Arm and Leg Girths of Industrial Workers During a Workday

Ülo Kristjuhan
Tallinn Technical University, Estonia

The aim of this study was to characterize changes in the limb perimeters of workers in various widespread occupations in Estonian industry. Investigations were carried out using special measuring instruments designed at Tallinn Technical University. The subjects under investigation consisted of 202 workers: garment workers, tailoring cutters, shoe factory operators, weavers, press operators, fitters, and drivers.

Investigations in the workshops showed that during the initial part of a work-shift perimeters often decreased. By the end of the shift, girths increased markedly (up to 1.6%), depending on the properties of the external load. There are many reasons for this change, with fatigue often playing an important role.

The exact measurement of the girths of human limbs is of great importance for collecting information in the field of ergonomics. It is possible to find effective preventive measures against fatigue and occupational diseases.

1. INTRODUCTION

The perimeter of a muscle increases during contraction. However, comparisons of the perimeter of a human limb or its part (a finger or toe) at rest at different times of a day also show that dimensions are not always the same and depend on the person's previous activity. Therefore, by measuring them, it is possible to draw conclusions about necessary ergonomic intervention.

Changes in the girths of upper and lower limbs reflect alterations in the volume of soft tissues (muscle, skin, the rest of connective tissue). The volume of a muscle depends on the volumes of muscle cells and the connective tissue between them, and on the local blood flow; in the other words, it depends on the volume of the intracellular, interstitial, and intravascular fluid, as about 55 to 60% of the adult human body consists of fluid.

For dozens of years, physiologists have studied factors causing the limb volume increase under laboratory conditions: at loads of relatively short duration, during 2 to 3 experimental days, and at some simple fixed body position (sitting, standing). The increase of lower leg and feet volumes that occurs at low physical activity as a result of heightened hydrostatic pressure in veins has been relatively well studied. Thus, Winkel and Jørgensen (1986) showed that after 8 hr of seated office work, the foot swelling was 4.8% in the case of no leg activity, 2.3% when the legs were moved freely, and 0.8% at the highest activity level. The increase of limb volume caused by other factors such as compression of veins, fatigue, and so forth has been studied less, although much attention has been paid to muscle fluid and electrolyte balance following exercise. In fact, industry and services involve a complex of factors influencing the motion of fluid over a period of years. The size of the perimeter changes has been studied sporadically.

One of the reasons for the inadequate investigation of the perimeters under field conditions is the lack of sufficiently precise, convenient, and time-efficient instruments for measuring limb perimeters in a worker during usual everyday activity.
The purpose of this study is to characterize the changes in the limb perimeters of workers in various widespread occupations in Estonian industry.

2. MATERIAL AND METHODS

Limb perimeters have been studied for more than 10 years. These investigations were commissioned by industrial enterprises to improve the workplace and working conditions. Subjective rating methods of fatigue in different regions of the human body as well as pedometers were used to get complementary information.

The participants in this investigation consisted of 202 workers in different occupations in light and building-materials industries of Estonia including garment workers, tailoring cutters, shoe factory operators, weavers, press operators, fitters, and drivers (Table 1).

The age range of the participants was from 18 to 56 (M age = 38). The age distribution of the groups was similar. According to sanitary and epidemiological stations, the working conditions of the participants were mostly satisfactory (apart from noise). Air temperature was 20 to 23°C, and air humidity was 40 to 60%. During the shift some workers were in a sitting position. The table below shows the changes in limb perimeters during the shift for different occupations.

**Table 1. Changes of Limb Perimeters During Shift**

<table>
<thead>
<tr>
<th>Occupation</th>
<th>Worker Group</th>
<th>Participants (N)</th>
<th>Region</th>
<th>% Change During Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garment worker</td>
<td>1</td>
<td>13</td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>23</td>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>1.3*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td>1.2*</td>
</tr>
<tr>
<td>Tailoring cutter</td>
<td>1</td>
<td>16</td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>25</td>
<td>4</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>30</td>
<td>7</td>
<td>1.0*</td>
</tr>
<tr>
<td>Shoe factory operator</td>
<td>1</td>
<td>17</td>
<td>5</td>
<td>1.0*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td>1.3*</td>
</tr>
<tr>
<td>Weaver</td>
<td>1</td>
<td>10</td>
<td>5.7</td>
<td>0.3</td>
</tr>
<tr>
<td>(less nervous tension)</td>
<td>2</td>
<td>11</td>
<td>5.7</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>11</td>
<td>6.8</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>0.1</td>
</tr>
<tr>
<td>Press operator</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>-0.2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>11</td>
<td>2</td>
<td>-1.1*</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>11</td>
<td>3</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>11</td>
<td>4</td>
<td>-0.7*</td>
</tr>
<tr>
<td>Fitter (ordinary shift)</td>
<td>1</td>
<td>11</td>
<td>5</td>
<td>0.6*</td>
</tr>
<tr>
<td>(privileged shift)</td>
<td>2</td>
<td>12</td>
<td>6</td>
<td>-0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>0.3</td>
</tr>
<tr>
<td>Driver</td>
<td>1</td>
<td>13</td>
<td>5</td>
<td>1.4*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td>1.0*</td>
</tr>
</tbody>
</table>

*Note. Regions are identified by the following: (1) middle part of the left forearm, (2) left wrist, (3) middle part of the right forearm, (4) right wrist, (5) middle part of the left lower leg, (6) distal part of the left lower leg, (7) middle part of the right lower leg, (8) distal part of the right lower leg.

*significant change from the beginning of the shift, p < .05.
position: garment workers, shoe factory operators, press operators, and drivers. Other workers were in a standing position: cutters, weavers, and fitters. The thigh veins of garment workers and shoe operatives were slightly compressed. The posture of weavers and fitters often changed during the shift. Work in the investigated occupations was not monotonous. The duration of tasks was usually longer than 2 to 3 min. The mechanical load was moderate, and sometimes low, as in the case of garment workers. As for garment workers, practically only the right upper limb took part in dynamic work. A continuous strain of the right lower leg muscles was often observed in weavers of Group 3. Usually, the workers did not use remarkable force: generally 10 to 20 N, but in some cases (drivers, fitters) several hundred N. The work of press operators, who all were female in this sample, was not easy during a shift: They performed up to $10^4$ motions, sometimes using force of 30 N. The workload of the Group 2 fitters was very low; several times during the shift they had nothing to do. The fitters of Group 1 and the drivers wore boots, and therefore the temperature of their lower legs and feet was higher.

As suitable methods for precise measurement (to within 0.2 mm) of the girths of human limbs could not be found, it was necessary to work out a practical method for measurement: Perimeter gauges that consisted of measuring tapes, loads, and calibrated rulers were used. The thickness of measuring tapes was from 0.05 to 0.08 mm, and the loads at their ends were from 3 to 10 g. When measured, the studied limb segment was supported so that it was horizontal. Measuring tape was put around the marked place of the limb so that the loads were hanging. The perimeter was measured with the help of a calibrated ruler and a magnifying lens. The measurement lasted 1 to 2 min. The standard deviation of the data did not exceed 0.2 mm under the same experimental conditions. For a subjective assessment of fatigue in different regions of the human body, analog–visual 15 cm scales (15 cm = 100% intensity) were used.

For estimating physical activity, the ShM-6 pedometers of the Pensa integrated plant Zarya were used. They counted paces from 80 to 140 steps/min. Healthy participants were studied and those who had musculoskeletal or cardiovascular disorders were excluded. Fitters and drivers were male; all other workers were female.

Investigations were carried out mostly near the workplace (within 10–15 m), usually three times (before work and 1–1.5 hr after the beginning and at the end of a shift) during the morning work shift (7:00 a.m.–3:30 p.m.). The second measurement was taken before lunch. For the comparison of the perimeter measurements during the shift, t-tests were used. A Spearman rank-order correlation was calculated between the objective and subjective variables; P = .05 was chosen as the level of significance.

3. RESULTS

The results of the investigations in the workshops (Table 1) show that during the initial period of a shift the perimeters did not change much. They often decreased, especially in the wrist-regions of press operators and in the distal part of the lower legs of fitters. Towards the end of a shift the limb girths mainly increased, up to 1.4% in the middle part of the lower leg of the bus drivers and up to 1.3% in the right wrist of the garment workers. The increase of the limb perimeters is more striking in light of comparison between the data obtained after the initial period of the shift with the data obtained at the end of the shift.

On average, general physical activity was 2,100–2,300 footsteps during a shift for sitting-position occupations and tailoring cutters; it was 5,000 to 5,900 footsteps for fitters and weavers. The correlation coefficient was 0.75 between the increase of limb perimeters and the intensity of the fatigue sensation of tailoring cutters.

4. DISCUSSION

At the beginning of a shift, perimeters often decrease. Various factors are probably contributory. One must take into account that before the beginning of a shift the participants were engaged in different activities (dressing, eating, housework, going to work) for 1 to 1.5 hr. Therefore, the decrease of girths should not be explained only as a result of improving vein
and lymph return by muscular contractions at the beginning of work. The perimeter decrease was hardly a result of intensive perspiration (diminishing the quantity of water in the organism), as the microclimate was close to optimum for work. Apparently some of these changes in the girths could be explained by an improvement in the vasomotor regulation. In those cases where no decrease in the volume was observed, factors that contribute to the increase in the perimeter by the end of the shift apparently compensate for this decrease.

In most cases, the perimeter increase did not exceed 1.5%. Relatively big changes sometimes occurred both for the sitting and for the standing posture. In the subject literature, bigger changes have often been noted. Thus, Ryzhov (1976) showed that for young spinners the increase in the lower leg perimeter during the shifts was 0.4 cm, and after 15 to 20 years of service it was 1.3 to 1.7 cm (3-5%). Pathology of veins apparently causes these changes in older workers. Bendix, Winkler, and Bojsen-Møller (1987) found 4.5% to 5.0% foot swelling after 3 hr of sitting with absolutely relaxed leg muscles. Their situation essentially differs from work in the sitting position examined in this study, where in addition to little leg activity workers sometimes walked during a shift bringing things, visiting the canteen, and so forth.

There are many possible reasons for the increase in the perimeters at the end of a shift:

- increased hydrostatic pressure in the vessels of legs and feet,
- inactivity of limb muscles,
- thermal increase,
- drinking and eating during a shift,
- compression of veins,
- fatigue.

In the sitting position, the distance between the base of a worker’s heart and the floor is 90 to 110 cm; in the standing position it is 130 to 140 cm. Therefore, the hydrostatic pressure in the blood vessels of the lower limbs is heightened. “Inactive” sitting or standing, that is, lack of “muscle pump,” contributes to the pressure rise and to filtration in capillaries. Introducing motions at that moment has positive as well as negative effects. Some effects of slight leg activity promote and others prevent oedema formation in the feet (Noddeland, Aukland, & Nicolaysen, 1988). It seems unlikely that small foot movements can significantly reduce capillary fluid filtration. They can refill the capillaries with arterial blood and thus increase the functional area available for filtration.

It is a well-known fact that elevated temperature dilates blood-vessels and increases leg and feet volume as well as fatigue. In some worker groups this influence must be remarkable, for example, in drivers who wear boots that contribute to an increase in skin temperature. Drinking and eating probably do not contribute to an increase in the perimeters of the worker groups studied. Drinking some liquid (lemonade, tea, coffee, etc.) or eating (soup) does not increase the volume of a muscle very much. Thus, Matsubara and Matsuda (1969) showed that consuming a quantity of water equal to 1% of body weight (600–700 ml) increases the volume of the lower leg by less than 0.6% (7.2 ml for the volume of 1,340 ml) and, therefore, the girth by about 0.3%. At the same time, perspiration and urine secretion diminish the quantity of water in the organism. As a result, the loss of water during a shift is roughly the same as its use.

The connection between fatigue and increase in the limb volume has been known since the beginning of this century. Atzler and Herbst (1923) found that walking, higher temperature, and unfitness increased the volume of the lower extremities. Later it was shown that these volume changes remained for some hours, and the more intensive the work, the more lasting the changes were (Livingstone, 1961).

The influence of fatigue on the perimeters is two-phased at heavy loads: the second phase of swelling of the muscle occurs later with muscle ache (Brendstrup, 1962). This problem has also been studied for the light industry. In 1983, Ryzhov and Tkhostovovsky showed that the correlation coefficient between the number of footsteps and the increase in the volume of the lower leg was 0.46 (p < .01) in weavers. They also pointed to an interrelation between volume
changes and the feeling of fatigue. The results of this study confirm the correlation between the volume changes and fatigue sensations.

When considering various occupations separately, a number of interesting facts emerge. The increase of the perimeters of lower legs of garment workers is relatively high. The same is true for shoe factory operators performing similar work. Apparently, a constant sitting posture is an essential factor. Also, the shape of the chair, a relatively sharp front edge with a small curvature radius, plays a certain role.

Among the Group 2 weavers, whose work was similar to Group 1 but with less nervous tension, the changes of girths were smaller. In Group 3 weavers, the changes in the right lower leg were relatively large. Apparently the specificity of this work (on tiptoe) exerts some influence.

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An essential decrease in the perimeters of both wrists (0.7–1.1%) for press operators during the initial period of a shift is probably connected with the heavy load in this region and with chronic fatigue. Apparently, during the first hours of a shift, metabolism improves in these tissues.

Among the Group 1 fitters, the changes were smaller after a shift at the end of which bonuses were paid. Some researches (Maspers, Ekelund, Björnberg, & Mellander, 1991) have shown the protective role of sympathetic nerve activity in the regulation of fluid filtration in the skeletal muscle. For fitters of Group 2, the girth of the middle of the right forearm decreased during the shift. This may have been caused by low work intensity on the day of the investigation.

5. CONCLUSIONS

These results show that at the beginning of a shift the girths of the workers’ limbs often decrease, mainly by up to 0.7%, but sometimes they also increase. By the end of a shift the perimeters increase. This increase depends to a large extent on the occupation, and, in most cases, it does not exceed 1.6%. There are many possible causes for this change—frequent ones being muscle inactivity and fatigue.

Measurements showed that the perimeter gauges and calibrated rulers were practical. These findings suggest that by measuring the girths of limbs during a work shift, it is possible to find adequate preventive measures for fatigue and occupational diseases. It would be interesting to study the changes of these perimeters in greater detail.

REFERENCES


