Advances in Industrial Ergonomics and Safety VI
Edited by F. Aghazadeh
Taylor & Francis, 1994

IS A SIT-STAND SEAT AN APPROPRIATE ALTERNATIVE IN STANDING WORK SITUATIONS?

H.H.E. Oude Vrielink, S.G.M. Cloosterman, J.A. van der Bunt, R.M.A. Krijnen*, J.H. van Dieën

Institute for Environmental and Agricultural Engineering (IMAG-DLO), P.O. Box 43, NL-6700 AA Wageningen, and
*Department of Dermatology, Free University Academic Hospital, Amsterdam, The Netherlands

Conveyor belt work in Dutch horticulture often demands for whole day standing. Because sitting postures cannot be adapted, mainly due to technical limitations, use of a sit-stand seat is recommended by ergonomists. The effect of its use on the muscles of the shoulder-neck region, low back and lower limbs, and on lower leg swelling during a 4 hour simulated work task, is compared with that during the same task performed standing. Electromyography and force measurements demonstrated a significant development of fatigue after both tasks. For the trapezius muscle only, indications were found that fatigue development was more pronounced after the seated task. Furthermore, this task resulted in a significantly greater lower leg swelling compared to standing. These data do not support the use of a sit-stand seat as an alternative for standing. However, since it has been reported to have a positive effect on the lumbar spinal structures, it is advised to use the sit-stand seat alternatingly with standing.

INTRODUCTION

Considerable changes in the nature of human labour have occurred in the last few decades. Mechanisation and automation have reduced the contribution of physically demanding types of work. At the same time, a tendency towards longer duration of monotonous work loads, e.g. in repetitive tasks, can be recognised. This shift is accompanied by an increasing occurrence of previously less frequent types of health problems like repetitive strain injury (RSI). Indications have been found that the cause of these problems is related to exhaustion and overload of local musculoskeletal structures (Veiersted *et al.*, 1993).

Comparable changes in the nature of work are seen in Dutch horticulture. For example, introduction of a conveyor belt in flower production forced many workers involved to stand for the greatest part of the day. This type of work is notorious because the limited space below the conveyor belt does not allow sitting postures. In these situations application of a sit-stand seat is often recommended as an alternative for standing in order to relieve the load on both the back and legs. Eklund and Corlett (1987) demonstrated a sit-stand seat to reduce the load on the spinal structures, compared to a conventional chair. In addition, because up to 60% of the body weight is beared by the seat, legs and feet are unloaded as well (Windberg & Rademacher, 1983). However, the latter authors also observed a slight increase in reaching distance. Farther reaching of only 10 cm increases the load on the shoulder-neck region by more than 25%, as estimated using electromyography (EMG; Takala & Viikari-Juntura, 1991). In addition, the load on the back muscles may increase due to a possible increased trunk flexion (Habes, 1984). Finally, activity of the calf muscles when using a sit-stand seat is almost absent. This hampers the return of blood and interstitial fluid from the legs to the heart, and contributes significantly to the swelling of feet and lower legs (Winkel, 1985). On the long term the development of various pathological phenomena (see Hebeda *et al.*, 1993) might be favoured by this.

In order to evaluate the benefits, if any, of application of a sit-stand seat in a standing work situation, effects (in terms of fatigue development, discomfort rating and tissue swelling) on the shoulder-neck region, low back and lower legs were investigated in a laboratory during a simulated standing work situation. Except for the discomfort rating, the measurements necessarily interrupted the task. Fatigue development was tested by periodically performed maximal voluntary contractions (MVC). Besides, changes in EMG parameters during submaximal isometric test contractions were taken as indicators of muscular fatigue.

MATERIALS AND METHODS

Subjects

The experiments were performed on 6 healthy men (age: 23.7 ± 2.1 years (mean ± s.d.); weight: 75.7 ± 6.1 kg; height: 1.83 ± 0.02 m). All subjects were right handed. The subject's elbow height and hip height were used to individually adjust the experimental set-up. The subjects were informed about the goal and possible risks before they gave their voluntary consent to participate in the experiments.

Set-up

Each subject performed a repetitive task by making bunches of 10 tulips, conveyed on a belt of 60 cm deep immediately in front of the subject. The belt height was set at 10 cm below the subject's elbow height, either when standing or when sitting on the sit-stand seat. The bunches were put on a second conveyor belt, 20 cm above the first belt and approximately 60 cm in front of the subject, transporting the bunches to the starting point of the first belt where they were separated to follow the cycle again. The time needed per bunch was approximately 13 s.

The sit-stand seat used was a pendulum-type (Safimex, Dordrecht, NL). Its height was set at 10 cm below hip height.

Test contractions were performed in a sitting position (hip and knee angle both 90°). In this postion a home-built chair allowed for rapid isometric testing of bilateral shoulder elevation, back extension and ankle extension of the right leg. Forces produced were recorded by strain gauges and fed back on-line via a PC screen.

Measurements

For each MVC test, the subject was asked to build up the force from zero to maximal in approximately 10 s, whereafter the maximum level was sustained for 2 s. Forces recorded during the MVC procedure were stored digitally on-line at a sample frequency of 1000 Hz.

Electrical activity (EMG) of the right trapezius, left and right multifidus and right soleus muscles during submaximal (10% MVC) test contractions (target force) was measured using Ag-AgCl surface electrodes (Hellige, Freiburg, GER). EMG signals of approximately 5 s were amplified, filtered (high-pass: 0.3 Hz, low-pass: 300 Hz), on-line digitized and stored on a PC at a sample frequency of 1000 Hz. Skin temperature over each of the muscles mentioned was measured throughout the experiment (Ellab, Rødovre, DK).

Lower leg swelling was measured with an optical leg volume meter (Bösl Medizintechnik, Aachen, GER), described in more detail by Hebeda and colleagues (1993). The apparatus examines a length of 30 cm between knee and ankle, and calculates the volume in arbitrary units assuming a circular transsectional shape of the lower leg. Of all subjects only the left lower leg was investigated. A foot-support ensured a constant position of the leg during the measurements throughout the experiment. During each test trial, the leg volume measurement was repeated 5 times.

Local discomfort was rated per body part using the diagram of Corlett and Bishop (1976). Per body part the degree of discomfort was rated using the 10-point scale of Borg (1982). Subjects were asked to mention the body parts, if any, in which they experienced discomfort and the intensity of it per part mentioned.

Procedure

One experiment lasted 4 hours. Each of the subjects was asked to perform both a standing and a seated task on 2 different days. Half of the subjects started standing. Before an experiment, 2 attempts to produce a MVC for the 3 muscle groups were made. The attempt with the highest force level was considered the MVC. This was followed by maintaining the target force during which EMG was sampled. Pilot studies had indicated the target level to concur with the level of activity during the task. Furthermore, lower leg volume and local discomfort were tested. These measurements were repeated every hour, for which the bunching task was interrupted.

Data analysis

EMG data were analysed off-line for the rectified averaged amplitude (RA-EMG) and frequency content (mean power frequency, MPF) of the signal. Changes in MVC, EMG amplitude, EMG frequency content, and lower leg volume in time, normalized to their initial values, were tested using Wilcoxon matched-pairs signed-rank test, as well as the differences between the interventions. Significance was expected at the $p < 0.05$ level (one-tailed).

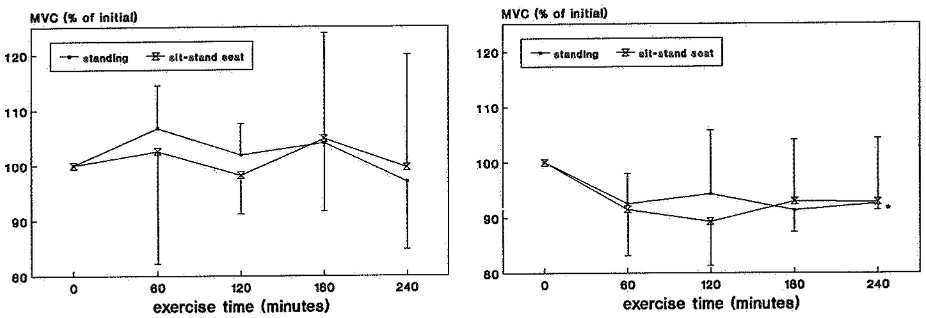

Figure 1. Changes in maximal voluntary contraction force (MVC) in time for shoulder elevation (left panel) and back extension (right panel) in the standing and seated experimental situation (* = significantly different from t=0; 1 S.D. is indicated).

RESULTS

Muscular fatigue

All subjects completed both experimental trials. The MVC for shoulder elevation (750N ± 12N, mean values for both interventions) was not affected in the standing task, nor when a sit-stand seat was used. Figure 1 (left panel) illustrates that the difference between both interventions was not significant. Note the large variation between the subjects. In contrast, back extension force (unfatigued: 1358N ± 10N) was significantly affected by the standing protocol and decreased by 7.5% (± 1.2%) after 4 hours ($p < 0.05$). This is illustrated in figure 1 (right panel). The decrease during the seated experiment seems comparable but, due to the large variation, did not reach the level of significance. Comparison of the matched data per subject, however, revealed that no difference existed between all conditions. For ankle extension, initial MVC (1306N ± 20N) did not change for both experiment-types (mean final value: 1320N ± 27N).

Trapezius EMG amplitude during the target test contractions showed a significant increase to 163% (± 33%) after 4 hours when using a sit-stand seat (figure 2, left panel). No change was seen in the standing experiment. The differences between both conditions were significant from the first hour. In contrast, the frequency content appeared not different between the experiments (figure 2, right panel). The observed increase in the latter after 1 hour could not be explained by a warming-up effect of the muscle, since skin temperature over the muscle remained constant (33.3°C) throughout both types of experiments.

EMG amplitude of both multifidus muscles tended to increase (final values: 112% ± 22%, standing, and 120% ± 35%, seated) but this did not reach the level of significance. No differences were observed between the left and right side, nor between the 2 interventions. For both muscles the frequency content did not change in any situation.

Also the soleus muscle did not demonstrate a change in target EMG amplitude, neither during standing nor when seated. However, the MPF showed a significant non-linear decline in time to 92%

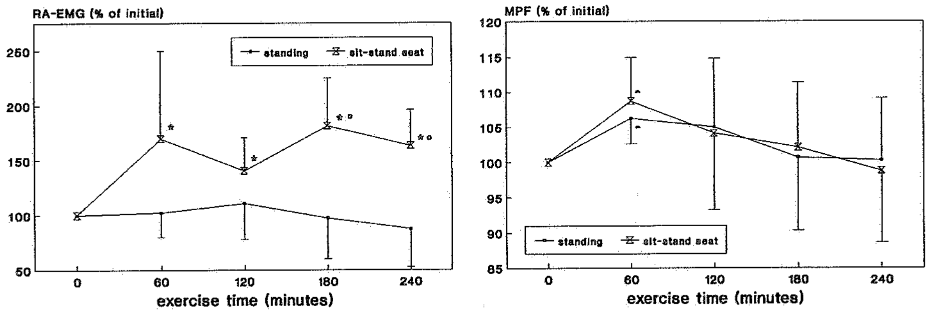

Figure 2. Changes in time of the EMG amplitude (RA-EMG; left panel) and EMG frequency content (MPF; right) of the trapezius muscle during the 2 tasks (* = significantly different from t=0; o = different from standing; ^ = different from t=240).

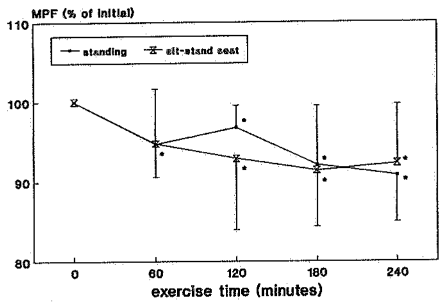

Figure 3. Changes in EMG frequency content (MPF) in the soleus muscle for the standing and seated situation (* = significantly different from t=0; 1 S.D. is indicated).

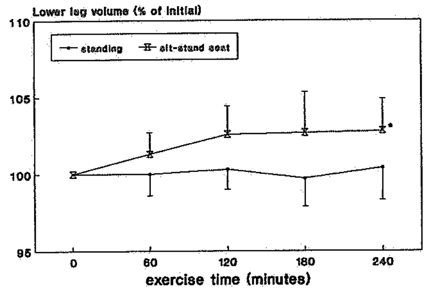

Figure 4. Swelling of the lower leg in time during standing and in seated situation (1 S.D. is indicated; * = significantly different from t=0 and from standing).

(± 8%) after 4 hours. Figure 3 shows the lack of difference between the 2 interventions.

Lower leg swelling

The results are shown in figure 4. The standing work task did not result in a change in lower leg volume. However, when a sit-stand seat was used, the volume increased to 102.8% (± 2.1%) of initial at the end of the experiment, which was a significant change. The difference between both interventions appeared to be significant as well.

Local discomfort

The subjects completed their tasks without complaints in most of their body regions. When complaining, 1 to 5 body regions were involved (standing: neck, low back, lower legs and feet; seated: neck, shoulder, upper back and low back). Discomfort ratings varied from just noticable to moderate. For none of the body regions involved, a systematic change in discomfort rating was observed. In addition, the total number of body regions causing any degree of discomfort did not increase in time during both types of experiments, nor differed between both.

DISCUSSION

The present results demonstrate that a 4 hour monotonous bunching task, performed either standing or using a sit-stand seat, is enough to evoke indications of muscular fatigue in the shoulder-neck region, low back and lower legs. Fatigue developed most clearly when a sit-stand seat was used. On the basis of this finding and of the observed difference in lower leg swelling, the use of a sit-stand seat as an alternative for standing cannot unequivocally be recommended.

The standing and seated work situation were compared using various measurement techniques. For the larger part, these techniques concentrated on muscular parameters. The comparison was based upon MVC trials, yielding fatigue development by definition, and on fatigue-related phenomena: changes in the EMG signal. The primary argument was that the preferable intervention would be the one resulting in the least fatigue development. The measurements mentioned above have been reported to be affected by low-intensity exercise of long duration. Sustained isometric contractions of the quadriceps muscle at only 5% MVC resulted in a 12% decrease of the MVC after 1 hour (Sjøgaard *et al.*, 1986). Furthermore, a repetitive task of the calf muscle group at an intensity of 10% MVC resulted in a MVC decline of 25% after 4 hours (Oude Vrielink & Van Dieën, 1993). Besides, many low-intensity endurance experiments demonstrate increases in EMG amplitude and a decline in EMG frequency content (Fallentin *et al.*, 1986; Christensen & Fuglsang-Frederiksen, 1988; Krogh-Lund, 1993), indicating the homeostasis being disturbed by the task.

The measures related to muscular fatigue (MVC, EMG amplitude, and EMG frequency content) did not behave uniformly when the different body regions are compared. E.g. for the back muscles a decline in the MVC was observed while the EMG frequency content did not change. In the calf muscle group the opposite occurred. Several explanations can be generated for these non-uniform changes in fatigue parameters. Firstly, since force output seldomly is developed by one single, homogeneously activated muscle, the relative contribution of each of the activated muscles to the task compared to the MVC is unknown (the muscle-equivalent problem; see Perry and Bekey, 1981). Secondly, the number and type of motor units involved in a low-intensity task and a MVC attempt are different. It is hypothesized that a low-intensity task almost exclusively uses small type I motor units (Milner-Brown *et al.*, 1973), and it is still under question whether, even in a fatigued situation, recruitment of the large type II motor units may occur (see e.g. Fallentin *et al.*, 1993). The latter motor units, however, contribute for the greatest part to the maximal force output which, hence, might be hardly affected. At the same time motor units involved in the task may be severely fatigued, expressed e.g. by changes in EMG parameters during task performance or test contraction. Thirdly, different mechanisms underly the changes in EMG parameters amplitude and frequency content. The latter generally is observed to decline during prolonged or intense muscle use. Mechanisms responsible for this are, amongst others, slowing of the action potential conduction velocity over the muscle fiber membrane and synchronisation of motor unit firing (see e.g. Kranz *et al.*, 1983). An increase in EMG amplitude in part may be explained by a reduction in the frequency content. It additionally may be the result of an increased muscle fiber activation, a compensatory reaction of the central nervous system for a failure in the force generation (Fallentin *et al.*, 1993), which is not necessarily occurring in parallel with action potential slowing.

A remarkable phenomenon was found in the trapezius muscle, in which an increase of the frequency content was seen after 1 hour whereafter a continuous decline. One possible explanation is a warming-up effect of the muscle due to task performance: an increase in muscle temperature will lead to an increase in EMG frequency content (Petrofsky & Lind, 1980). In the present experiments, the skin temperature immediately over the trapezius muscle was measured to get an impression of an eventual muscle temperature change. However, these data on skin temperature must be interpreted with care. Muscle use results not only in heat production, responsible in part for an eventual warming-up of the skin. It also evokes vasodilation of vessels in the skin and an increased perspiration. The latter phenomenon results in cooling of the skin and might compensate for any warming-up effect. Therefore, an unchanged skin temperature may not be extrapolated to an unchanged temperature of the underlying muscle.

Measurement of the lower leg volume showed a significant increase of 2.8% after 4 hours in the seated experiment only. The observed swelling is comparable with that measured in the foot during 'inactive sitting' (4.8% after 8 hours: Winkel and Jørgensen, 1986). The latter authors ascribe the magnitude of tissue swelling to the venous hydrostatic pressure in combination with the absence of a musculovenous pump. This was also the case in the present experiments when a sit-stand seat was used: the subjects were observed to stretch their knees almost completely, having both of the calf muscles completely relaxed. In contrast, in standing position the subjects could move over short distances and frequently interchange their supporting leg. It probably was this active squeezing of venous blood back to the heart that prevented significant swelling of the lower leg in the 4 hour observation period. In this respect, it is worth mentioning the study of Winkel and Jørgensen (1986), in which the foot swelling mentioned above was considerably decreased when sitting was combined with frequent leg activity.

The results discussed thus far do not support the view that use of a sit-stand seat is an improvement of a standing work situation. However, Eklund (1986) demonstrated that a sit-stand seat may contribute to an unloading of the spinal structures of the low back. A possible explanation mentioned by this author is enhancement of a less kyphotic curvature of the lumbar spine. Combining these beneficial effects with the present data, it is advised to use a sit-stand seat not as an alternative for, but alternatingly with standing. This conclusion is in line with an alternative strategy for improving work situations (Vøllestad, 1993) by stimulating variation in the loads for different body regions.

ACKNOWLEDGEMENTS

The authors are indebted to A.A.J. Looije and J. van Galen for their technical assistance.

REFERENCES

Borg, G.A.V., 1982, Psychophysical bases of perceived exertion. Medicine and Science in Sports and Exercise, 14, 377-381.

Christensen, H. and Fuglsang-Frederiksen, A., 1988, Quantitative surface EMG during sustained and intermittent submaximal contractions. Electroencephalography and clinical Neurophysiology, 70, 239-247.

Corlett, E.N. and Bishop, R.P, 1976, A technique for Assessing Postural Discomfort. Ergonomics, 19, 175-182.

Eklund, J.A.E., 1986, Industrial seating and spinal loading. Thesis, Linköping, University of Technology, Department of Industrial Ergonomics).

Eklund, J.A.E. and Corlett, E.N., 1987, Evaluation of spinal loads and chair design in seated work tasks. Clinical Biomechanics, 2, 27-33.

Fallentin, N., Sidenius, B. and Jørgensen, K., 1985, Blood pressure, heart rate and EMG in low level static contractions. Acta Physiologica Scandinavica, 125, 265-275.

Fallentin, N., Jørgensen, K. and Simonsen, E.B., 1993, Motor unit recruitment during prolonged isometric contractions. European Journal of Applied Physiology, 67, 335-341.

Habes, D.J., 1984, Use of EMG in a kinesiological study in industry. Applied Ergonomics, 15.4, 297-301.

Hebeda, C.L., Boer, E.M. de, Verburgh, C.A., Krijnen, R.M.A., Nieboer, C. and Bezemer, P.D., 1994, Lower limb volume measurements: standardization and reproducibility of an adapted optical leg volume meter, Phlebology, (in press).

Kranz, H., Williams, A.M., Cassell, J. Caddy, D.J. and Silberstein, R.B., 1983, Factors determining the frequency content of the electromyogram. Journal of Applied Physiology (Respiratory, Environmental and Exercise Physiology), 55, 392-399.

Krogh-Lund, C., 1993, Myo-electric fatigue and force failure from submaximal static elbow flexion sustained to exhaustion. European Journal of Applied Physiology, 67, 389-401.

Milner-Brown, H.S., Stein, R.B. and Yemm, R., 1973, The orderly recruitment of human motor units during voluntary isometric contractions. Journal of Physiology (London), 230, 359-370.

Oude Vrielink, H.H.E. and Dieën, J.H. van, 1993, Evaluation of fatigue in a heterogeneous muscle group during low level repetitive activity. In: Advances in Industrial Ergonomics and Safety V, edited by R. Nielsen and K. Jørgensen, (London, Taylor & Francis), pp. 7-13.

Perry, J. and Bekey, G.A., 1981, EMG-force relationships in skeletal muscle. CRC Critical Reviews in Biomedical Engineering, 4, 1-22.

Petrofsky, J.S. and Lind, A.R., 1980, The influence of temperature on the amplitude and frequency components of the EMG during brief and sustained isometric contractions. European Journal of Applied Physiology, 44, 189-200.

Sjøgaard, G., Kiens, B. Jørgensen, K. and Saltin, B., 1986, Intramuscular pressure, EMG and blood flow during low-level prolonged static contraction in man. Acta Physiologica Scandinavica, 128, 475-484.

Takala, E.-P. and Viikari-Juntura, E., 1991, Loading of shoulder muscles in a simulated work cycle: comparison between sedentary workers with and without neck-shoulder symptoms. Clinical Biomechanics, 6, 145-152.

Veiersted, K.B., Westgaard, R.H. and Andersen, P., 1993, Electromyographic evaluation of muscular work pattern as a predictor of trapezius myalgia. Scandinavian Journal of Work Environment and Health, 19, 284-290.

Vøllestad, N.K., 1993, Muscle fatigue and activation during low force contractions - consequences for intervention studies. In: Advances in Industrial Ergonomics and Safety V, edited by R. Nielsen and K. Jørgensen, (London, Taylor & Francis), pp. 125-129.

Winkel J., 1985, On foot swelling during prolonged sedentary work and the significance of leg activity. Arbete och Hälsa, 35 (Stockholm, Liber Truck AB).

Winkel, J. and Jørgensen, K., 1991, Significance of skin temperature changes in surface electromyography. European Journal of Applied Physiology, 63, 345-348.

Windberg, H.-J. and Rademacher, U., 1983, Grenzen und Möglichkeiten des Einsatzes von Stehhilfen. Zeitblatt für Arbeitsmedizin, 33, S192-S198 (abstract in English).