

From the Department of Anatomy, Karolinska Institutet, Stockholm.
(Head: Professor Ture Petré.)

INFLUENCE OF FRONTAL AND DORSAL LOADS ON MUSCLE ACTIVITY AND ON THE WEIGHT DISTRIBUTION IN THE FEET

By

SVEN CARLSÖÖ

If a person who has adopted an upright, symmetric standing rest position has his back loaded by, for instance, a heavy rucksack on the shoulders or a box which he holds in front of him, he alters his posture spontaneously in order to compensate for this load. Through changes in the position of various joints, the line representing the combined gravitational pull of the body and the load will thus pass through the area on which the person is standing.

Such a load and the changes in posture result in an increased load on the musculature and a modified distribution of muscle activity as compared with the original posture.

The object of this investigation has been to make comparisons between the muscle activity in the major postural muscles when standing with and without a load and also when walking with and without a load. Investigations were likewise made into the distribution of the body's weight between the right and left foot and between forefoot and heel in a standing position, with and without a load.

METHOD

Fifteen students between the ages of 19 and 21 were examined. Muscle activity was recorded with a Disa electromyograph, using surface electrodes. The muscles studied were sacro-spinalis, rectus abdominis, tibialis anterior, quadriceps, the ischiocrural muscles, soleus and trapezius.

The pressure exerted by the weight of the body on its support was measured by means of two stress plates: one under the left heel and

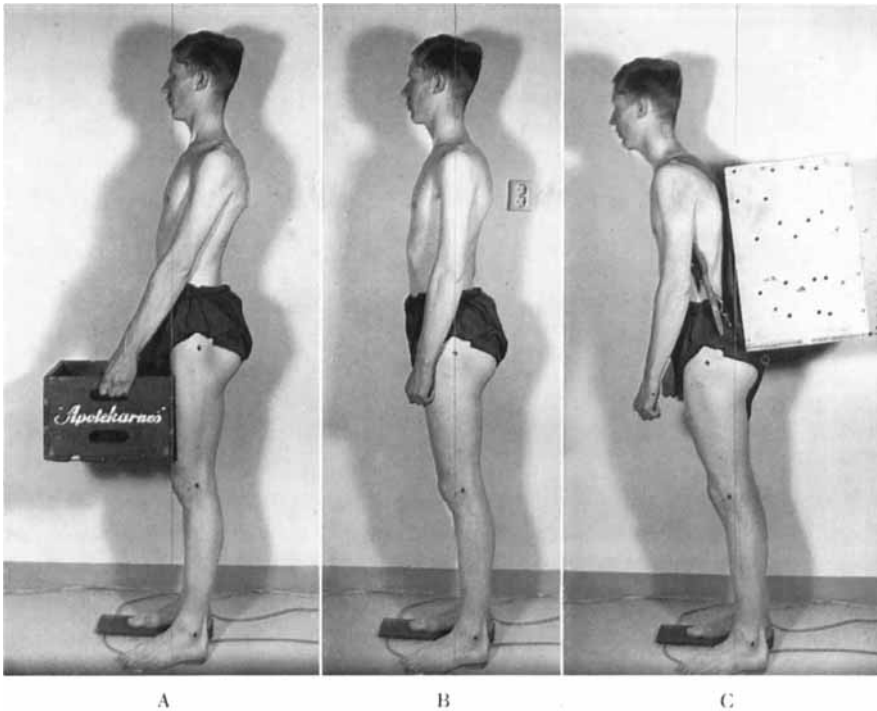


Fig. 1.

Subject standing—without a load, with a front load and with a back load—with the left foot on the two stress plates used for measuring heel and forefoot pressure and with a simple metal plate under the right foot.

one under the left forefoot (Fig. 1). The right foot stood on a simple metal plate of the same thickness as the stress plates. The stress plate used for measuring heel pressure has been described previously (Wetzenstein 1961). The stress plate for the forefoot was designed on the same principles as that for the heel, *i.e.* a stiff spring balance, consisting of a plate which is carried by three cantilevers, on which are mounted straingauges—but was somewhat larger so as to support the entire forefoot. There was no support for the arch of the foot. The load on the left foot is thus the sum of the pressures of these two plates. The load on the right foot is then the difference between this sum and the total body weight.

During the investigations the subjects were dressed in light trousers or gymn clothes. For the registration of the foot loads they were required to adopt a symmetric rest posture with what they considered to be an even distribution of weight between sole and forefoot. Once in

this posture, recordings were made during a period of five seconds, using a Visicorder mirror galvanometer.

The subjects then remained on the plates while the load was attached to the shoulders by means of leather straps. The total weight of this load, hereinafter referred to as the "back load", was 20.5 kg. (Fig. 1 c).

As soon as the subject had adopted a comfortable and balanced posture another five second registration of the foot loads was made. Subsequently the back load was exchanged for a front load, this time a 20.5 kg. box which the subject held in his hands in front of him (Fig. 1 a). Once a balanced posture had been achieved, the third registration was made. Even within a five second period the postural sway produces fluctuations on the pressure curves, but the measurements from these curves were taken from the periods of minimum fluctuation.

The muscle activity was first registered with the subject in an upright symmetric standing rest position and then during walking. Next the activity was registered in the standing position with the back load and then walking with the same load. Corresponding registrations were then made standing and walking with the front load. In the standing positions the registrations were made after the subject had adopted the most comfortable and balanced position possible. The registrations were then made during a thirty second period. During the walking tests the subject walked in a straight line for about five meters at a smooth, even pace.

RESULTS AND DISCUSSION

Foot loads. (Tables 1, 2 and 3. Figs. 2 and 3).

When standing symmetrically in a rest posture, ten of the fifteen subjects put more weight on the right foot than on the left, while the remaining five put more on the left than on the right. In thirteen of the fifteen cases there was more weight on the left forefoot than on the left heel. *Abramson* (1927), on the other hand, found that an average of 57 per cent of the weight was on the heel and 43 per cent on the forefoot and arch. This discrepancy is probably attributable to different methods of measuring and possibly even more to different procedures. *Abramson* used the Brinell method and measured the foot's pressure at a number of points on the support. The subjects stood upright but with the body-weight all on one foot while the other foot was immediately above the measuring instrument. The latter foot was then lowered on to the measuring plate so that the body-weight was dis-

TABLE 1
Symmetric Rest Position.

| Subjects | Sex | Height | Weight | On left heel plate | | On left forefoot plate | |
|----------|-----|--------|--------|--------------------------|------------------|--------------------------|------------------|
| | | | | Vertical pressure in kg. | % of body-weight | Vertical pressure in kg. | % of body-weight |
| I.B. | ♀ | 168 | 58.6 | 12 | 21 | 17 | 37 |
| B.T. | ♀ | 163 | 59.6 | 11 | 18.5 | 18 | 30.03 |
| B.R. | ♀ | 164 | 62.5 | 13 | 21.6 | 16.5 | 26.8 |
| K.F. | ♀ | 170 | 65.7 | 18 | 27.4 | 16 | 24.35 |
| L.O. | ♂ | 171 | 65.8 | 7 | 10.6 | 23 | 35 |
| G.B. | ♂ | 172 | 66.5 | 12 | 18.05 | 21 | 31.6 |
| J.P. | ♂ | 186 | 66.6 | 12 | 18 | 24 | 36 |
| T.E. | ♂ | 180 | 72.2 | 10.5 | 14.6 | 21.5 | 29.8 |
| U.B. | ♂ | 180 | 73.2 | 18 | 24.6 | 20 | 27.3 |
| B.H. | ♂ | 172 | 74.3 | 16 | 21.5 | 19 | 25.6 |
| B.F. | ♂ | 175 | 75.2 | 12 | 15.95 | 26 | 34.55 |
| B.A. | ♂ | 183 | 77 | 17 | 22 | 22 | 28.5 |
| K.B. | ♂ | 179 | 77.5 | 7 | 9.4 | 24 | 30.9 |
| D.B. | ♂ | 181 | 80.1 | 21 | 26.2 | 19 | 23.7 |
| H.A. | ♂ | 183 | 83 | 12 | 14.45 | 20 | 24.2 |

TABLE 2
Standing with Back Load.

| Subjects | Sex | Height | Weight | On left heel plate | | On left forefoot plate | |
|----------|-----|--------|--------|--------------------------|---------------------------|--------------------------|---------------------------|
| | | | | Vertical pressure in kg. | % of body-weight and load | Vertical pressure in kg. | % of body-weight and load |
| I.B. | ♀ | 168 | 58.6 | 16 | 20.2 | 28 | 35.2 |
| B.T. | ♀ | 163 | 59.6 | 6 | 7.5 | 35 | 43.7 |
| B.R. | ♀ | 164 | 62.5 | 16 | 19.3 | 21 | 25.3 |
| K.F. | ♀ | 170 | 65.7 | 14 | 16.23 | 30 | 34.8 |
| L.O. | ♂ | 171 | 65.8 | 8 | 9.28 | 30 | 34.8 |
| G.B. | ♂ | 172 | 66.5 | 5 | 5.76 | 42 | 48.2 |
| J.P. | ♂ | 186 | 66.6 | 18.5 | 20.07 | 28 | 32.15 |
| T.E. | ♂ | 180 | 72.2 | 14 | 15.1 | 26 | 28 |
| U.B. | ♂ | 180 | 73.2 | 12 | 12.8 | 33 | 35.2 |
| B.H. | ♂ | 172 | 74.3 | 10 | 9.48 | 32 | 33.8 |
| B.F. | ♂ | 175 | 75.2 | 15 | 15.78 | 31 | 32.35 |
| B.A. | ♂ | 183 | 77 | 17.5 | 17.95 | 27 | 27.7 |
| K.B. | ♂ | 179 | 77.5 | 10 | 9.8 | 28 | 28.6 |
| D.B. | ♂ | 181 | 80.1 | 23 | 23.9 | 24 | 23.9 |
| H.A. | ♂ | 183 | 83 | 9 | 8.7 | 37 | 36 |

tributed between the two feet. Two seconds later the foot was raised again from the measuring plate. It is questionable whether during such a brief period it is possible to distribute the body-weight between the two feet in a manner which is entirely consistent with a symmetric, upright, resting posture.

TABLE 3
Standing with Front Load.

| Subjects | Sex | Height | Weight | On left heel plate | | On left forefoot plate | |
|----------|-----|--------|--------|--------------------------|---------------------------|--------------------------|---------------------------|
| | | | | Vertical pressure in kg. | % of body-weight and load | Vertical pressure in kg. | % of body-weight and load |
| I.B. | ♀ | 168 | 58.6 | 9 | 11.35 | 31 | 39.2 |
| B.T. | ♀ | 163 | 59.6 | 8 | 10 | 33 | 41.2 |
| B.R. | ♀ | 164 | 62.5 | 8 | 9.64 | 30 | 36.3 |
| K.F. | ♀ | 170 | 65.7 | 14 | 16.26 | 29 | 33.6 |
| L.O. | ♂ | 171 | 65.8 | 13.5 | 15.7 | 26.5 | 30.7 |
| G.B. | ♂ | 172 | 66.5 | 23 | 29.1 | 26.5 | 30.5 |
| J.P. | ♂ | 186 | 66.6 | 11.5 | 13.2 | 29 | 33.3 |
| T.E. | ♂ | 180 | 72.2 | 16 | 17.2 | 26 | 28 |
| U.B. | ♂ | 180 | 73.2 | 21 | 22.4 | 25.5 | 27.5 |
| B.H. | ♂ | 172 | 74.3 | 18 | 19 | 25 | 26.4 |
| B.F. | ♂ | 175 | 75.2 | 22 | 23 | 25.5 | 26.7 |
| B.A. | ♂ | 183 | 77 | 16 | 16.4 | 27 | 24.6 |
| K.B. | ♂ | 179 | 77.5 | 11 | 11.2 | 35 | 33.9 |
| D.B. | ♂ | 181 | 80.1 | 24 | 23.8 | 27 | 26.6 |
| H.A. | ♂ | 183 | 83 | 18 | 17.35 | 25 | 24.2 |

If the subject stood with the 20.5 kg. box held in front of him, or if the box were strapped on his back, this addition to the body-weight tended to load the forefoot more than the heel. This proved to be so in twelve of the fifteen cases with the back load and in nine of the fifteen cases with the front load. There were large individual variations. The relationship heel load/forefoot load varied in one case between 0.28 and 0.32, while in another case the variation was from 1.13 to 0.58. Ventral shifting of the point where the line of gravity passes through the area supporting the body may be seen as a safety measure. A person who loses his balance is more likely to fall forwards than backwards. His field of vision and the range of movement of the arms give him a much better chance of saving himself if he falls forwards.

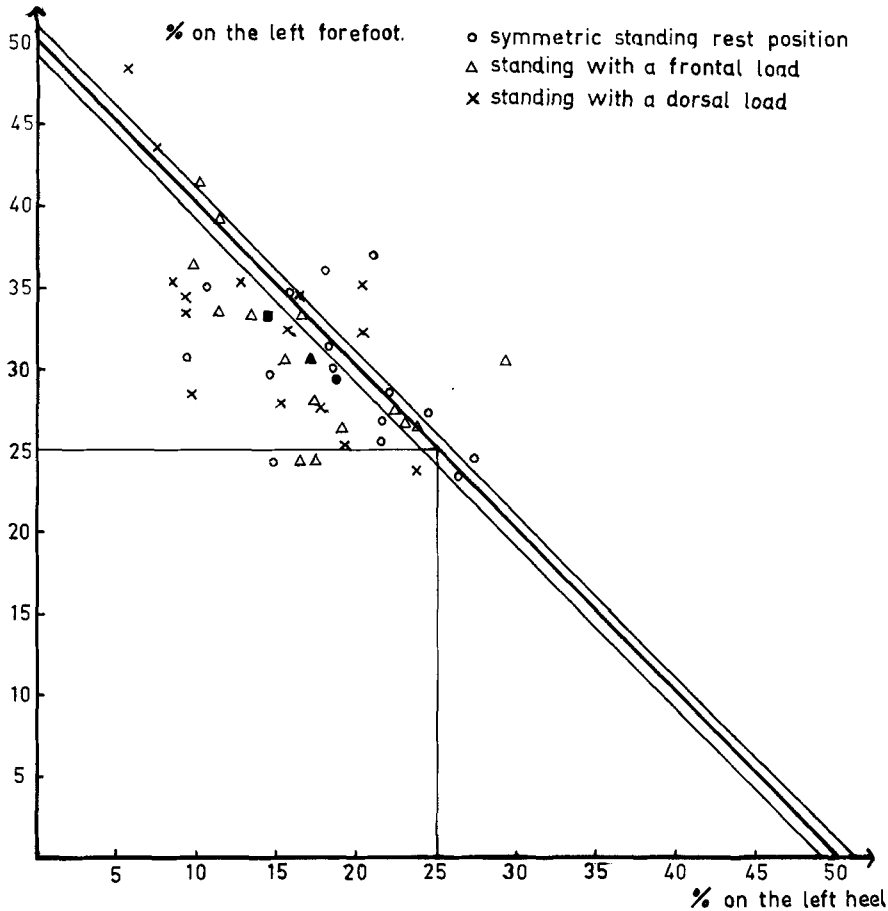


Fig. 2.

The percentage of the bodyweight carried by the left heel and left forefoot respectively, with the subject standing symmetrically with and without a load.

MUSCLE ACTIVITY

With the subject standing in a symmetric, rest position it was possible regularly to register activity in sacro-spinalis and soleus. Often, though not regularly, it was also possible to register activity in the ischiocrural musculature. On the other hand it was never possible to register activity in tibialis anterior, quadriceps or rectus abdominis. These results confirm earlier investigations (*Åkerblom 1948, Floyd & Silver 1950, 1955, Joseph, Nightingale & Williams 1955, Joseph & Williams 1957, Portnoy & Morin 1958, Carlsöö 1961*). Slight activity was registered in trapezius.

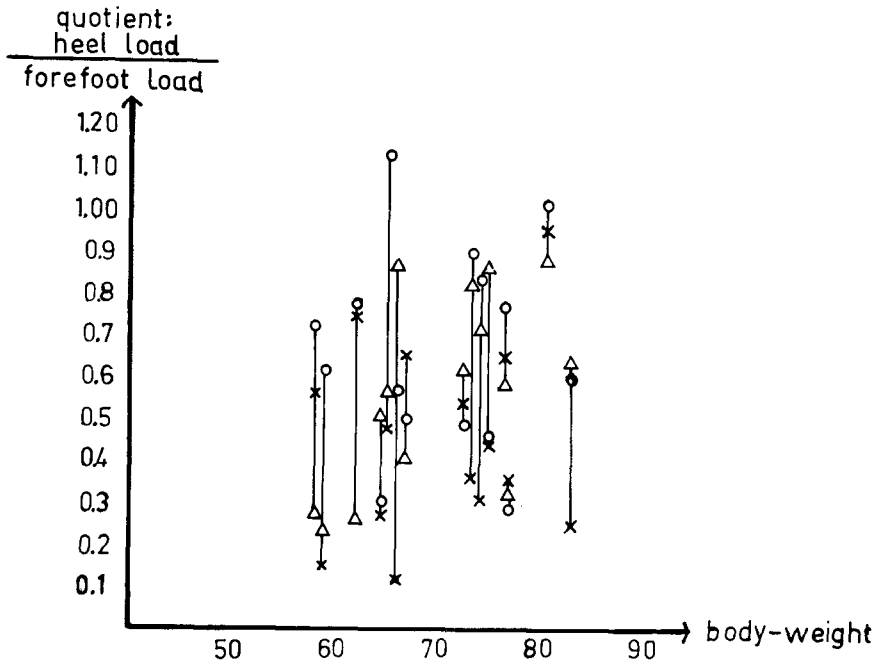


Fig. 3.

The diagram shows the changes in the ratio between the loads on the left heel and left forefoot when subject standing symmetrically without a load (o) receive a back load (o) or a front load (x).

Activity in trapezius, soleus and rectus abdominis was always more pronounced *with the back load* than without a load, whereas tibialis anterior and quadriceps were always passive.

With the back loaded, the ischiocrural muscles showed large variations. In certain cases the activity increased, in others it diminished, while in some cases the activity was much the same as in the standing rest position. Sacro-spinalis, on the other hand, displayed much less activity and in certain cases none at all.

No further report will be made here on the activity during walking of the muscles investigated, since this will be dealt with in a later paper and in another connection. However, it should be noted at this point that the activity in sacro-spinalis is considerably less when walking with a back load than without, in other words the conditions are analogous with the standing position (Fig. 4).

When standing *with the front load* the activity in soleus and trapezius

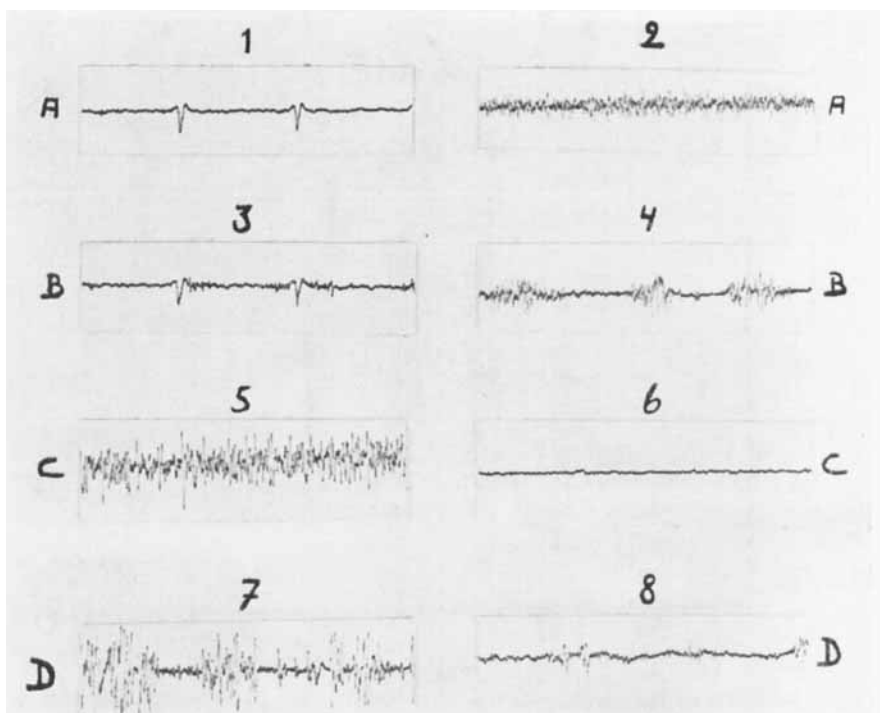


Fig. 4.

A: standing in rest position. B: walking without load. C: standing with back-load. D: walking with back-load. Records 1, 3, 5 and 7 from *m. rectus abdominis* and records 2, 4, 6 and 8 from *m. sacro spinalis*.

was much the same as with the back load. There was regular, pronounced activity in sacro-spinalis.

As with the back load, the ischiocrural muscles displayed individual variations. In some subjects they were pronouncedly active while in others they were passive. Rectus abdominis, tibialis anterior, and quadriceps remained completely inactive.

When the subjects altered their posture to counterbalance the back load, this change took the form mainly of increased thoracic kyphosis, flexion of the trunk at the hip joint (ca. 15°) and flexion of the talocrural joint (ca. 5°). If this position is adopted voluntarily without a back load then the activity in sacro-spinalis is always more pronounced than when standing in the upright, rest position without a load. A back load would thus seem to relieve sacro-spinalis. The explanation for this must be that the back load helps counterbalance the trunk's tendency

to fall forward, a function which falls chiefly to erector spinae in the upright symmetric rest position. If the subject was requested to lean even further forward as he stood with the back load, the activity in sacro-spinalis increased and became about the same as in the symmetric upright rest position. In other words, leaning forwards is a way of compensating for the backwards pull of a back load. This forward leaning, however, is not so pronounced that the muscle is loaded to the same extent as it is in the upright symmetric rest position. On the other hand, there was pronounced activity in rectus abdominis with the back load. At the same time as a back load relieves the deep muscles of the back it loads the abdominal muscles.

If the body leans forward without a back load from the symmetric standing rest position, the flexion in the hip joints is generally accompanied by extension in the talocrural joints and a slight flexion in the knee joints. With the back load in question, on the other hand, all the subjects stood with the crus bent forward somewhat, which partly explains the pronounced activity in soleus. It would seem that the individual variations in the activity of the ischiocrural musculature are connected with the degree of flexion at the hips. Further investigations revealed that if the subjects leant further forwards than normal, activity in the ischiocrural muscles always increased. If on the other hand they leant less than normal, activity in these muscles diminished or ceased altogether. It seems that when activity is present, the trunk's centre of gravity is in front of the transverse axis of the hip joints and that when there is no activity the line of gravity passes through or behind this axis. The ischiocrural muscles could also be relieved in the standing position with a back load by slightly bending the knees.

The distribution of weight between the different muscles within the ischiocrural group depends upon the position of the feet. The wider the angle at which the feet are set, the greater the load on biceps femoris: the smaller the angle, the greater the load on the medial muscles.

With the front load the effect on the body is compensated partly by increased lumbar lordosis and partly through a slight extension in the hip joints, backward tilting of the head and a backward inclination of the crus.

Since the front load accentuates the normal tendency of the trunk to fall forward when in an upright standing position, it follows that a weight in the hands increases the load on sacro-spinalis, at the same time as it relieves rectur abdominis. The fact that the load on the

ischio-crural muscles varied so much may be explained by the same reasons as are discussed above.

When, in an upright symmetric rest position, the body makes a slight backward extension in the talocrural joint, the activity in soleus diminishes because the line of gravity of the body approaches the transverse axis of this joint. Such a movement with a front load does not involve dorsal displacement of the centre of gravity. As mentioned earlier, the centre of gravity is instead displaced towards the forefoot. The moment arm of the load is increased and this, combined with the increased load, explains the pronounced activity in soleus. The pronounced activity in trapezius is naturally connected with the load on the shoulders, whether directly through the straps or indirectly via the arms.

S U M M A R Y

Muscle activity in the major postural muscles was studied electromyographically on fifteen students carrying different loads. The tests were made in the standing position and while walking. Investigations were also made into how the body-weight is distributed between the heel and forefoot in a symmetric standing position, with a front load held in the arms and with a back load attached to the shoulders.

R E S U M E

L'activité des muscles dans les principaux muscles de posture a été étudiée par électromyographie chez quinze étudiants portant différents poids. Les essais ont été pratiqués en position debout et pendant la marche. On a cherché par ailleurs à étudier comment se répartit le poids du corps entre le talon et l'avant-pied en position debout symétrique avec un poids frontal tenu dans les bras et avec un poids arrière attaché aux épaules.

Z U S A M M E N F A S S U N G

Die Muskeltätigkeit in den grösseren Haltungsmuskeln von fünfzehn Studenten, die verschiedene Lasten trugen, wurde mittels Elektromyographie untersucht. Die Proben wurden im Stehen und während des Gehens vorgenommen. Die Verteilung des Körpergewichtes zwischen der Ferse und dem Vorfuss bei einer symmetrischen, stehenden Stellung mit einer voran in den Armen gehaltenen Last und mit einer rückwärts an den Schultern befestigten Last wurde ebenfalls untersucht.

REFERENCES

- Akerblom, B.*: Standing and Sitting Posture. (Stockholm: A.B. Nordiska bokhandeln). 1948.
- Carlsöö, S.*: The static muscle load in different work positions: an electromyographic study. *Ergonomics*, Vol. 4, No. 3, p. 193-211, 1961.
- Floyd, W. F. & Silver, P. H. S.*: Electromyographic study of patterns of activity of the anterior abdominal wall muscles in man. *J. Anat.* 84: 132-145, 1950.
- Floyd, W. F. & Silver, P. H. S.*: The function of the erector spinae muscles in certain movements and postures in man. *J. Physiol.* 129: 184-203, 1955.
- Joseph, J., Nightingale, A. & Williams, P. L.*: A detailed study of the electric potentials recorded over some postural muscles while relaxed and standing. *J. Physiol.* 127: 617-625, 1955.
- Joseph, J. & Williams, P. L.*: Electromyography of certain hip muscles. *J. Anat.* 91: 286-294, 1957.
- Portney, H. & Morin, F.*: Electromyographic study of postural muscles in various positions and movements. *Amer. J. Physiol.* 186: 122-126, 1958.
- Wetzenstein, H.*: A new method for assessment of the static and dynamic weight-bearing of the foot. *Acta orthop. Scandinav.* 30, 2: 91-100, 1960.