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Subjective, physiological and biomechanical response to prolonged manual work performed standing on hard and soft surfaces

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ORIGINAL ARTICLE

Pascal Madeleine · Michael Voigt · Lars Arendt-Nielsen

Subjective, physiological and biomechanical responses to prolonged manual work performed standing on hard and soft surfaces

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Abstract The aim of this laboratory study was to examine the subjective, physiological and biomechanical responses to prolonged light repetitive manual work during standing on soft (polyurethane standard mat) and hard (aluminum casting) surfaces. The subjects stood on the hard (10 subjects) and on the soft surfaces (11 subjects) for 2 h. Intensity of unpleasantness, shank circumference, electromyograph (EMG) activities from the right soleus and tibialis anterior muscles, mean amplitude and total angular displacement around the left and right ankle in the saggital plane, centre of pressure (CoP) displacement in the frontal and saggital planes, calf surface temperature, and pain intensity in experimentally induced muscle pain were recorded. Maximal voluntary contraction and fatigue tests were performed before and after the 2 h experiment. Standing on a soft surface caused a lower intensity of unpleasantness. During standing on a hard surface compared to a soft one the results showed an enhanced swelling of the shank, an increased EMG activity (right soleus muscle) of the lower leg, a greater amplitude and total angular displacement, and a larger CoP displacement in the frontal plane. Indications of more pronounced muscle fatigue while standing on the hard surface were also noticed. After 105 min, experimental muscle pain was elicited by injecting hypertonic saline. The intensity of the induced pain was lower when standing on the soft surface. Amplitude, angular distance and CoP displacement showed a tendency to be greater after injection of the hypertonic saline. It was found that the experimentally induced pain influenced postural activity, underlining central interactions between proprioceptors and nociceptors. The results highlighted a higher feeling of comfort when standing on the soft surface. In addition, postural activity was lower when standing on the soft surface, but the activity was sufficient to prevent swelling of the lower legs.

Key words Repetitive light work · Standing · Soft surface · Hard surface · Subjective, physiological and biomechanical responses

Pascal Madeleine (✉) · Michael Voigt · Lars Arendt-Nielsen
Center for Sensory-Motor Interaction (SMI),
Aalborg University, Fredrik Bajers Vej 7 Bldg D-3,
DK-9220 Aalborg East, Denmark

Introduction

More than a quarter of the workforce have indicated that they work in painful or tiring positions for at least half of the time (First European Survey on the Work Environment 1991–1992). Work done while maintaining a relatively fixed erect posture has been shown to play a role in the development of low-back pain and disorders of the extremities (Sommerich et al. 1993). It has been reported that the impact of these disorders on social insurance, absenteeism, productivity and well-being is substantial (Marras et al. 1995; Sommerich et al. 1993). An increasing number of industrial countries is giving the prevention of musculoskeletal disorders (MSD) a high priority.

It has been demonstrated that the handling of heavy loads is an important factor in the development of MSD (Sommerich et al. 1993), as is easily understood from a biomechanical point of view. Paradoxically, repetitive manual work with low loads also plays an important role in the development of MSD.

Substantial ergonomic work has been done to minimise the risks of MSD (Marras et al. 1995). Mats are often used in industries where dynamic standing is required, but the subjective, physiological and biomechanical responses during standing on a soft compared to a hard surface while working manually for prolonged periods have still not been clarified. Subjective responses have been described and it has been generally agreed that handling material manually is felt to be more comfortable when standing on a soft surface compared to a hard one (Jørgensen et al. 1993; Kim et al. 1994; Rys and Konz 1990, 1994; Zhang et al. 1991).

Foot volume, foot and calf temperature, electromyograph (EMG), heart rate, force platform and video recordings have been used to assess the physiological and biomechanical effects of soft mats (Brantingham et al. 1970; Cook et al. 1993; Jørgensen et al. 1993; Kim et al. 1994; Kim and Chung 1995; Rys and Konz 1990, 1994; Stuart-Buttle et al. 1993; Zhang et al. 1991). However, physiological and biomechanical findings related to standing on a soft or a hard surface are still controversial. As long as a large proportion of the working population needs to work on light repetitive tasks in an erect posture it is important to investigate the effects of the surface on which they stand on the sensory-motor system.

To study the interaction between muscle pain and movement, it has been shown that muscle pain can be elicited in healthy subjects by intra-muscular injection of hypertonic saline (Arendt-Nielsen et al. 1995; Svensson and Arendt-Nielsen 1995a; Svensson et al. 1995b). As chronic pain is a common work-related disease, it is of basic interest to investigate if increased muscle pain per se does cause changes in postural activity. In parallel, very little is known regarding the patho-physiological mechanisms related to MSD development. It has been suggested that increased muscle load may cause an accumulation of metabolites in muscles (Edwards 1988). An accumulation of metabolites has been reported to lead to the activation of nociceptive muscle afferents which may result in muscle hypersensitivity (Djupsjöbacka et al. 1994, 1995; Johansson et al. 1993). Thus, a study of interactions between muscle pain and motor control after prolonged work can enhance the general knowledge concerning the underlying phenomena leading to chronic muscle pain.

The aims of this study were:

1. To examine the differences among the subjective, physiological and biomechanical responses during standing on soft compared to hard surfaces while engaged in prolonged light repetitive manual work
2. To evaluate the muscle sensitivity to experimentally induced muscle pain after prolonged standing on the two surfaces and to test how experimentally induced muscle pain affects the postural activity.

Methods

Subjects

A group of 13 healthy and unmedicated male volunteers participated in the study [mean age 23.3 (SD 0.5) years, body mass 78.1 (SD 2) kg, height 181 (SD 2) cm]. Some of them took part in the experiment twice (standing on both soft and hard surfaces with a 1-week interval). Of all the subjects 10 of them stood on a hard surface and 11 on a soft surface. The subjects were in good health and had no history of injuries or back pain. The study was approved by the local Ethics Committee and informed consents were obtained from all the participants. The study was conducted in conformity with the Declaration of Helsinki.

Work task

A realistic work task was designed, i.e. the subjects were asked to produce letters for a sales campaign. During the experiment the subject stood in front of a 95-cm high table (Fig. 1). The raw materials (letters, envelopes, samples, addresses, stickers and glue) were organised on this table. The task consisted of:

1. Gluing a sticker on a product sample
2. Placing this sample on a letter
3. Inserting the letter in an envelope
4. Gluing an address on the envelope
5. Storing the final product on a 135-cm high shelf (situated in front of the subject and above the table).

The subjects were allowed to work at their own rhythm; two of them took part in the experiment together (twin experiment) to simulate a realistic work situation (Fig. 1). To standardise the footwear, the subjects wore Manolitos Big Tree shoes (Alicante, Spain) with steel toes during the experiment.

An Ergomat (Søndersø, Denmark) polyurethane standard mat (compressibility: 35 kg for a 3-mm compression with a 105-mm diameter probe) was chosen to be the soft surface tested. The top of the force platform was covered with the mat to meet the requirements of repetitive work during standing on a soft surface. Standing directly on the force platform (aluminum casting) was considered to be equivalent to standing on a hard surface.

Procedure

The experiment was divided into three parts. A prework test designed to measure the maximal voluntary contraction torque. Immediately after, the subjects carried out light repetitive work on either the soft or the hard surfaces for 2 h; during which time subjective, physiological and biomechanical parameters were recorded (Fig. 2). A postwork test was made consisting of a second estimation of maximal voluntary contraction torque and a fatigue test to assess the effects of 2 h of standing on the two different surfaces.

Prework test

A belt was tightened around the right thigh of the sitting subject. The right foot was placed on the top of the force platform with the estimated axis of rotation of the ankle joint vertically above and parallel to the X axis of the force platform. Three maximal voluntary plantar flexion trials of 3 s each were recorded. The trial with the greatest moment around the X axis (M_x) was considered to be the maximal voluntary contraction torque MVC_1.

Fig. 1 Twin experiment showing two subjects standing on soft surfaces during the 2-h test, producing letters for a sales campaign

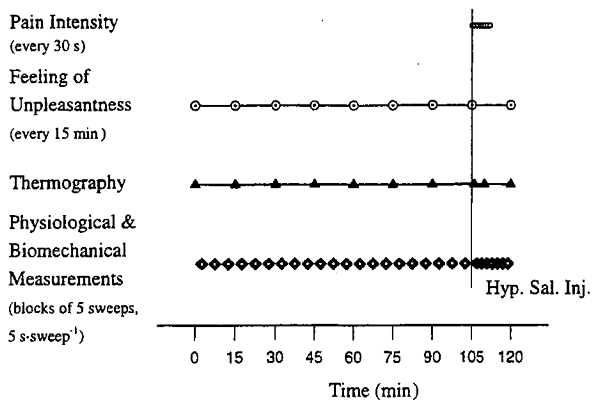

Fig. 2 Time schedule of the parameters recorded over the 2 h of manual work performed standing. After 105 min, muscle pain was experimentally induced

Work

Manual work was performed for 2 h.

A. During the first 105 min, the general intensity of unpleasantness was rated every 15 min. Calf circumference, EMG activities from the right soleus and tibialis anterior muscles, right and left ankle movement in the saggital plane, centre of pressure (CoP) displacement in the saggital and frontal planes and calf surface temperature measurements were recorded for 5 s every min.
B. The last 15 min were dedicated to measurements of the responses to experimentally induced muscle pain; the subjects scored the intensity of their experimentally induced pain every 30 s, the above-mentioned physiological and biomechanical parameters were recorded for 5 s every 0.5 min.

Postwork test

The setup was the same as described in the prework-test. Three 3 s maximal voluntary right ankle plantar flexion trials were carried out. The trial with the highest M_x was used as MVC_2. A fatigue test was performed, i.e. the subjects were asked to produce a maximal voluntary plantar flexion of the right ankle until they were exhausted. They were encouraged verbally during the test.

Measurements procedure

1. During standing the subjects were asked to rate the intensity of unpleasantness on a linear scale graduated in centimetres from 0 to 10. Zero corresponded to *not unpleasant* and ten to the *most unpleasant feeling*.
2. Experimental muscle pain was elicited by injecting 0.5-ml hypertonic saline (6%) over a 15-s in the mid-part of the left soleus muscle. The subjects scored the intensity of the pain between 0, *no pain* and 10, *most intolerable pain*.
3. A silastic mercury strain gauge (Medicoline, Valby, Denmark) used for plethysmograph measurements was attached around the right calf muscle to measure changes in shank circumference.
4. EMG recordings. Bipolar EMG surface electrodes (Medicotest N-10-E, Ølstykke, Denmark) were aligned vertically (2-cm apart) on abraded ethanol-cleaned skin along the mid-part of the right soleus and tibialis anterior muscles. Pre-amplifiers with a gain of 100 were attached to the electrodes. Overall the EMG were amplified 2000 times and band-pass filtered 0.1–400 Hz (Axon CyberAmp 380, Foster City, USA). Postprocessing of EMG signals was by high-pass filtering at 20 Hz (Butterworth, second order).
5. Goniometers (Penny and Giles M180, Gwent, United Kingdom) were attached to the skin with tape along the fibula and to the shoes along the 5th metatarsal bones to record left and right ankle movement in the saggital plane.
6. Force platforms (AMTI model OR6-5-2000, Watertown, USA) were used to record forces and moments in the frontal, saggital and transversal planes. Forces and moments were amplified 4000 times and low-pass filtered at 10.5 Hz (second order).
7. Thermography. A 12-bit digital resolution colour thermography system (Thermovision 900 Series, Agema, Danderyd, Sweden) was used to measure the shank surface temperature. Pictures of the shank skin surface temperature were taken at 0, 30, 60, 90, 106, 110 and 120 min.

Analogue signals were digitised via an Amplicon (Brighton, United Kingdom) liveline PC226 A-D board and stored on a PC for further analysis. The sampling frequencies used were 1 kHz for EMG signals and 0.5 kHz for all the others.

Data analysis

2-h manual work

1. The area under the curves representing the intensity of unpleasantness versus time and the maximum of the unpleasantness scores rated were calculated and compared between standing on hard and soft surfaces.
2. The area under the curves representing the intensity of muscle pain versus time and the maximum of the muscle pain scores rated were calculated and compared between the two conditions.
3. The first shank circumference measurement was used as a reference value, and subtracted from all subsequent shank circumference values to obtain the changes.
4. The EMG signals were analysed in both time and frequency domains. Root mean square (rms) and mean power frequency (MPF) values were calculated for each recorded sweep (Inbar et al. 1987; Lindström and Petersén 1983). The number of soleus muscle events at rest was also calculated. A resting event was defined as a period of EMG activity less than 2% of the mean of MVC_1 and MVC_2 rms values lasting longer than 0.2 s.
5. Goniometers. The mean amplitudes of the movements and the total angular displacement around the left and right ankle in the saggital plane were calculated, the total angular displacement being defined as the integral of the absolute values over time.
6. Force platform. The displacement in the frontal and saggital planes of the CoP was computed (Winter 1990).
7. Thermography. An area corresponding to the calf was scanned for the seven pictures taken (range of the areas: 0.0162–0.0251 m^2). The mean value of the area was calculated. As colour thermography was performed on only 10 subjects, the data reported were not evaluated statistically.

The parameters calculated from the analogue signals obtained during the work period were averaged over five successive sweeps to reduce effects resulting from leg movement during sampling.

Pre- and postwork measurements

To test the effect of 2 h standing, the maximum of the right ankle moment around the X axis M_{xmax} (frontal plane), and the mean of rms and MPF for the soleus muscle were computed for MVC_1 and MVC_2. The mean of MVC_2 M_{xmax} and MPF values were then subtracted from those of MVC_1.

The parameters extracted from the fatigue tests after 2 h of light work performed standing on either hard or soft surfaces were: (1) the duration of the test, (2) the minimal and maximal values of M_x (M_{xmin} and M_{xmax}), (3) the slope (linear regression analysis) of M_x versus time, and (4) the slope (linear regression analysis) of the MPF and rms versus time for the soleus muscle.

Statistics

The Mann-Whitney rank sum test was used to compare the two conditions. Two-way analysis of variance (ANOVA) was used to test differences in the effect of experimental condition (hard, soft) on EMG activity (two muscles). This ANOVA was also used to test differences in the effect of experimental condition (before injection, after injection) on non-EMG physiological parameters during standing on hard or soft surfaces. A $P < 0.05$ level was considered significant. Pairwise multiple comparison procedures were performed with Student-Newman-Keuls (SNK) method for compensation.

Results

First 105 min

Intensity of unpleasantness

The mean maximal intensity of unpleasantness (reached after 105 min) was greater ($P = 0.004$) for the hard surface [3.85 (SEM 0.85) cm] than for the soft surface [2.25 (SEM 0.56) cm]. For hard and soft surfaces, the mean areas under the curves were 253.9 (SEM 35.8) arbitrary units (range 82.5–412.5) and 158.5 (SEM 21.7) arbitrary units (range 45–262.5), respectively. The difference in the area under the curve between the two groups was not significant ($P = 0.104$). The curve *unpleasantness intensity versus time* showed a greater slope for the standing on a hard surface condition (0.036 vs 0.021 arbitrary units; Fig. 3).

Shank thickness

The difference in diameter between the last and the first recorded sample was 0.86 (SEM 0.19) mm for the hard surface and 0.27 (SEM 0.34) mm for the soft surface, ($P < 0.001$). This indicates a greater swelling when standing on the hard surface compared to the soft surface (Fig. 4).

EMG Analysis in time and frequency domains

The two-way ANOVA showed a significant difference in the rms (time domain) of EMG between the two conditions ($F_{3,83} = 253.7$, $P < 0.0001$).

The muscle activity of the tibialis anterior tended to increase ($P > 0.05$, SNK) when standing on the soft surface compared to the hard surface, 83.3 (SEM 3.31) μV versus 78 (SEM 3.48) μV, while the soleus muscle activity decreased ($P < 0.05$, SNK), 258.2 (SEM 3.2) μV (soft surface) versus 385 (SEM 5.95) μV (hard surface). The number of resting events was 132.9 (SEM 36.2) and 102.5 (SEM 37.7) for soft and hard surfaces, respectively ($P > 0.05$).

The two-way ANOVA showed a significant difference between the MPF values (frequency domain) of EMG for the two conditions ($F_{3,83} = 12.3$, $P < 0.0007$; Fig. 5). The MPF of both muscles were lower for the soft surface than for the hard surface. For the soleus muscle, the MPF were significantly different ($P < 0.05$, SNK), 90.6 (SEM 0.44) Hz for the hard surface and 83.2 (SEM 0.6) Hz for the soft surface. The MPF varied ($P < 0.05$, SNK) from 61.1 (SEM 1.05) Hz (hard surface) to 47.1 (SEM 1.39) Hz (soft surface) for the tibialis anterior muscle.

Goniometers

The amplitude of the movement and the total angular displacement around the left leg ankle in the saggital plane showed no statistically significant difference between the hard and soft surfaces ($P = 0.459$ and $P = 0.164$, respectively).

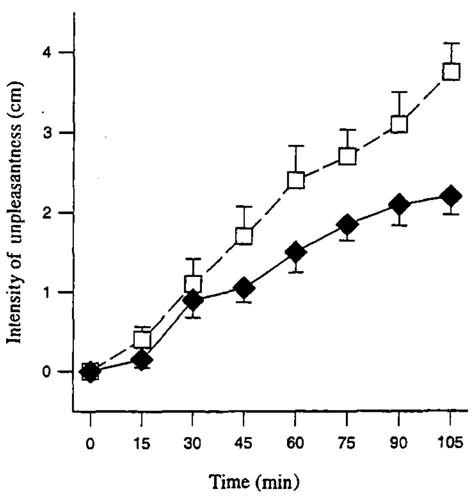

Fig. 3 Mean and SEM intensity of unpleasantness vs time during manual work standing on soft ($n = 11$, ◆) and hard ($n = 10$, □) surfaces

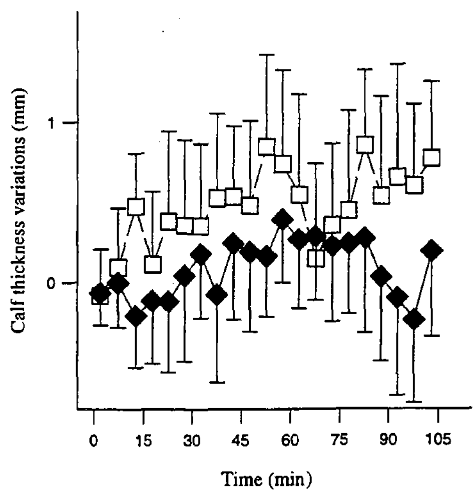

Fig. 4 Mean and SEM calf thickness variations vs time during manual work standing on soft ($n = 11$, ◆) and hard ($n = 10$, □) surfaces

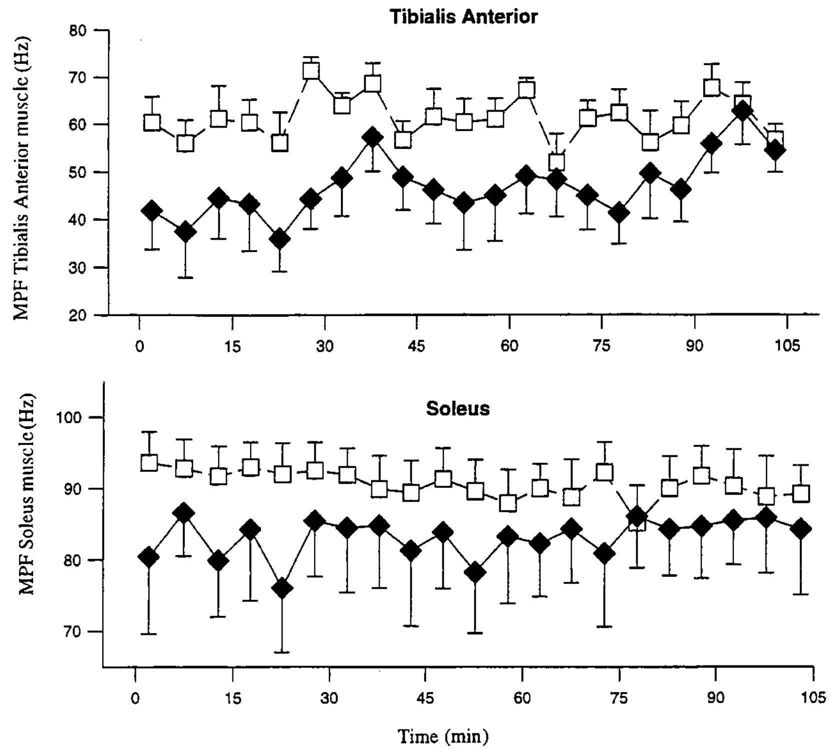

Fig. 5 Mean of individual mean power frequency (*MPF*) and SEM for the right tibialis anterior and soleus muscles vs time during manual work standing on soft (n = 11, ◆) and hard (n = 10, □) surfaces

For the right leg ankle (in the saggital plane), both amplitude and total angular displacement when standing on the hard surface [3.9 (SEM 0.11) degree and 32.7 (SEM 0.84) degree respectively] were greater than standing on soft surfaces [2.64 (SEM 0.1) degree and 26.8 (SEM 0.94) degree respectively; Fig. 6a] ($P < 0.001$ in both cases).

Force platform

The CoP displacement in the frontal plane was greater for the hard surface than for the soft surface: 0.58 (SEM 0.01) m versus 0.52 (SEM 0.01) m respectively ($P = 0.0003$). In the saggital plane, the same tendency was present: 0.5 (SEM 0.01) m versus 0.47 (SEM 0.01) m respectively ($P = 0.058$; Fig. 6b, c).

Last 15 min

Experimentally induced muscle pain intensity

The maximal experimentally induced muscle pain intensity was larger for the hard surface [7.2 (SEM 0.75) cm] than for the soft surface [5.9 (SEM 0.62) cm] ($P = 0.009$). The mean areas under the curve for the hard surface tended to be greater than those for the soft surface, 38.35 (SEM 3.2) arbitrary units (range 23.75–56.25) and 32.5 (SEM 2.1) arbitrary units (range 17.75–40.75) respectively ($P = 0.257$). After 7.5 min, the pain intensity had returned to the level before infusion (Fig.7).

Goniometers

The effects of the different experimental conditions (hard/soft surface and before/after injection) on the movement amplitude and the total angular displacement around the left leg ankle in the saggital plane were not significantly different for the left ($F_{3,16} = 1.48$, $P = 0.24$ and $F_{3,16} = 0.019$, $P = 0.89$) or for the right ankle ($F_{3,16} = 0.761$, $P = 0.39$ and $F_{3,16} = 3.69$, $P = 0.073$). The amplitude and total angular displacement showed a tendency to be greater after hypertonic saline injection.

The surface played a significant role for the mean amplitude of the movement around the right ankle, and the amplitude was greater during standing on the hard surface versus the soft surface [4.1 (SEM 0.18) degree vs 2.77 (SEM 0.17) degree, $P < 0.001$]. The same effects were observed for total angular displacement around the right ankle which was greater during standing on the hard surface versus the soft surface [34.6 (SEM 2.33) degree vs 29.6 (SEM 2.22) degree, $P < 0.05$].

Force platform

The effects of the different experimental conditions (hard/soft surface and before/after injection) on the movement of the CoP in the frontal and saggital planes were not significant ($F_{3,16} = 0.674$, $P = 0.42$ and $F_{3,16} = 1.34$, $P = 0.263$). The condition before/after injection played a significant role ($P < 0.05$, SNK) on the movement of CoP in the frontal plane. Intramuscular injection of hypertonic saline provoked an increase in

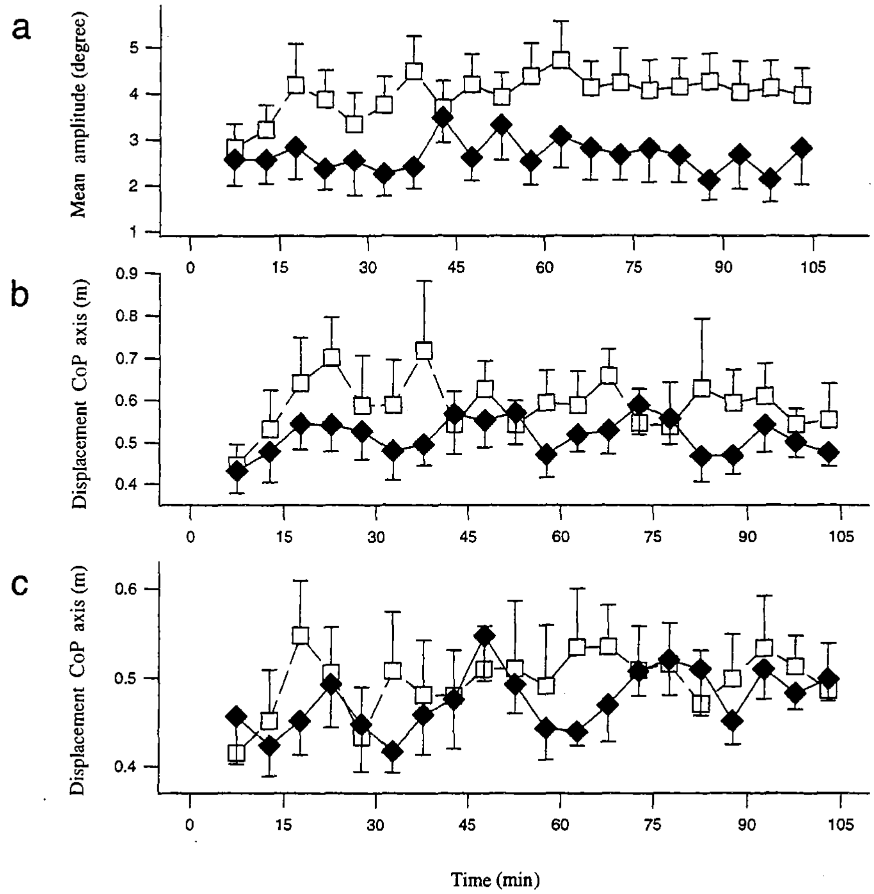

Fig. 6a, b, c Mean and SEM amplitude of the movement around the right ankle in the saggital plane (**a**), displacement of the centre of pressure (*CoP*) in the frontal (*X*) (**b**) and saggital (*Y*) (**c**) planes vs time during manual work standing on soft ($n = 11$, ◆) and hard ($n = 10$, □) surfaces

the movement of CoP from 0.537 (SEM 0.028) m (before injection) to 0.615 (SEM 0.018) m (after injection).

Thermography

The following tendencies were observed: an increased temperature during standing on the hard surface (mean +0.37°C for the left leg and +0.32°C for the right leg) and a decrease during standing on the soft surface (mean −0.2°C for the left leg and −0.36°C for the right leg). At $t = 110$ min, a decrease in the temperature was observed in all cases. The left leg surface temperatures were lower than the right ones. The mean range of temperatures was lower during standing on the soft surface [3.24 (SEM 0.27)°C] compared to the hard surface [4.08 (SEM 0.14)°C].

Pre- and postwork results

MVC_1 and MVC_2

Mean values of the M_{xmax} and mean rms and MPF values measured before and after 2-h standing were unaffected by the different conditions ($P > 0.05$).

The following tendency was observed: a more clear decrease in M_{xmax} for the hard surface [−12.03 (SEM 6.1) N · m] than for the soft surface [−0.63 (SEM 4.9) N · m] with regard to the MPF for the soleus muscle in both conditions the mean MPF tended to increase after 2-h dynamic standing: hard surface [1.68 (SEM 3) Hz], soft surface [1.24 (SEM 1.8) Hz].

Fatigue test

Standing on soft or hard surfaces did not influence the fatigue parameters differently. The observed tendencies were as follows. A longer duration of standing on a soft surface [$t_{duration}$ = 49.12 (SEM 7.14) s vs 45.14 (SEM 6.7) s, $P = 0.62$]. A greater M_{xmax} and M_{xmin} in the case of the soft surface, the maximums for soft and hard surfaces were 158.71 (SEM 11.24) N · m and 150.44 (SEM 8.13) N · m ($P = 0.67$), respectively, and the minimums for soft and hard surfaces were 145.66 (SEM 6.84) N · m and 141.92 (SEM 11.85) N · m ($P = 0.78$), respectively. A decrease in the MPF of the soleus muscle was observed, resulting in a negative sign in front of the r coefficient. The slope was also greater after 2-h standing on the hard surface than for the soft surface, −0.12 (SEM 0.03) Hz · s^{-1} vs −0.09 (SEM 0.01) Hz · s^{-1} ($P = 0.94$). With regard to the rms value a general decrease was observed, but no evidence of the effect of the condition (hard/soft) on the soleus rms value was observed.

Discussion

The aim of this study was to quantify subjective, physiological and biomechanical responses to standing on a soft compared to a hard surface during 2 h of light repetitive work. The findings highlighted a reduced subjective effect of the soft surface on the intensity of unpleasantness accompanied by low postural activity and no swelling of the shank. Standing on a hard surface was accompanied by an enhanced swelling of the shank, a larger EMG activity (right soleus muscle) of the lower leg, a greater movement of CoP, and an increased total angular displacement and amplitude around the right ankle in the saggital plane. Signs of muscle fatigue were also detected during standing on the hard surface.

The intensity of the experimentally induced muscle pain was larger for the hard surface. During experimentally induced muscle pain, increased postural activity was recorded.

Responses to 105 min dynamic standing on hard and soft surfaces

Various methods have been used to collect subjective data regarding the intensity of unpleasantness. Previously, linear scales have been widely used (Brantingham et al. 1970; Kuorinka et al. 1978; Zhang et al. 1991). Jørgensen et al. (1993) have utilised a visual analogue scale in which study the subjects were asked to score discomfort sensation of their feet, lower leg, and low back. Konz et al. (1990) and Rys and Konz (1990, 1994) have made an even more detailed analysis by a clustering of the body parts in the sense that they asked the subjects for comfort ratings of 11 locations.

The subjective findings in the present study (Fig. 3) were consistent with the major part of the findings of Brantingham et al. (1970), Kuorinka et al. (1978), Konz et al. (1990), and Rys and Konz (1990, 1994): standing on a soft mat is more comfortable and less fatiguing than standing on, e.g. concrete. Konz et al. (1990) have tested different mats and concluded that comfort decreased more for the lower part of the body with time and was a function of the surface on which the subject was standing. According to Rys and Konz (1990), comfort diminished with the duration of standing and was inversely related to the mat compressibility. On the other hand, Zhang et al. (1991) and Jørgensen et al. (1993) have found no positive effect of standing on a soft surface as perceived fatigue or discomfort depended first of all on the length of standing.

Kuorinka et al. (1978) have not recorded any changes in calf circumference measurements due to the surface for standing, but this could have been due to the method used (a strip of paper fixed elastically around the calf). Plethysmography has previously been used to study foot volume. Jørgensen et al. (1993) have found that during the 1st h of work the foot volume increased, but it then stabilised during the 2nd h. Rys and Konz (1994) have also found an increase in the foot volume during standing, but this phenomenon was more influenced by the duration of the experiment than by the type of surface.

An enhanced shank circumference when standing on the hard surface was observed after 105 min (Fig. 4) and this was used as an estimator of the calf volume, i.e. the amount of fluid pooled in the lower leg. The explanation was that an increased blood circulation appeared and was due to a greater postural activity when standing on the hard surface while blood flow remained almost unchanged on the soft surface.

The integrated EMG activity of the tibialis anterior muscle did not show any difference between the two conditions of standing. Those results were consistent with the results obtained by Cook et al. (1993) who have recorded EMG activity from the tibialis anterior and paraspinal muscles and found no effects of surface. For the soleus muscle, the activity was, however, greater when standing on the hard surface, the explanation for this is the greater postural activity observed.

Veiersted et al. (1993) have used EMG measurements as a predictor for trapezius myalgia and observed that patients had lower EMG gaps (period of at least 0.2 s of EMG activity below 0.5% of maximal EMG activity) than nonpatients. A tendency towards fewer resting events during standing on the hard surface was observed and this could be of importance for understanding the development of MSD.

The MPF of the EMG signal has commonly been used to estimate muscle fatigue and has also been used to assess the effects of standing on soft surfaces. Jørgensen et al. (1993) have monitored the lumbar paravertebral muscle and found that the changes observed were more time dependent than standing-surface dependent. Rys and Konz (1994) have concluded that EMG was not sensitive enough to assess muscle fatigue at low levels of contraction. Stuart-Buttle et al. (1993) and Kim et al. (1994) have indicated that soft surfaces reduced localised muscle fatigue only in the erector spinae muscle and not in the gastrocnemius and tibialis anterior muscles. Kim and Chung (1995) have recorded some trends of fatigue in left and right erector spinae and in left latissimus dorsi muscles during repetitive lifting tasks.

In this study, MPF was not used as an index for muscle fatigue as muscle length and eccentric/concentric muscle activity were not controlled. However, low MPF were observed when the subjects were standing on the soft surface (Fig. 5). This could be due in part to the difference in EMG amplitude as the variations in EMG frequency contents have been reported to be highly correlated with EMG activity (Shankar et al. 1989). Furthermore, many studies, e.g. Arendt-Nielsen and Mills (1988), have shown that the shift towards low frequency of the power density spectrum was correlated with a decreased propagation velocity of the action potential along the muscle fibres.

The various conditions did not play any role in the mean amplitude and the total angular displacement of the left ankle flexion-extension. On the other hand, the right leg side showed greater values during standing on the hard surface (Fig. 6a). An explanation for this could be that the right leg was the leading leg in 19 cases out of 21 and the subjects did more flexion/extension around their right ankles in order to perform the packing task.

The magnitude of the displacement of CoP reflects the movement of the subject in the saggital and frontal planes. The CoP analysis showed a greater amplitude movement when standing on the hard surface in both planes (Fig. 6b, c). This result corresponded with the findings related to calf circumference, EMG activities and right ankle movement in the saggital plane.

Contrary to the results of this study, Zhang et al. (1991) have not found any difference between standing on a soft or hard surface with hard or soft-soled shoes: the body movement, however, was dependent on the duration of standing. This could be explained by the fact that the subjects were standing for only 15 min on each kind of surface.

The pre- and postexperiment results indicated some tendencies. A greater general decrease of performance, lower moment for instance, when standing on the hard surface. The fatigue test also showed the same trends in the sense that the general performance, time length of MVC, maximal and minimal moment, and slope of the MPF linear regression analysis, decreased more after standing 2 h on the hard surface. These tendencies may be seen as the prime indicators of a general performance diminution after 2 h of light work performed standing on the hard surface. It is suggested that a longer experiment could be a way of detecting long-term effects of standing on either soft or hard surfaces.

Brantingham et al. (1970) have reported a decreased venous pressure and higher calf temperatures during standing on a soft surface, but on the other hand Konz et al. (1990) have observed that calf temperature increased when standing on concrete, while it remained constant or decreased when standing on different mats. Rys and Konz (1994) have concluded that calf temperature is influenced by the surface, however this effect is not always consistent as long as it is dependent on the mat itself.

In the present study, calf surface temperature seemed to increase during standing on the hard surface. This was consistent with the larger EMG activity following greater postural activity. In the same way, a decreased calf surface temperature was observed during standing on the soft surface.

In conclusion, standing on the soft surface had a beneficial subjective effect. A decreased general postural activity can be detrimental and lead to oedema. No negative effects were observed as the calf circumference remained constant. It is suggested therefore that the postural activity induced during manual repetitive light work in an erect posture on a soft surface is enough to avoid negative effects on the return of the venous blood from the lower leg.

Our findings can be interpreted in an alternative way and raise the question: why did standing on the soft surface with hard-soled shoes seem to offer an advantage? Our explanation would be that standing on the soft surface with hard-soled shoes provided the postural system an extra *degree of freedom*. This resulted in a diminished and less static plantar pressure, while standing on the hard surface induced increased and more static plantar pressure. Edwards (1988) has suggested that the lack of harmonious recruitment among motor units and relaxation of muscles might play a role in MSD.

Decreased and more dynamic plantar pressure should correspond to a rhythmic re-adaptation over the pool of the sensitised mechano-receptors and over the recruitment of muscle spindles involved in erect posture. In contrast, during standing on a hard surface the pools of active motor units could remain more stable. Hagg (1991) has proposed a model explaining occupational myalgia based on the fact that low threshold motor units are recruited first and remain active during the entire work load, these phenomena could lead to some degenerative process and finally to MSD. In addition to this, it can be suggested that standing on a soft surface may result in a reduction of the risk factors leading to MSD.

Responses to experimentally induced muscle pain

The acute pain condition was tested after unilateral injection of hypertonic saline in the mid-part of the left soleus muscle. The intensity of the experimentally induced pain reflected similar changes to the ones seen for the unpleasantness score i.e. higher pain intensity during the last 15 min of recording when standing on the hard surface (Fig. 7). Arendt-Nielsen et al. (1995) and

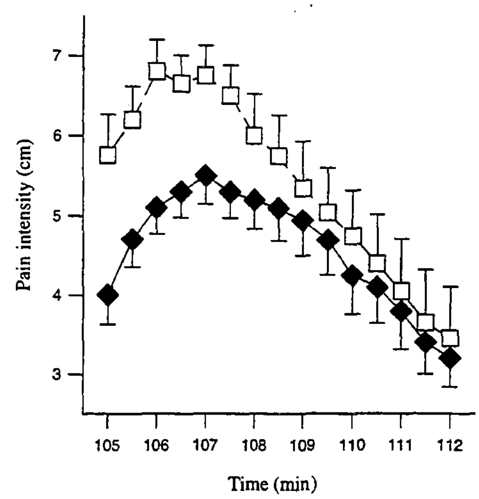

Fig. 7 Mean pain intensity and SEM vs time during manual work standing on soft ($n = 11$, ◆) and hard ($n = 10$, □) surfaces

Svensson et al. (1995b) have indicated functional adaptation of the motor system to acute musculoskeletal muscle pain possibly via reflex pathways. In this study, the general postural activity was larger during pain in both conditions of standing. A larger postural activity would indicate that experimentally induced muscle pain perturbates the motor system.

According to Edwards (1988), it could be expected that the increased muscle load when standing on a hard surface would result in a higher accumulation of metabolites in the muscles. Johansson et al. (1993), and Djupsjöbacka et al. (1994, 1995) have observed that these metabolites activate nociceptive afferents. Wall and Woolf (1984) have found that this effect could result in central hyperexcitability as nociceptive muscles afferents are very potent in generating such changes.

In conclusion, standing on a hard surface may sensitise the nociceptive system and lead to hyperexcitability which may be an extremely important factor in the development of MSD.

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