comfortably with the knees bent to a right angle and the feet and legs supported).

(4) Standing at ease, recording from right tibialis anterior.

(5) Standing at ease, recording from right soleus.

(6) Weight on left limb, recording from right tibialis anterior.

(7) Weight on left limb, recording from right soleus.
(8) Weight on right limb, recording from right tibialis anterior.
(9) Weight on right limb, recording from right soleus.
(10) Recording of active contraction of right soleus.
(11) Standing at ease, recording from right gastrocnemius.
(12) Weight on left limb, recording from right gastrocnemius.
(13) Weight on right limb, recording from right gastrocnemius.
(14) Recording of active contraction of right gastrocnemius.

RESULTS

When standing at ease, potentials were recorded from the right soleus electrodes in all twelve subjects. In this position none showed potentials from the right tibialis anterior and seven showed them from the right gastrocnemius. Of these seven, two showed much less activity in the gastrocnemius than in the soleus. When weight was borne mainly on the right limb, all twelve subjects recorded potentials from the soleus, six from the gastrocnemius and none from the tibialis anterior of the weight-bearing limb. When

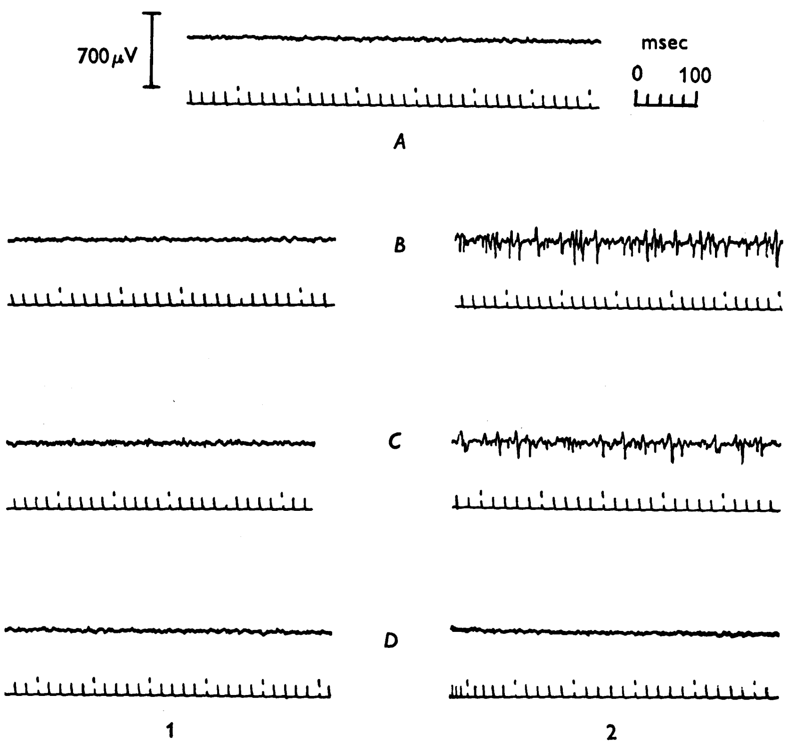

Fig. 2. *A* is the base-line obtained by recording from the right soleus with the muscle relaxed; *B*1, right tibialis anterior, standing at ease; *B*2, right soleus, standing at ease; *C*1, right tibialis anterior, weight on right limb; *C*2, right soleus, weight on right limb; *D*1, right tibialis anterior, weight on left limb; *D*2, right soleus, weight on left limb.

weight was transferred to the left limb, in one subject potentials were recorded from the tibialis anterior and in another from the soleus of the non-weight-bearing limb. No subject recorded potentials from the gastrocnemius of the non-weight-bearing limb. These results are summarized in Table 1 and representative records are shown in Figs. 2 and 3.

TABLE 1. Number of subjects (out of twelve) showing potentials in right tibialis anterior (RTA), right soleus (RS) and right gastrocnemius (RG) in three standard postures (see text)

Muscle	Standing at ease	Weight on right limb	Weight on left limb
RTA	0	0	1
RS	12	12	1
RG	7	6	0

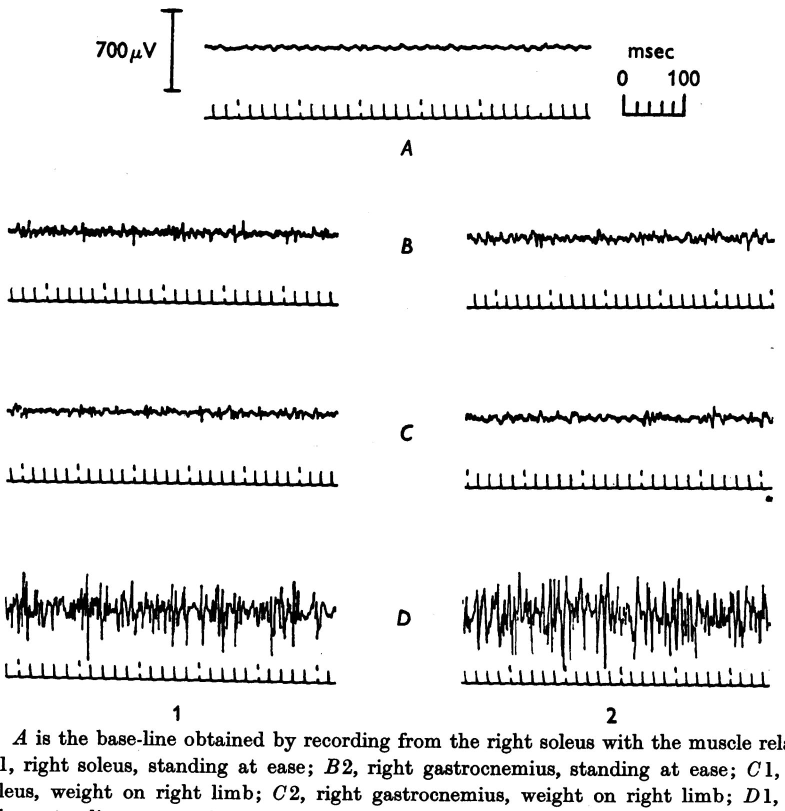

Fig. 3. *A* is the base-line obtained by recording from the right soleus with the muscle relaxed; *B* 1, right soleus, standing at ease; *B* 2, right gastrocnemius, standing at ease; *C* 1, right soleus, weight on right limb; *C* 2, right gastrocnemius, weight on right limb; *D* 1, right soleus, standing on toes, i.e. actively contracted; *D* 2, right gastrocnemius, standing on toes, i.e. actively contracted.

DISCUSSION

It can be seen from the results that when a limb is bearing weight, whether in a position of standing at ease or so that the weight is mainly on one limb, the anterior muscles of the leg do not produce any detectable potentials, and the soleus invariably and sometimes the gastrocnemius are apparently active.

The suggestion that the upright posture is maintained by 'minimal activity' or only by the 'elastic properties' of the muscles should be rejected in the case of the calf muscles. The activity of muscles in the upright position depends on the way in which the weight is distributed in relation to a particular joint. If gravity produces further movement, i.e. gravity is acting as the prime mover, then those muscles which are normally the prime movers of the joint relax so that potentials cannot be recorded from them. On the other hand, when the muscles of a joint become the antagonists against gravity they always show activity. This has been demonstrated by Allen (1948) and by Floyd & Silver (1950). In the present investigation it was found in several subjects that if electrodes were attached to the front and back muscles of the leg simultaneously, every position produced by swaying backwards and forwards resulted in potentials from the front or back muscles. This experiment is being followed up in other subjects, especially with regard to the thigh muscles. It appears that one of the reasons for the variable results obtained in similar experiments is that other workers have always placed the electrodes either in or on the back of the calf. Since apparently soleus is the muscle which is constantly active the electrodes must be placed on that muscle where it is superficial, 1 cm behind the posteromedial border of the tibia.

It is possible that the potentials recorded are due not to the activity of the soleus and gastrocnemius but of other muscles. It is claimed, however, that soleus and gastrocnemius are the active muscles, because in this type of investigation muscles are contracted to only a limited extent and it is possible to pick up their potentials only if the electrodes are directly over the muscles. If other muscles were active and soleus and gastrocnemius were not, surface electrodes in the positions described would not record any potentials.

Another problem is whether it is correct to assume that in some subjects soleus is the only muscle which is active and in others both soleus and gastrocnemius are active. It must be admitted that the failure of the gastrocnemius electrodes to record potentials may be due not to absence of activity in that muscle but to the arrangements of its fibres or a layer of fat between the muscle and the electrodes or to the inadequate sensitivity of the recording apparatus. There is no apparent reason, however, why the first two of these factors should operate in only five of the twelve subjects.

With regard to the sensitivity of the apparatus, it is necessary to estimate the minimum amplitude detectable above the noise and interference. The noise level of the amplifier as used in the observations on the twelve subjects reported here was equivalent to an input signal of about 35 μV peak to peak, with the input grids earthed. In addition, the records were made in an unscreened laboratory in the vicinity of other electrical apparatus, and it was usually impossible to avoid pick-up of a noisy character as well as mains interference. Thorough preparation of the skin and adjustment of the leads and balance control usually eliminated the mains interference. It is obvious, however, that the peak to peak amplitude of the action potential must be greater than that of the noise before it can be definitely distinguished, and this depended on the interference conditions at the time of the experiment. The record taken in each case, of noise and interference background with the subject seated and the muscle relaxed, was therefore set side by side with the record under consideration. In most cases action potentials of 70 μV peak to peak were considered to be just detectable. It must therefore be stressed that the failure to detect activity did not prove that none was present. However, the most significant result in this experiment has been the presence of activity at least in soleus, rather than its absence in gastrocnemius.

It may be argued that in five subjects the soleus electrodes were actually recording potentials from the gastrocnemius. This is tantamount to saying that electrodes not over a muscle can pick up its potentials more readily than ones directly over the muscle, and this is considered to be very unlikely.

That only some of the subjects show activity in gastrocnemius may be due to the way in which they hold their knees in standing. By bending the knees and hips it is possible to bring the line of weight backwards towards the centre of the ankle joint. Even with the knees straight the extent to which the leg and rest of the body is bent forwards at the ankle is variable. The greater the anterior angle between the leg and the foot the nearer is the line of weight to the ankle joint. Consequently, less activity is required in the calf muscles and apparently the gastrocnemius becomes less active or even inactive. Soleus then becomes the muscle preventing falling forwards at the ankle. There is some indication from a close study of the recordings that the activity of the soleus is well marked in all subjects, but that there is a considerable variation in the extent to which the gastrocnemius is used in those who apparently require this muscle. It has already been noted that the gastrocnemius in two cases is apparently used much less than the soleus, where both muscles were apparently active.

SUMMARY

1. It has been suggested by previous workers that in certain postures (e.g. 'standing at ease') the upright position is maintained largely by the 'inherent elasticity' of the muscles involved. Consideration of the line of weight and of the force exerted on the calf muscles makes it extremely unlikely that the calf muscles are inactive in this position.

2. In twelve males, the soleus in a weight-bearing limb was found to show well-marked activity, and in seven of the twelve the gastrocnemius was also active.

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