A method to quantify frequency and duration of sustained low-level muscle activity as a risk factor for musculoskeletal discomfort

Tove Østensvik a,*, Kaj Bo Veiersted b, Petter Nilsen a

a Department of Forest Resources, Norwegian Forest and Landscape Institute, Høgskoleveien 8, 1432 Ås, Norway
b Department for Work Related Musculoskeletal Disorders, National Institute of Occupational Health, Oslo, Norway

Received 11 July 2006; received in revised form 10 July 2007; accepted 17 July 2007

Abstract

Aim: The purpose of this paper was to describe and evaluate different aspects of muscle activity patterns associated with musculoskeletal discomfort/pain.

Method: Surface electromyography (sEMG) of the right upper trapezius and the right extensor digitorum muscles was conducted continuously during one working day in 19 male forest machine operators driving harvesters, 20 driving forwarders and 20 researchers at the Forest Research Institute.

Perceived discomfort/pain in the right side of the neck and the right forearm was rated morning, noon and afternoon with Borg’s CR-10 scale. Static, median and peak levels of muscle activity were analyzed and the number and total duration of EMG gaps (muscular rest) were calculated. Sustained low-level muscle activity (SULMA) was defined as continuous muscle activity above 0.5% of the maximal EMG activity quantified into 10 periods of predetermined duration intervals from 1.6 to 5 s up to above 20 min. The number of SULMA periods is presented within each interval and as cumulative periods above the already determined levels. The operators handled control levers seated in a fixed position while the researchers performed mainly PC work and other varied tasks.

Results: A positive correlation was found between discomfort/pain in the right upper trapezius muscle region in the afternoon and cumulative SULMA periods above 10 min duration, and a negative correlation to cumulative SULMA periods also including the short durations. No specified patterns were found for discomfort/pain in the right extensor digitorum or for the other EMG measurements. All EMG measurements distinguished to some extent between the occupational groups, especially between machine operators driving harvesters and researchers.

Conclusions: Number of SULMA periods longer than 10 min per hour was positively correlated, and predominantly short periods were negatively correlated, to complaints in the neck region. This seems promising in order to find duration limits for sustained low-level muscle activity as a risk factor for musculoskeletal disorders.

© 2007 Elsevier Ltd. All rights reserved.

Keywords: Methodology; Risk assessment; Surface EMG; Static muscle load; EMG-gaps; Borg’s CR-10 scale; WRUEMSDs; Forest machine operators

1. Introduction

Exposure to static muscle activity is a well-established risk factor for musculoskeletal disorders, especially with regard to neck pain (Bernard, 1997; Jensen et al., 1993, 2000; Sjögaard et al., 2000). Work-related musculoskeletal disorders in the upper extremities are also prevalent among forest harvesting machine operators (Aronsson et al., 2000; Attebrant et al., 1995, 1997). This is generally believed to be due to monotonous work tasks characterized by bilateral hand-intensive work in constrained body postures (Attebrant et al., 1995, 1997).

Muscle activity performed during different occupational activities is often evaluated by electromyography (EMG) and presented in percent of maximal measured activity (%EMGmax). Several data reduction methods have been
developed to examine the relationship between muscle activity and muscle pain. The static activity is mostly defined as the lower 10% of muscle activity in a certain time interval (Jonsson, 1982, 1988). This method uses the amplitude probability distribution function (APDF) and measures the "mean" activity during a certain recording time, disregarding the temporal pattern of the activity. However, convincing evidence of a positive correlation between the level of static muscle activity and the risk of neck pain has not been presented (Westgaard, 1999). The analysis of EMG gaps was introduced in order to get a measure of temporal aspects of static muscle activity (Veiersted et al., 1990). The EMG gaps were defined as interruptions in muscle activity during work below 0.5% of EMGmax, and the analysis made it possible to count number of gaps per time unit and the total amount of gaps, i.e. muscle rest per time unit. A low number of these EMG gaps has been shown to predict trapezius myalgia in a prospective study (Veiersted and Westgaard, 1993; Veiersted et al., 1993). The gaps are mainly too short to constitute a significant possibility for restitution during work, though studies exist that propose EMG gaps as indicators of motor unit rotation, possibly decreasing the load on single muscle fibres (Westgaard and de Luca, 1999). A hypothesis for the pathological mechanism of muscle pain may be the continuous range test).

The aim of this study was to present a method to quantify sustained low-level muscle activity (SULMA periods) and evaluate the method’s ability to discriminate between occupational groups and its association to musculoskeletal discomfort/pain.

2. Methods

2.1. Subjects

A total sample of 59 healthy men in three different occupational groups volunteered to participate in this cross sectional field study in 2000/2001. Two groups of forest machine operators (exposure groups), one driving harvesters (n = 19) and the other driving forwarders (n = 20) and a group of researchers at the Norwegian Forest and Landscape Institute (n = 20) were included. The main selection criteria for the choice of these three occupational groups were that they all had in common the presence of low-level static muscle activity, but to a different degree with work tasks demanding both the neck and bilateral use of hands. The researcher group was significantly older and had more education compared to the exposure groups (Table 1). Based on an interview, data showed that the three groups were comparable with respect to right-hand dominance, perceived degree of personal economy graded from 1 to 4 with the numbers anchored by verbal expressions, i.e. 1 was “very good”, 2 was “rather good”, 3 was “less good” and 4 was “bad”, percentage living together with a spouse or partner, and the perceived degree of both personal stress and support from family to reduce stress at work. The percentage of smokers was significantly different between the operators driving the harvesters (89%) and the researchers (36%).

The forest machine operators were recruited within the Machine Entrepreneurs Union in Oslo. Four municipalities in the south-eastern part of Norway were selected for the field work. Each contractor and the worksites were picked out on the basis of accessibility for the investigator. The reference group was randomly selected at the Norwegian Forest Research Institute at Ås. The Regional Ethical Committee for Medical Research approved the study protocol and a written informed consent was obtained.

Table 1

<table>
<thead>
<tr>
<th>Background variables</th>
<th>Harvesters (n = 19)</th>
<th>Forwards (n = 20)</th>
<th>Researchers (n = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>34** (8.0)</td>
<td>31** (10.9)</td>
<td>42** (10.9)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>85 (13.1)</td>
<td>88 (11.8)</td>
<td>82 (11.5)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>180 (6.8)</td>
<td>181 (5.8)</td>
<td>182 (8.0)</td>
</tr>
<tr>
<td>Maximum force (N) in right shoulder elevation</td>
<td>790 (175)</td>
<td>749 (171)</td>
<td>741 (136)</td>
</tr>
<tr>
<td>Maximum force (N) in right wrist extension</td>
<td>241 (49)</td>
<td>231 (48)</td>
<td>210 (98)</td>
</tr>
<tr>
<td>Maximum force (N) in right hand grip</td>
<td>525 (97)</td>
<td>540 (96)</td>
<td>465 (101)</td>
</tr>
<tr>
<td>Education (years)</td>
<td>11** (1.3)</td>
<td>10** (0.9)</td>
<td>16** (1.1)</td>
</tr>
</tbody>
</table>

Figures marked in boldface and with different letters a and b within the same row are significantly different at p < 0.05 and marked * (Tukey’s Studentized range test).
from all the volunteers in advance. The two exposure groups were tested in a specially designed mobile van/office at 14 different forest enterprises while the researchers were tested in a test room at the research institute.

2.2. Work load

In this study the two main types of forest machines in both operations were Timberjack and Valmet, which reflected the usual situation in the Norwegian forestry. The forest vehicles can handle the different kinds of terrain in Scandinavia from totally flat, stony and bumpy to a slope of 40–50%.

The fixed, seated working posture in the cabin with the main work task of continuous, intensive bilateral use of the hands operating the control levers, especially the index finger and thumb. The level of repeated neck movements with flexion, extension, lateral bending and twisting are more common among the operators driving harvesters compared to those driving forwarders. Down-sizing has increased the work load among the forest work force left that often results in long working hours with little restitution. The extraordinary wet, windy and foggy weather conditions during the whole fieldwork increased the workload considerably for the operators.

2.2.1. Harvesting operations

The workload of these operations may be divided into spotting, tree felling, disbranching and crosscutting. The operator selects and drives towards the tree, places the crane in the right position, grasps the tree around the lowest point of the stem with the aggregate and fells it while balancing the long stem in a horizontal position while disbranching. Once the aggregate gets into contact with the tree, a constant flow of information, based on the steadily changing diameter and length of the stem will be given to the computer in the cabin. The operator will use a combination of his own experience and the digitalized information to do the most favourable and economic crosscuts from the valuable bottom of the stem to the useless top. Expected time consumption for an experienced machine operator is in the range of 0.16–7.31 min (mean 0.62 min) to perform the described work task of continuous, intensive bilateral use of the hands operating the control levers, especially the index finger and thumb. The level of repeated neck movements with flexion, extension, lateral bending and twisting are more common among the operators driving harvesters compared to those driving forwarders.

2.2.2. Forwarding operations

The work task of the forwarder is to load the more or less organized piles of logs, transport them from the worksite to the loading yard and unload them for further truck transport. Depending on how well piled the logs are, and the size of the piles, the operator will use the grabbing crane to pick them up and place them on the vehicle approximately 50–60 times per load. The most strenuous transport is to drive the fully loaded forwarder from the worksite to the forest road, while the return is more of a rest period in comparison, with little risk of tilting. The driving distance back and forth from the worksite varies a lot, from approximately 5–30 min one way. The same movements are repeated during the unloading procedure, but here it is essential to make a quality assessment and sort them into first, second and third ranking piles. The final task is to stamp each log with a delivery number, which is often done at the end of the day, at least before the timber is transported by hauling from the deposit by the forest road to the next step in the processing industry, saw- or pulp mill. The production measure here is the number of logs as a total per day, mostly not digitalized and not as accurate as among the harvesters.

The physical job characteristics among the machine operators in the forwarders are less strenuous compared to those described for the harvesters. The total body posture is equal apart from fewer functions to attend on the control lever, bilaterally, absence of a computer display unit to operate, and a relaxed period during transport to and fro work site, reduce the work load both in the neck and hands. The forest machine operators driving forwarders will henceforth be designated “forwarders”.

2.2.3. Researchers

In spite of low-level static loading an overall increased variation is to be found in the work tasks of the researchers compared to the former groups. The fixed posture of both groups of machine operators in the cabin is in contrast to a spacious PC-workplace in an office with more space to move while sitting. The researchers work in a seated position with both hands operating the keyboard, while the right index finger, and to some extent the thumb, mostly operate the control functions with the mouse. During the main PC work the neck movements will be more or less flexed and deviated and twisted towards the left in order to work with documents. Any other office functions, like copying, meetings, writing with a pencil, walking to and fro, talking to colleagues, etc., give a break from the strenuous PC-posture. The demand for production and stress in this group are more on a long-term basis.

The working hours were significantly less for the researchers, compared to both groups of forest machine operators (Table 2). The same situation was reflected in the working hours during the test day.

2.3. Electromyography

2.3.1. Equipment and techniques

Surface electromyography (sEMG) amplitude and frequency parameters were used to measure the load in the right shoulder and forearm (Akesson et al., 1997; Jonsson, 1982; Petrofsky et al., 1982; Sommerich et al., 2000; Westgaard, 1988; Winkel and Mathiassen, 1994; Winter et al., 1992; Aaras and Westgaard, 1987). We selected the right upper trapezius as this muscle is reported to be most at risk of developing pain in occupational life (Jensen et al., 1993), and right extensor digitorum was selected due to high use of this muscle during control lever operation. A four channel EMG recorder, Physiometer PHY-400 (PHY-400, 1998), was used to collect the myoelectric signals.

The bipolar electrode technique was utilised for the acquisition of the EMG signal (Fuglevand et al., 1992; Hermens et al., 2000). Two pairs of disposable non-gelled, rectangular, 19 mm wide and 24 mm long neurology electrodes (Neuroline, type 725-01-K, Medicotest A/S, Denmark) were applied. The skin area of current
interest was shaved, sandpapered (Skin Rasp, Premed as, Oslo, Norway) and cleaned with 75% alcohol (1/4 ether and 3/4 alcohol) to reduce skin impedance to acceptable levels for recording (<10 kΩ). The reference electrode was, identical to the recording electrodes, integrated with a preamplifier and attached locally on the skin surface, overlying an electrically unrelated tissue to those being investigated. The three electrodes were smoothly applied with electrode paste (Medicotest A/S, Ref: 75741-91) only in the contact area, sited after careful palpation, parallel to the underlying muscle fibres with a 20-mm inter-electrode distance at the following sites:

- **Right upper trapezius muscle**: Over the muscle belly and 2 cm lateral of half way between the origins of the seventh cervical vertebra (C7) level and the insertion at the acromion of the scapula. The reference electrode was placed in the centre below the recording electrodes over the bone (Basmajian and De Luca, 1985; Petrofsky and Laymon, 2005; Winter et al., 1994).
- **Right extensor digitorum muscle**: Over the muscle belly half way between the origin of the lateral epicondyle of the humerus and the insertion by the four tendons on the dorsum of the second to fifth digits. The reference electrode was placed in the centre below the recording electrodes over the bone.

### 2.3.2. Data collection and procedures

EMG and force signals were acquired through a Data Acquisition Unit (DAU) and transmitted to a host computer. The DAU consisted of a 12 bit Analogue to Digital converter and a microcomputer (HD63AB3VF) operating at 7.37 MHz and had 128 k of external RAM. It had an opto-isolated, asynchronous serial interface, operating at 4800 bauds (eight data bits, no parity and one stop bit). The sampling rate for the EMG inputs was 1280 and 10 Hz for the force signals. The EMG signals were amplified and Band-Pass filtered (15–500 Hz) in a differential pre-amplifier close to the electrodes. The pre-amplifier had a gain of 215, input impedance >5 GΩ, Common Mode Rejection Ratio (CMRR) >100 dB and noise <3 μV. The DAU had two different amplification factors for low and high signals: 10× or 1×, respectively, giving a total gain of the EMG signal equal to 215 or 2150. During data acquisition, the gain was dynamically selected (10× or 1×) according to the EMG input level and the resulting total value calculated (for high input levels, the digital value were multiplied by 10). This ensured a total dynamic range of more than 15 bits, even if a 12 bit A/D converter was used. The root mean square (RMS) value of the EMG signal was calculated (Kumar and Mital, 1996; Mathiassen et al., 1995). In addition, the frequency and variation of the EMG signal “baseline” was calculated. All values were transferred to a HP200LX portable microcomputer (Hewlett-Packard) 10 times per second via the serial interface (Com Port). Data was stored every 0.1 s on a 32 MB Compact Flash adapter card (Simple Technology, Canada). This Flash card was used to transfer data to a second portable PC (Microsoft-98. Think Pad 390, IBM) where the separate muscle signals were analyzed.

The amplitude probability distribution function (APDF) was used to evaluate the static, median and peak levels of EMG activities during one working day (Petrofsky et al., 1982). The total number of EMG gaps/min below 0.5% of EMGmax, the mean duration of the EMG gaps and their total duration (s/min) were calculated (Veiersted et al., 1990). The reference value EMGmax was recorded during calibration. The minimum values were adjusted to the lowest registered value electronically in the raw data.

The RMS values were transformed into ASCII files for the whole sample and finally transferred electronically to a portable PC (Microsoft Excel 2000, Toshiba Satellite). A program was made in Turbo Pascal to visualize graphically the continuous muscle activity pattern in both muscle groups. A manual analysis was performed twice per subject to detect artefacts or anomalies, separate work from pauses, separate specific work from other work tasks, and determine what kind of activity was performed and for how long time. Diaries and video recordings assisted these analyses and data sets were obtained at two different levels; firstly, the whole usable registration of a working day minus artefacts and secondly, the whole working day with all work tasks and pauses minus transport back and forth to work. Only results from the latter level are analysed and presented in this study.

### 2.3.3. Sustained low-level muscle activity (SULMA)

Averages of 16 samples, each of 0.1 s duration, were analysed for the number of periods with certain duration with continuous activity below and above 0.5 % EMGmax. The averaging resulted in a lower peak and a higher static level in the APDF. A period with sustained low level muscle activity (SULMA) is defined as a period with continuous (without interruptions) muscle activity (below and) above 0.5 % EMGmax of 1.6 s duration or longer. This means that shorter interruptions, i.e. EMG gaps or peaks that are shorter than 1.6 s duration may occur, but were not registered as interruptions. Since the physiological effect of these short interruptions is questioned, we focused on longer periods with sustained activity as we have a hypothesis of them as being related to muscle pain. We believe that if the muscle rest duration is 1.6 s or more, it has a possible positive physiological effect on muscle relaxation and blood perfusion. The number of SULMA periods was calculated and analyzed for each muscle in the following ten predetermined intervals: $1.6 < x < 4.8 s$, $4.8 < x < 9.6 s$, $9.6 < x < 19.2 s$, $19.2 < x < 59.2 s$, $59.2 s < x < 2 min$, $2 < x < 4 min$, $4 < x < 8 min$, $8 < x < 10 min$, $10 < x < 20 min$ and $x \geq 20 min$. Two numbers were calculated for each interval, the number of

<table>
<thead>
<tr>
<th>Working conditions</th>
<th>Harvesters (n = 19)</th>
<th>Forwarders (n = 20)</th>
<th>Researchers (n = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>History with present type of work (years)</td>
<td>Mean 9.6 (6.9)</td>
<td>Mean 8.8 (9.0)</td>
<td>Mean 10.3 (8.1)</td>
</tr>
<tr>
<td>Usual working hours (h/w)</td>
<td>47.1 (14.1)</td>
<td>48.3 (9.8)</td>
<td>42.4 (6.6)</td>
</tr>
<tr>
<td>Work with the control lever or the PC (h/d)</td>
<td>8.6** (1.5)</td>
<td>9.3** (1.3)</td>
<td>4.5** (1.6)</td>
</tr>
<tr>
<td>Duration of the main pause (min/d)</td>
<td>30.0 (20.9)</td>
<td>37.7 (19.2)</td>
<td>33.2 (22.5)</td>
</tr>
<tr>
<td>Working time during the test day (h)</td>
<td>7.2** (1.5)</td>
<td>6.4** (1.6)</td>
<td>4.9** (0.7)</td>
</tr>
</tbody>
</table>

Figures marked in boldface and with different letters a, b and c within the same row are significantly different at $p < 0.05$ and marked * (Tukey’s Studentized range test).
periods below 0.5% \(\text{EMG}_{\text{max}}\) and the number of periods above 0.5% \(\text{EMG}_{\text{max}}\) (Fig. 1). Only data from the latter are used in this paper. The predetermined SULMA periods will for simplicity henceforth be designated as >1.6–5 s, 5–10 s, 10–20 s, 20 s–1 min, 1–2 min, 2–4 min, 4–8 min, 8–10 min, 10–20 min, >20 min.

The number of SULMA periods was also expressed in ten cumulative periods above the minimum value of the already predetermined ten intervals: >1.6 s, >4.8 s, >9.6 s, >19.2 s, >59.2 s, >2 min, >4 min, >8 min, >10 min and >20 min. This means that the cumulative period named, e.g. >1.6 s, is the sum total of all SULMA periods above 1.6 s and so forth. Cumulative SULMA will henceforth be designated as >1.6 s, >5 s, >10 s, >20 s, >1 min, >2 min, >4 min, >8 min, >10 min and >20 min.

2.4. Response or outcome assessment

Borg’s CR-10 scale has been constructed for ratings of perceived exertion and is graded from 0 to 10 with the numbers based on verbal expressions, i.e. 0 is “nothing at all”, 5 is “strong” and 10 is “very, very strong” (Borg, 1990). It has been used for perceived discomfort/pain in previous studies (Strimpakos et al., 2005; Thuresson et al., 2005). We only used recordings above 0.5 (more than extremely little discomfort/pain).

2.5. Test procedures

Initial verbal information of the schedule for the whole test day was followed by the first rating on Borg’s scale of perceived discomfort/pain early in the morning.

Electrodes were applied in accordance with the described procedures as early as possible to increase the contact with the skin before assessment (Mathiassen et al., 1995). A simultaneous recording of the EMG signal and force was established continuously from minimum to maximum level while the machine operator was asked to contract the muscle gradually for approximately 10 s. In a seated position on a wooden bench, unable to touch the floor with the feet, the subject performed maximal shoulder elevations as voluntary contractions (MVC). These were performed with straight vertical arms pulling the straps that were connected to force transducers that were mounted to a calibration platform (Premed as, Oslo, Norway). The length of the straps was adjusted such that the force transducer was activated when the shoulders were lifted a few mm. Bilateral efforts were made to avoid participation by unwanted muscles, although only one side of the body was tested at a time.

The maximal contraction of the right extensor digitorum muscle was achieved with the ventral side of the subject’s forearm in full contact with the bench and the wrist extended at an angle of 20–30° with the strap from the calibration platform placed distal to the phalange joints. The individual maximal shoulder elevations of the right upper trapezius muscle and wrist extension of the right extensor digitorum were used as references for the later EMG measurements (Aaras and Westgaard, 1987). The EMG recordings were spread all over the week similar for all three groups of participants.

A Lafayette hand dynamometer (model 78010, Lafayette instrument Co., 1-800-428-7545, IN 47903, Box 5729, USA) was used to measure force in the handgrip (kg) (transformed to Newton in Table 1) in a standing position. With the dynamometer in the hand with a straight wrist and elbow and the palm towards the body, the subject was asked to press as hard as possible with his dominant hand and afterwards with the other one. The highest of three efforts was chosen as the result.

The EMG equipment was applied to the body in custom-made water repellent bags where the physiometer and the portable computer were safely placed close to each other in separate bags connected with protected cables in the chest area. Wide adjustable longitudinal bonds over the shoulders, together with a horizontal girdle with the bags attached, constituted a waistcoat adjustable both in length and width to fit anyone. Instructions to fill out a diary of all tasks during the day together with the time schedule were given to the machine operator before he started to work.

The subjects were introduced to Borg’s scale and were given both verbal and written explanation. An additional bilateral posterior drawing of the head, neck, shoulder and upper forearm with distinct boundaries between the body regions helped them to be more precise when rating. Four repeated measurements of perceived discomfort/pain were carried out during the test day, before and after the calibration procedures in the morning, at noon and in the afternoon. The test before calibration in the
morning was used to check that no harm occurred during the calibration procedure. The machine operator brought the questionnaire with him to the worksite to fill in at noon, while the last one was filled in after work in the van in the afternoon. All the above-mentioned tests were performed in a van designed for the purpose. The mobile van was parked as close to the worksite as possible to enhance the maximum time for EMG measurements.

2.6. Statistics

For data treatment and analyses the SAS system, release 8.02, was used (SAS, 1999). For static, mean and peak muscle activities from the EMG data, differences in expected median values between groups were analyzed by means of non parametric Kruskal-Wallis tests. Variables, such as age and education showing normal distributions, were tested by ANOVA analyses and multiple comparisons by Tukey’s Studentized range tests.

On the individual level, the relationships between Borg’s CR-10 scale of discomfort/pain and SULMA periods were analyzed with simple linear regressions and correlation analyses.

The significance level was 0.05 if nothing else is stated.

3. Results

3.1. Exposure

Table 3 shows that the reference group had a significantly lower static and median level of muscle activity in the right upper trapezius (RUT) muscle compared to the two exposure groups, calculated by the amplitude probability distribution function (APDF). Correspondingly, the APDF data (Table 4) show that the reference group had significantly higher values of total duration of EMG gaps in the RUT muscle compared to both exposure groups. No differences were found among the three groups concerning the APDF data and gap analysis of the right extensor digitorum (RED) muscle.

3.1.1. Sustained low-level muscle activity (SULMA)

Table 5 reveals that the reference group had significantly more SULMA periods of shorter duration in the RUT muscle compared to the exposure groups, with regard to periods of both 1.6–5 s and 5–10 s duration. The numbers of SULMA periods between 10 and 20 s duration in the reference group were only significantly higher than in the harvesters. These results correspond with the APDF data and gap analysis. The harvesters had significantly more long predetermined SULMA periods with durations above 20 min in the RUT muscle than the reference group. As can be seen, there was a change in the working pattern for the RUT muscle from the medium long interval of 4–8 min to durations greater than 20 min. The total score of the median values of the four last intervals was 2.5 periods for the harvesters, 2.3 for the forwarders and 1.5 for the researchers, as shown in Table 5. No differences were found among the three groups in the RED muscle.
The reference group had consistently significantly more cumulative predetermined SULMA periods above 1.6 s and above 5 s in the RUT muscle compared to the harvesters, but mainly with short duration (Table 6). With an eye to the periods with long durations above 8 and above 10 min, both the exposure groups had significantly more cumulative periods compared to the reference group, while in the last period with durations above 20 min, only the harvesters deviated significantly from the reference group. No differences were found in the SULMA periods of the RED muscle among the three groups.

3.2. Response

Fig. 2 reveals no significant difference in perceived discomfort/pain above 0.5 (extremely little) in the right neck.

Table 5
Number of sustained low-level muscle activity (SULMA) periods per working hour during one working day in three male occupational groups

<table>
<thead>
<tr>
<th>Work groups (n)</th>
<th>Duration intervals of SULMA periods</th>
<th>1.6–5 s Median</th>
<th>5–10 s Median</th>
<th>10–20 s Median</th>
<th>20 s–1 min Median</th>
<th>1–2 min Median</th>
<th>2–4 min Median</th>
<th>4–8 min Median</th>
<th>8–10 min Median</th>
<th>10–20 min Median</th>
<th>&gt;20 min Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right upper trapezius muscle</td>
<td>Harvesters (19)</td>
<td>6.7*** (0.5–49.3)</td>
<td>4.2*** (0.3–27.1)</td>
<td>3.1*** (0.5–28.8)</td>
<td>5.2 (1.2–22.7)</td>
<td>3.4 (0.3–8.5)</td>
<td>2.0 (0.2–5.5)</td>
<td>1.3 (0.3–3.2)</td>
<td>0.3 (0.0–0.7)</td>
<td>0.7 (0.0–1.4)</td>
<td>0.2*** (0.0–1.1)</td>
</tr>
<tr>
<td>Forwarders (20)</td>
<td>17** (1.2–49.3)</td>
<td>8.4a (0.2–27.1)</td>
<td>7.8ab (0.3–28.8)</td>
<td>9.4 (0.7–22.7)</td>
<td>4.7 (0.1–8.5)</td>
<td>2.6 (0.0–5.5)</td>
<td>1.5 (0.4–3.2)</td>
<td>0.3 (0.0–0.7)</td>
<td>0.5 (0.0–1.4)</td>
<td>0.0b (0.0–1.1)</td>
<td></td>
</tr>
<tr>
<td>Researchers (20)</td>
<td>24.7b (0.0–76.3)</td>
<td>13.8ab (0.0–29.8)</td>
<td>8.6b (0.0–21.0)</td>
<td>9.3 (0.0–18.0)</td>
<td>3.4 (0.0–8.3)</td>
<td>2.8 (0.0–5.3)</td>
<td>1.1 (0.0–3.5)</td>
<td>0.2 (0.0–0.8)</td>
<td>0.2 (0.0–1.7)</td>
<td>0.0b (0.0–0.7)</td>
<td></td>
</tr>
<tr>
<td>Right extensor digitorum muscle</td>
<td>Harvesters (19)</td>
<td>18.3 (2.1–116.5)</td>
<td>11.3 (2.0–74.2)</td>
<td>8.3 (1.4–54.7)</td>
<td>14.6 (1.8–35.6)</td>
<td>3.8 (0.6–10.1)</td>
<td>2.4 (0.3–5.5)</td>
<td>0.8 (0.0–2.9)</td>
<td>0.1 (0.0–1.4)</td>
<td>0.0 (0.0–0.8)</td>
<td></td>
</tr>
<tr>
<td>Forwarders (20)</td>
<td>23.8 (0.0–185.1)</td>
<td>13.7 (0.0–93.8)</td>
<td>11.4 (0.0–56.0)</td>
<td>10.7 (0.0–34.4)</td>
<td>4.9 (0.0–10.2)</td>
<td>2.3 (0.0–6.4)</td>
<td>0.9 (0.0–3.1)</td>
<td>0.0 (0.0–0.6)</td>
<td>0.1 (0.0–1.2)</td>
<td>0.0 (0.0–0.7)</td>
<td></td>
</tr>
<tr>
<td>Researchers (20)</td>
<td>26.1 (0.0–93.2)</td>
<td>15.7 (0.2–42.7)</td>
<td>11.1 (0.0–32.7)</td>
<td>12.4 (0.0–28.9)</td>
<td>5.5 (0.0–10.0)</td>
<td>2.7 (0.0–4.8)</td>
<td>1.3 (0.0–3.9)</td>
<td>0.0 (0.0–1.3)</td>
<td>0.3 (0.0–0.8)</td>
<td>0.0 (0.0–0.6)</td>
<td></td>
</tr>
</tbody>
</table>

Figures marked in boldface and with different letters a and b within the same column are significantly different at the levels: ***p < 0.001, **p < 0.01, *p < 0.05 (Kruskal-Wallis test).

Table 6
Number of cumulative sustained low-level muscle activity (SULMA) periods per working hour during one working day in three male occupational groups

<table>
<thead>
<tr>
<th>Work groups (n)</th>
<th>Number of cumulative SULMA periods with duration above predetermined levels</th>
<th>&gt;1.6 s Median</th>
<th>&gt;5 s Median</th>
<th>&gt;10 s Median</th>
<th>&gt;20 s Median</th>
<th>&gt;1 min Median</th>
<th>&gt;2 min Median</th>
<th>&gt;4 min Median</th>
<th>&gt;8 min Median</th>
<th>&gt;10 min Median</th>
<th>&gt;20 min Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right upper trapezius muscle</td>
<td>Harvesters (19)</td>
<td>28.4*** (4.8–135.5)</td>
<td>22.3*** (4.3–86.3)</td>
<td>19.2 (3.9–59.2)</td>
<td>16.1 (3.4–32.0)</td>
<td>7.6 (1.8–14.6)</td>
<td>5.0 (1.3–8.7)</td>
<td>3.1 (0.3–4.6)</td>
<td>1.7** (0.0–3.1)</td>
<td>1.2** (0.0–2.5)</td>
<td>0.3*** (0.0–1.1)</td>
</tr>
<tr>
<td>Forwarders (20)</td>
<td>53.7ab (5.8–141.5)</td>
<td>40.9ab (4.6–77.5)</td>
<td>29.9 (4.1–51.5)</td>
<td>20.9 (3.7–35.5)</td>
<td>10.2 (2.7–15.2)</td>
<td>5.6 (2.3–8.6)</td>
<td>2.7 (1.2–4.4)</td>
<td>1.2** (0.2–2.4)</td>
<td>0.8** (0.0–1.7)</td>
<td>0.0b (0.0–1.5)</td>
<td></td>
</tr>
<tr>
<td>Researchers (20)</td>
<td>70.0b (0.0–140.1)</td>
<td>44.0b (0.6–70.9)</td>
<td>26.7 (0.6–46.9)</td>
<td>18.0 (0.6–27.7)</td>
<td>9.0 (0.6–13.6)</td>
<td>4.9 (0.6–7.8)</td>
<td>1.6 (0.3–4.3)</td>
<td>0.6b (0.0–2.9)</td>
<td>0.2b (0.0–2.2)</td>
<td>0.0b (0.0–0.7)</td>
<td></td>
</tr>
<tr>
<td>Right extensor digitorum muscle</td>
<td>Harvesters (19)</td>
<td>56.9 (10.0–272.2)</td>
<td>38.6 (8.0–155.7)</td>
<td>32.7 (6.0–88.4)</td>
<td>24.4 (4.7–48.4)</td>
<td>9.7 (2.9–16.1)</td>
<td>4.1 (0.7–10.2)</td>
<td>1.5 (0.0–4.6)</td>
<td>0.3 (0.0–2.3)</td>
<td>0.1 (0.0–1.8)</td>
<td>0.0 (0.0–0.8)</td>
</tr>
<tr>
<td>Forwarders (20)</td>
<td>74.0 (0.0–319.1)</td>
<td>50.9 (0.0–166.0)</td>
<td>36.5 (0.0–94.2)</td>
<td>21.9 (0.0–43.7)</td>
<td>9.3 (0.0–16.9)</td>
<td>4.3 (0.0–8.7)</td>
<td>1.7 (0.0–4.2)</td>
<td>0.2 (0.0–2.3)</td>
<td>0.2 (0.0–1.9)</td>
<td>0.0 (0.0–0.7)</td>
<td></td>
</tr>
<tr>
<td>Researchers (20)</td>
<td>82.0 (0.8–194.4)</td>
<td>54.6 (0.8–109.6)</td>
<td>34.5 (0.6–66.9)</td>
<td>23.1 (0.6–16.5)</td>
<td>11.2 (0.0–9.3)</td>
<td>5.1 (0.0–5.6)</td>
<td>1.7 (0.0–1.7)</td>
<td>0.5 (0.0–1.7)</td>
<td>0.4 (0.0–0.9)</td>
<td>0.0 (0.0–0.6)</td>
<td></td>
</tr>
</tbody>
</table>

Figures marked in boldface and with different letters a and b within the same column are significantly different at the levels: ***p < 0.001, **p < 0.01, *p < 0.05 (Kruskal-Wallis test).
between the three male occupational groups, neither in the morning, noon nor in the afternoon during the test day. The non-significant trend shows that both exposure groups, mostly the harvesters, reported most pain at noon, while the reference group stayed at one level throughout the day. The group size was reduced due to lack of reporting from some participants in the afternoon. No differences were found in the right forearm.

3.3. Exposure-response

Table 7 shows that the perceived discomfort/pain in the right part of the neck was positively correlated to the number of EMG gaps/min at noon ($r = 0.49, p = 0.014$) and to peak EMG activity in the afternoon ($r = 0.58, p = 0.03$) in the RUT muscle within the three male occupational groups. No differences were found for the RED muscle.

Table 8 reveals that perceived discomfort/pain in the right part of the neck in the afternoon correlated negatively with cumulative numbers of SULMA periods above 1.6 s, above 5 s and above 10 s, and positively with the number of SULMA periods above 10 min and above 20 min for the RUT muscle. No significant correlations were found for the RED muscle. The variation in SULMA periods above 10 min explained 31% of the variation in discomfort/pain above 0.5 (Fig. 3a). In Fig. 3b the analogous regression for the number of SULMA periods below 1 min is shown, and the degree of explanation of discomfort/pain was 29%.

4. Discussion

This study revealed that the sustained low-level muscle activity (SULMA) method distinguished between work loads in different occupational groups. The traditional EMG measurements (ADPF data and gap analysis) also separated the three groups, as could be expected from a vast number of earlier investigations (Hägg, 2000; Hägg, 1991; Jonsson, 1988; Veiersted et al., 1993; Aaras and Westgaard, 1987) However, the SULMA method additionally highlighted the differences between the three groups with regard to continuous muscle activation (SULMA periods) during work. The SULMA periods quantify the frequency of these periods with different duration. A main finding in the present study is that the two predetermined SULMA periods of less than 10 s clearly divided the exposure groups from the reference group, the latter with 2–3
times as many short SULMA periods when looking at the right upper trapezius (RUT) muscle. Interestingly, the opposite picture emerged when the duration of the SULMA periods increased; the exposure groups had higher numbers of long periods of SULMA. This is even more evident when summing up the periods with long duration; e.g. more than 8 and 10 min. This working pattern was characterized by periods of long duration with continuous activity that may be a risk factor, or even a pathological mechanism, for musculoskeletal pain (Sjøgaard et al., 2000).

Even if the number of long SULMA periods seems small compared to the number of short periods, their contribution to the total static activity was considerable, e.g. one period of 10 min activity will contribute at the same level as 120 periods of 5 s, but with different effects. This is reflected in the high values of static EMG activity in the RUT muscle in the exposure groups, especially among the harvesters. The corresponding high value for the muscle rest in the reference group increases support for the argument of differences in work patterns among the three groups. The exposure groups had more static work load compared to the reference group, mainly due to more periods with long lasting static activity. Additionally, they had a significantly shorter duration of muscle rest.

Much work has been published on reduction methods for EMG data and the exposure variation analyses (EVA) method (Mathiassen and Winkel, 1991) is perhaps the most often adopted. The similarity between these methods is that both methods divide the total work load, the SULMA method into specified periods of different duration, and the EVA method into different levels (bands) of workload that are further counted within each duration interval and expressed as a percentage of total work time. However, the number of periods within each duration interval is not expressed in the EVA system. We think that our method demonstrate that the introduction of the number of SULMA periods adds important information on risk levels and dosage to the evaluation of EMG data, even though the two methods has not been directly compared. These last arguments suggest that the SULMA method is easier to understand and more practical to use, the dose and level are stated straight away. We believe the SULMA method can be a practical tool for the researcher to give advice and feedback concerning occupational life. It is crucial that the working population too can grasp the essential information in order to move towards a sustainable work pattern on the individual level.

A main topic in EMG studies has been the search for a convincing connection between exposure and response, particularly in the sense of data output to describe an EMG data reduction method to quantify the muscle load that may be causatively related to musculoskeletal pain (Jensen et al., 1993; Mathiassen et al., 2002; Strimpakos et al., 2005; Aaras, 1994). From our point of view, the SULMA method can contribute to the search for potential components affecting the development of WRUEMSDs. Earlier studies using the 10 or 50-APDF percentiles of EMG amplitude seem to have low statistical power in detecting an association (Mathiassen et al., 2002). So far, no “safe” lower limit of static muscle activity, preventing development of pain, has been detected (Westgaard, 1999; Westgaard and de Luca, 1999). The number of EMG gaps that was introduced to reflect the variation in muscle activity pattern that may prevent the development of WRUEMSDs, lacks a well established physiological explanation of its mechanism (Veiersted, 1995; Veiersted et al., 1990; Westgaard and de Luca, 1999). The muscular rest estimated by the total gap time per minute, or in per cent of working time, has been evaluated extensively (Hansson et al., 2000; Nordander et al., 2004), and some evidence exists for an association to musculoskeletal pain (Mork and Westgaard, 2006; Sjøgaard et al., 2000; Westgaard and de Luca, 1999). A new method for data reduction of EMG data is the analysis of “EMG bursts”. An EMG burst has been defined as an interval that has an amplitude >2% EMGmax and a duration >0.1 s (Kern et al., 2001),
the duration later having been modified by Mork and Westgaard (2006) to a duration >0.2 s. They found that persistent pain during the last 6 months was more prevalent in a group with long total duration of EMG burst periods (>70% of working time) compared to a group with shorter total duration of bursts (>50%). A long total duration of these burst periods may indicate a higher or more prolonged static muscle activity, but does not describe the distribution of periods with continuous muscle activity. A total burst time of 70% of working time may in theory constitute one single continuous burst period, or many interrupted much shorter periods, making a more varied work pattern.

In the present study cross occupational analyses on the individual level showed a significant positive correlation between perceived discomfort/pain in the right neck and the number of long duration periods of SULMA. These findings support the hypothesis that low threshold motor units are overloaded during long-term occupational static work (Hägg, 2000; Hägg, 1991). The relationship between the work pattern with long lasting SULMA periods and discomfort/pain in the RUT muscle was most relevant among the harvesters, where the additional work load of viewing the computer monitor might contribute (Sommerich et al., 2001). Correspondingly, a negative correlation was found between the total number of short SULMA periods cumulated up to 1 min duration and discomfort/pain. This may indicate the preventive effect of short interruptions of muscle activity, in this case, above 1.6 s duration. The lower level of pain among the researchers could perhaps be explained by a high total duration of EMG gaps in the RUT muscle. The weak but significant correlation described could be due to a low number of reports at the end of the working day. The lack of correlation between discomfort/pain in the morning and the SULMA periods may be explained by the fact that the subjects experienced discomfort/pain of previous origin. The discomfort/pain in the afternoon may be an effect of the load during the working day. In accordance with earlier studies, it might be that the future complex framework found in most workplaces today needs new methods to deal with the obvious differential concomitant individual response to low-level isometric contractions combined with duration of exposure and work style (Cole and Rivlis, 2004; Crenshaw et al., 1997; Hägg, 2000; Kazmierczak et al., 2005).

According to earlier studies, the RUT muscle is at risk of developing pain in occupational life (Jensen et al., 1993). Looking, however, at the right extensor digitorum (RED) muscle, a lack of significant results was found at all different levels of EMG activities. Neither could any differences in discomfort/pain in the right forearm nor any correlation with EMG activities be traced. Our inconclusive findings with regard to the RED muscle point in several directions that make it difficult to find any reasonable explanation. The manual tasks performed by machine operators and researchers may be rather similar concerning forearm activities. Several studies point to the large importance of social and environmental factors for the workers’ welfare and expression of discomfort. In this study, the researchers were significantly older and were better educated, while the harvesters smoked significantly more. However, we do not believe these findings can explain why the harvesters seem to be most exposed. Small differences between the occupational groups were found in the background data. These data had been checked on an individual level against discomfort/pain without any striking correlations. On this basis, we think that these factors are of minor importance in explaining the reported differences between individuals in perceived discomfort/pain.

In the present study the variation in both muscle activity and reported discomfort/pain was large, both within and between working groups, as has been found previously (Mathiassen et al., 2002; Veiersted et al., 1990). The difference in working pattern was not accompanied by any significant differences between the three occupational groups in discomfort/pain in the right neck. Throughout the working day, both exposure groups tended to report more discomfort/pain in the RUT muscle than the reference group; however, the differences were small and non-significant. Borg’s CR-10 scale has previously been used as a subjective assessment of fatigue and discomfort/pain in several studies concerning neck and forearms (Borg, 1982, 1990; Strimpakos et al., 2005; Thuresson et al., 2005). The reduced number of workers that reported throughout the day makes a group analysis uncertain. In addition, it must be taken into account that the lower limit of Borg’s scale used in this study was above 0.5, i.e. extremely little discomfort/pain, thus reducing the number of participants.

A final consideration of why we chose to demonstrate and test the SULMA method during a field study rather and not in a controlled laboratory. To separate between the number of short, medium and long duration of SULMA period, we needed the variation in the continuous flow of the three different working tasks during practical low-level static loading. The total muscle load during a stressing field operation can only be measured in the field. In a laboratory setting it is not possible to create the complexity in the work situations because simulators lack the varying situations as only the terrain can create. The varying degrees of the continuous work flow of all these tasks together are essential in order to separate one from the other. A final comment is that the simulators lack the possibility to create varying foundation that demands a constant change of work postures.

5. Conclusions

The traditional EMG data reduction methods, such as APDF data and gap analysis, discriminate between occupational groups, especially for the right upper trapezius muscle, but no obvious relationship was found between these parameters and discomfort/pain in the right side of the neck after a working day. Both short periods of sus-
tained low-level muscle activity (SULMA periods) and long SULMA periods differentiated between the occupational groups, and also showed obvious patterns with regard to discomfort/pain at the end of the working day. The total numbers of SULMA periods over 1.6, 5 and 10 s duration were negatively correlated, and SULMA periods over 10 and 20 min duration were positively correlated, to discomfort/pain after a working day. The interpretation of these results may be that short SULMA periods have a salutary effect on muscle use, and SULMA periods over 10 or 20 min have a deleterious effect. We suggest that further research on this topic including whole-day measurements also include an analysis of SULMA periods over 10 min duration when evaluating EMG predictors for musculoskeletal pain.

Acknowledgements

We express our gratitude to the Research Council of Norway, NRC Nos. 115004/110, 139116/110 and 144680/110 for financial support. We would like to thank the volunteer forest machine operators and researchers for participating. We want to thank Ola Ro for support to further development of EMG software and repair of equipment. A special thank you to colleagues at the Norwegian Forest and Landscape Institute; Tore Vik for organizing the agenda of participants during fieldwork, Jan Bjerketvedt and Jørn Lileng for assistance to prepare large data sets to be analysed and Solveig Tangen for the needlework of the custom-made waistcoat to carry and connect the EMG equipment.

References


Tove Østensvik completed her training at the Oslo College, School of Health, Department of Physiotherapy in 1983 and obtained her master degree at the University of Bergen in 1997 with special emphasis on psychosocial working environment, neck and shoulder disorders and coping strategies among forest machine operators. She is now a research officer at the Norwegian Forest and Landscape Institute, Ås. Her main research interest is work related musculoskeletal disorders, neck and upper extremities and muscle work patterns.

Kaj Bo Veiersted completed his medical training at the Copenhagen University in 1983 and obtained his PhD at the University of Oslo in 1995 on muscle activity pattern related to trapezius myalgia. He is now the head of a group performing field studies at the National Institute of Occupational Health, Oslo, Norway, and is working one day a week as a occupational physician. His main research interest is work-related musculoskeletal disorders, hand-arm vibration and electrical injuries.

Petter Nilsen obtained his master degree in forestry in 1979 and in 1988 his PhD within silviculture at the Norwegian University of Life Sciences with special emphasis on harvesting systems and forest regeneration aspects. He is now a senior research scientist at the Norwegian Institute of Forest and Landscape, Ås. His field of work spans silviculture, forest yield and production and environmental and human effects of forest harvesting systems.